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EPIDEMIOLOGIC RESEARCH ON THE ETIOLOGY OF INJURIES AT WORK

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INTRODUCTION

During the past half century, traumatic injuries have emerged as a pre-eminent public health challenge. Injury is the leading cause of hospitalization and death in persons younger than 45 years of age; results in more years of potential life lost than cancer or heart disease; and is second only to respiratory conditions as a reason for contact with physicians (3). One third of all nonfatal injuries and one sixth of all injury fatalities among adults aged 20 to 64 occur on the job (3).

The public health response to a broad spectrum of occupational health and safety problems has embraced three traditional applications of epidemiology: surveillance; etiologic research (i.e. studies to identify risk factors); and evaluation of the effect of interventions. With the increased recognition of injury as a serious public health problem, it is logical that efforts to prevent and control occupational injury should rely on the same epidemiological approach used to attack other public health problems (9, 13).

In industry and government, the role of surveillance in identifying the most important occupational injury problems, targeting high-risk populations, and monitoring trends has been recognized for a long time (16, 26, 28, 48). The application of epidemiological methods to the study of the etiology of occupational injury is far less common.

This review is intended to summarize etiologic studies of occupational injuries, identify their methodological strengths and limitations, point out needs for methodological improvement in such studies, and suggest a research agenda. In order to limit the scope of this broad topic, studies focusing exclusively on musculoskeletal injuries and intentional injuries have been excluded from this review. The epidemiological research literature on back injuries has been reviewed elsewhere (16a, 18a, 37). Intentional injuries have only been recognized as a serious public health problem (outside and within the workplace) within the past decade (2a, 34, 52a, 58) and the preponderance of causality studies to date have appeared in criminology and sociology literature, rather than in the public health literature.

BACKGROUND

We reviewed studies of occupational injuries or mishaps with the potential to result in injury that were published in peer-reviewed journals after 1969 and which evaluated hypotheses by comparing risk of injury among workers of varying characteristics. Surveillance studies, case-series, intervention evaluations, and studies that exclusively focus on musculoskeletal and intentional injuries were excluded from review. Abstracts of studies of work-related injury published in eight selected journals or identified by a key-word literature search of multiple databases were reviewed to determine whether they met the above inclusion criteria. A description of the key-word criteria, multiple databases, and journals included in this search as well as the complete reference list will be provided upon request.

Few studies of occupational injuries have been published that use the methods of analytical epidemiology. Our search of multiple databases and journals over the 22-year period from 1970 through 1992 found only 117 studies, including studies of work-related transportation injuries. The studies we reviewed were published in 42 different journals representing a variety of fields including medicine, safety, public health, and psychology. Sixty-five (55 percent) of the 117 articles reviewed were published in *Accident Analysis and Prevention* (21 articles), *Journal of Occupational Accidents/ Safety Sciences* (20 articles), *The Journal of Occupational Medicine* (12 articles), or *The Journal of Safety Research* (12 articles). Various study designs were used: 67 cohort studies (any longitudinal study comparing rates); 21 cross-sectional studies; 17 case-control studies; 4 quasi-experimental study designs; and 8 other designs, or designs that could not be determined.

THE FOCUS OF EPIDEMIOLOGICAL STUDIES

Worker Populations

Among the papers reviewed, manufacturing, with 29 studies, has been the most commonly studied industry group. There were eighteen studies in the transportation industry, particularly of bus and truck drivers. The mining industry and the military each had thirteen studies. There were only eight studies in health care, seven in farming, four in public administration, three in logging, two in construction, and one in utilities. Nineteen studies failed to specify if any particular industry was under study or considered risk factors common to many industries.

The emphasis on manufacturing may reflect the large proportion (24 percent) of the working population in the manufacturing sector (8) and the relative ease with which studies can be conducted in the fixed, measured, resource-rich, and organized environment of manufacturing facilities. The relative emphasis on mining and transportation seems appropriate, given that they have the first and third highest rates of traumatic fatalities among industry divisions (33). Although the greatest number of work-related fatalities occurs in the transportation industry, many studies in the transportation environment failed to distinguish between occupational injuries, injuries to nonworkers, and property damage crashes. Studies that isolated actual injuries to working drivers were rare. More research on occupational injuries in the transportation environment is needed.

That few studies have addressed agriculture and logging is a noteworthy gap given the high-risk nature of these industries (33, 52). Although there have been some surveillance studies (38, 61) and at least one series of mishap investigations (70), not even one study in our review targeted the fishing industry. That only two very limited studies targeted construction is inconsistent with the public health importance of injuries in this industry. The construction industry is second only to mining in fatality rates (33) and reports the highest rate of lost workday injuries to the Bureau of Labor Statistics (8). However, these higher-risk industry groups, particularly agriculture, logging, fishing, and construction, are difficult candidates for rigorous etiologic research due to the transient and independent nature of their workers.

Outcomes

While in some studies the case-definition included mishaps not resulting in injury, most studies excluded noninjury incidents. In many studies the case-definitions were not more detailed than the word "accident," making it difficult to determine injury involvement and interpret the results. Most studies examined injuries of all external causes (e.g. falls, motor-vehicle crashes) combined. Many studies that did restrict their case-definition or stratified their analysis by external cause, focused on mishaps involving buses or trucks. A few studies on slips, trips, or falls; needle-sticks and sharps exposure; diving injuries; and other miscellaneous classifications were noted. Except for one study on ambulance crashes (1) and another on automobile crashes among police officers (64), there were no studies of motor-vehicle injuries in industries other than transportation. This is inconsistent with the importance of motor-vehicle injuries, which are among the leading causes of occupational injury fatalities in many industries, not just in transportation (2a, 33).

Many studies included all injuries, however minor. Analytical studies that focused on severe injuries and fatalities were rare. Only four studies conducted analyses specific to fatalities and four studies focused on traumatic injuries severe enough to require hospitalization. Studies to identify risk factors unique to severe injuries are clearly needed since research has shown that external causes of minor injuries, the majority of injuries in employer reports, differ from those of severe occupational trauma and fatalities (60, 63).

In the occupational injury field studies are needed to examine risk factors that affect the severity of injury, given the occurrence of a mishap. Only fifteen studies in our review examined the severity of injury, usually measured using lost workdays as the dependent variable.

Risk Factors

Risk factors for occupational injury can be grouped into three broad categories: human, job content, and environment. The human category includes variables such as demographics, job title, experience, physical attributes and impairments, stress reactions, knowledge, and attitudes. Job content refers to the design of tasks, how tasks are organized into jobs, and how jobs are scheduled. The environment includes social and organizational factors, physical stressors (e.g. noise, heat), and physical hazards.

Risk factors for 32 better quality studies that did not appear to have shortcomings due to confounding, misclassification, or selection bias, are listed in Tables 1, 2, and 3. It is evident from these tables that many potential risk factors have been examined and found to be significantly associated with injury. However, with the exception of age, job title, experience, and number of hours worked, only a few risk factors have been examined by multiple studies.

In 79 of the 117 studies (68%), at least one human variable was evaluated. Often demographics or job title were included as potential confounders when studying other factors. Physical attributes or impairments (e.g. visual impairment, hearing loss, or prior back pain) were commonly studied risk factors. One particularly noteworthy example of a well-controlled study of physical attributes examined the risk of injury in shipyard workers as a function of noise exposure, hearing loss, alcohol use, and other factors influencing perceptual acuity (46). Another methodologically sound longi-

Table 1 Demographic and human factors examined in higher quality studies[a]

Risk factor	Reference	Risk factor	Reference
Ethnic group	2	Cardiovascular disease	30
Age	2[b], 6[b], 25, 27, 30[b], 31, 35[b],	Medication use	30
	36[b], 44, 47[b], 57[b], 66[b],	Fatigue	25[b]
Marital status	30, 31, 47	Job satisfaction	27, 44[b]
Years education	30, 47	Confidence in co-workers	27
Height	47	Mechanical aptitude	25
Weight	47, 66[b]	Perceived safety risk	17[b]
Gender	31[b], 40, 57[b]	Sleep pattern	30[b]
Number of children	25	Year of hire	2[b]
Job title/tasks	2[b], 6[b], 19[b], 27[b], 31[b], 43, 46,	Supervisory position	6[b]
	47, 57[b]	Safety high priority	17[b]
Experience	5, 6, 27[b], 29[b], 30, 36[b], 47[b]	Feel accidents preventable	17[b]
Unaccustomed to job	27	Lack of time	17[b]
Worked other jobs	27	Low value on safety	17[b]
Years worked	5, 6[b], 25	Morale	17[b]
Hearing loss	30, 46[b]	PPE not available	30
Left-handed	46	PPE not used	30[b]
Sports in leisure	30, 46	PPE thought inadequate	30
Somatic complaints	44	Glove type	19
Prior injury	30, 27[b], 45	Helmet use	15[b]
Reaction time	25	Ear plugs	46[b]
Simple motor speed	25	SCBA use	27[b]
Hand-eye coordination	25[b]	Glasses used	46, 66[b]
Body sway test	25[b]	Alcohol consumption	27, 30, 31, 46[b]
Coordination	25[b]	Drugs	31, 46
Involuntary control	25[b]	Smoking	30, 46

Table 1 *(Continued)*

Risk factor	Reference	Risk factor	Reference
Blood loss	19[b]	Previous traffic accident	46
Duration of surgery	19[b]	Intelligence	25
Vascular procedures	19[b]	Expectancy reaction	25[b]
Abdominal procedures	19[b]	Personality inventory	25
Perceived HIV/HBV risk	19	Attention level	25[b]
Previous laminectomy	73	Stable behavior	25[b]
Vision poor	30	Hand performance test	25[b]
Acute illness	30	Impeded movement	66[b]
Chronic illness	30		

[a] 32 studies without marked potential for confounding, misclassification bias, or selection bias
[b] P-value less than .05

Table 2 Job content variables examined in higher quality studies[a]

Risk Factor	Reference	Risk Factor	Reference
Job change during week	30	Lack of lunch break	30
Unusual task	30[b]	Resting/napping	46, 55[b]
Unusual material used	30	Time off before shift	27, 36[b]
Department	2	Slept during shift	27
Number job changes/year	47[b]	Volume of work	27, 57[b]
Shift	40[b], 56	Absent previous day	22
Hour start shift	41, 56	Driving pattern	36[b]
Hour of day	40[b], 41[b], 56	Location of job	5[b], 29[b], 35[b], 62
Hours worked	6, 25, 35[b], 36[b], 40, 41[b], 57[b]	Mining method	6
Alternating shift	30, 41, 55	Change in job location	27, 47[b]
Number days in shift tour	41[b]	Prior training	27[b]
Rapid change in shift	41	Flexibility in work schedule	25[b]

[a] 32 studies without marked potential for confounding, misclassification bias, or selection bias
[b] P-value less than .05

Table 3 Work environment variables examined in higher quality studies[a]

Risk Factor	Reference	Risk Factor	Reference
Seniority, pay grade	51	Stairway design factors	66[b]
Manager age	17	Season	57[b]
Manager experience	17[b]	Power equipment	5
On/off duty	29[b]	Geographic area	5[b]
Overtime	17	Road type	54[b]
Safety incentives	17[b]	Truck type	54[b]
Lack of training material	17[b]	Vehicle weight	54[b]
Cooperative Supervisor	17[b]	Equipment failure	35[b]
Cooperative Staff	17[b]	Load of truck	35
Management style: Discipline	17[b]	Truck carrier type	35[b]
Management style: Supervision	17[b]	Power steering	35[b]
Management style: Criticism	17[b]	Steering violation	35[b]
Management style: Enforcement	17[b]	Deceleration during crash	62[b]
Replacement crew members	22[b]	Parachute type	4
Work group size	23[b]	Circumstances of injury	5[b], 6[b], 21[b]
Ergonomic stress level	44[b]	Number of vehicles	21[b]
Survivability of accident	62	Poisson process	67
Noise	46[b]	Defective material used	30[b]
Slippery surface	30	Environmental annoyance	44[b]
Improper equipment used	30[b]		

[a] 32 studies without marked potential for confounding, misclassification bias, or selection bias
[b] P-value less than .05

tudinal study examined the risk of non-back occupational injuries associated with prior lumbar laminectomy for degenerative disc disease (73).

Another frequently studied human variable was experience in job or task experience, which was included in 33 studies. Other human variables examined included psychological traits (7 studies), knowledge and attitudes (11 studies), the use of personal protective equipment (10 studies), substance use and abuse (8 studies), and other work and nonwork-related practices and behaviors (8 studies). Only five studies examined psychological, physiological, or behavioral reactions to stress at work (e.g. job satisfaction) as risk factors for injury.

In a well-controlled study, Mohr & Clemmer showed that injury repeaters accounted for only a small proportion of injuries occurring among oil rig drillers (45). That this was the only study to address "accident proneness" suggests that the search for the "accident prone" individual as the primary research agenda typical of previous decades has finally diminished.

While 68 percent of the studies we reviewed included at least one human variable, 36 percent included a variable measuring some characteristic of job content. Difficulty in measuring these variables may partly explain why only 42 studies have evaluated how the risk of injury may be affected by job content. Existing personnel records and injury reports are not likely to include this type of situational and ergonomic information. Most of the cohort studies cited in this review are based on such records.

Among the job content variables examined, shiftwork and scheduling alone were the subject of 22 studies. Thus, shiftwork as a risk factor for injury may have followed lack of experience as the second most frequently evaluated hypothesis in epidemiologic causality studies of occupational injury. Other job-content variables examined as risk factors represented diverse dimensions of job design and layout. These included variables such as organization and planning of work, scheduling, frequency and number of tasks, job difficulty, workload, job rotation, level of mechanization, amount of walking, and, in studies of workers who drive, the nature of the trip (e.g. intercity, interstate).

Environmental factors were the least studied. Most environmental factors studied were design features such as stairway design (66) or recognized material hazards such as equipment defects (35). Some studies examined environmental factors that would affect human performance. For example, 16 studies examined the potential effect of variables describing the organizational and social environment such as firm size, method of payment, management commitment and style, work group size, peer and supervisor relations, and safety incentives. Only six studies evaluated physical stressors such as heat and noise exposure.

Risk Factors for Future Research

To identify which risk factors should be the subject of future research, it is first necessary to define (*a*) what types of risk factors for injury require the use of analytical epidemiology, and (*b*) what types of research questions are likely to lead to effective interventions. On the first point, epidemiological research is needed to do what a series of mishap investigations cannot do—evaluate the impact of risk factors whose contribution to injury can be measured only by a controlled study. The impact of many direct causes of injury (e.g. lack of machine guarding, equipment failure) can be measured by systematic mishap investigation techniques such as those described by Ferry (18). Examples of less direct risk factors that require controlled population studies to quantify their effects include physical stressors such as heat and noise, psychosocial variables such as decision latitude and psychological demands of the job, and ergonomic factors.

Having suggested that the less obvious, underlying risk factors require the use of analytical epidemiology for evaluation, which types of research questions would lead to effective interventions? Passive engineering controls that automatically protect the worker rather than rely on changing worker behavior have long been recognized as valuable in injury control (13a, 24, 57a, 71). The role of etiologic research in this approach is limited since the need for engineering controls is usually established by examining the direct and obvious causes of injury using surveillance and mishap investigation.

The greatest need for etiologic research may be to evaluate risk factors for injury that are identified by two emerging trends in occupational health. The first is the increasing role of ergonomics and human factors. The second related trend is the initiative to redesign the job and reorganize the workplace to reduce occupational stress. The epidemiological evaluation of risk factors for injury predicted by human factors, ergonomics, and occupational stress research would lead to injury-prevention measures based on redesigning jobs, improving physical and social work environments, and restructuring organizations.

Studies to date only begin to test the related hypotheses predicted by ergonomics, human factors, and occupational stress research. Although many studies have been conducted on shiftwork, much greater emphasis on other job content and environmental variables is needed. Even the human variables that should be examined to understand the relationships between workplace stressors and injury risk have not been adequately addressed in the literature. Outside of alcohol and substance use, only five studies examined the effects on injury risk of psychological, physiological, or behavioral responses to workplace conditions. Fatigue, hostility, depression, anxiety, sleep disorders, and impaired concentration are examples of the documented effects of workplace stress that may lead to increased injury risk, but for which there are very few studies.

Finnish researchers have examined hypotheses regarding the interaction between job design and human limitations in information processing (59). These hypotheses are promising candidates for more rigorous epidemiological evaluation. With respect to environmental variables, the few studies on the relationship of noise exposure and injuries underscore the importance of future research that may lead to changes in how noise is assessed and controlled in the workplace (46).

Behavioral and management approaches to occupational injury control are currently popular with industry, have demonstrated some effectiveness (53), and are often considered progressive (11). Assumptions underlying behavioral approaches to occupational injury control, such as the assumption that positive safety attitudes contribute to a reduction of risk, need to be evaluated. Etiologic studies of how injury risk is affected by such factors as knowledge, attitudes, beliefs, and intentions may improve the usefulness of evaluation research strategies that use these factors as indicators of safety performance. However, even more important than etiologic research is the need for properly controlled intervention studies to evaluate the effectiveness of behavioral and management approaches.

METHODOLOGICAL CHALLENGES

Rare Events and Situational Exposures

Researchers and commentators in the safety literature have observed that injuries, especially severe injuries, are too rare to be used as reliable outcomes in safety research and evaluation. This view is understandable from the perspective of injury reduction in a single plant, company, or production system. There are simply not enough severe trauma cases and fatalities to provide sufficient sample sizes for quantitative research. In the practice of epidemiology, however, studies of entire regions, states, and nations are commonplace, and sample size is usually less of a problem in these settings. If the events to be studied are rare, such as severe trauma and fatalities, hospital-based case-control studies can be used. Cohen & colleagues (12), for example, ascertained injuries from ladder falls that were treated in hospital emergency rooms throughout the entire United States and were reported to the Consumer Product Safety Commission. Workers from the same work site were selected as controls and exposures were measured by field investigations and interviews.

Another challenge in occupational injury epidemiology is the measurement of situational exposures (i.e. factors that change over time). Exposure to variables such as familiarity with tasks, the routineness of tasks, ambient temperature, and the presence of hazards right before the occurrence of injury is of interest. Jones & Stein (35) provide one example of how this problem is handled. They examined tractor-trailers involved in crashes (cases) for violations of safety standards, and then selected and stopped control vehicles traveling down the same road. These controls were inspected for the same violations. Thus, cases at time of injury were compared to controls at a time that did not result in injury.

Recurrent Events

Longitudinal studies of occupational injury require different statistical methods than classical occupational cohort studies where the endpoint is death or chronic disease. Injuries may occur to the same individual multiple times. The application of classical statistical methods violates the assumption of independence and may result in biased variance estimates (71a).

Greater use should be made of newly developed methods to analyze correlated, categorical data in longitudinal studies. To adjust variance estimates for correlated observations in a study of slips, trips, and falls among painters, Hunting (32) used generalized estimating equations in a longitudinal data analysis. This new method accommodates logistic and Poisson regression, which are popular in epidemiological studies (72). While this approach is functional for cohort studies, no straightforward methods have been developed to account for correlations between an individual's multiple events in case-control studies.

Homogeneous Exposures

Certain potential risk factors for occupational injury may affect entire worker populations, leaving little variation in exposure to permit the assessment of differences in risk. Examples of exposures that all employees in a firm may experience include management styles of an organization, worker-participation in safety, organizational stress indicators, measures of safety climate, shiftwork schedules, and mechanization. One potentially promising approach to this problem is to conduct large studies (e.g. national longitudinal surveys, population-based case-control studies) that compare individual workers from different firms. This approach is complicated by the need to measure and control for a large number of potential confounding variables.

Another option is to compare firms rather than individuals. Many studies comparing firms, however, are difficult to interpret because the measurements of exposures and confounders are incomplete or imprecise, and because they are vulnerable to "ecologic fallacy," i.e. the observation that the correlation between two variables observed in multiple populations is often very different from the corresponding correlation between individuals within any given population.

More longitudinal, quasi-experimental study designs such as time series comparisons are also needed. This approach can be an effective method of evaluating the injury effects of exposures that are homogeneous at one point in time but heterogeneous over time, even within a single company.

Confounding

One of the most difficult challenges in epidemiology is the measurement of, and control for, confounding. In this review, 60 percent of the studies only analyzed associations between injury and one other variable at a time without any effort to adjust for the effects of potentially confounding variables. Seventy percent were judged likely to have been biased by confounding.

In occupational injury epidemiology, many human, environment and job content variables are correlated to varying degrees with exposure to risk, i.e. the physical danger of the job tasks, work intensity, and hours of work. In some studies, it is particularly important to control for exposure to risk using very specific measures. Variables like shiftwork and piece-rate pay, for example, can conceivably be tightly correlated with work intensity. In studies of needle-stick injuries among nurses, it would be important to control for the number of procedures performed per shift when assessing the effect of shiftwork on injury rates. Some physical stressors, such as noise, can be strongly correlated with sources of hazardous energy.

Data on confounders are not routinely collected in employer records or injury reports. Thus, studies that collect original data are more likely to control successfully for confounding. Techniques that measure the exposure to risk associated with specific jobs and tasks are in common use in epidemiological studies of occupational illnesses (10). Similar techniques can be applied to the epidemiology of occupational injuries. One study, for example, validated an observational assessment of the job called the "ergonomic stress level" based on body motion and posture, physical effort, active hazards, and environmental stressors (44). The ergonomic stress level then served as an effective measure of exposure to risk in an analysis that also examined job satisfaction as a risk factor.

Other Biases

Selection and misclassification bias (i.e. measurement error) are common concerns in most of occupational epidemiology, including studies of injury at work. The use of existing records is an important source of measurement error because data were collected for other purposes and not collected in a scientifically rigorous manner. Only 40 percent of the studies we reviewed collected original data to measure exposures using interviews, questionnaires, or direct observation. More occupational injury studies that collect original data with valid instruments are needed.

Another form of misclassification noted in the literature stems from the use of one-year or longer recall periods in cross-sectional studies. Some studies even used three-year and five-year recall periods for relatively minor injuries (49, 50). A recent evaluation of recall bias in the National Health Interview Survey showed that a one-year recall period resulted in substantial underreporting of all injuries at work (39). Studies of self-reported injuries may be more valid when recall periods are confined or adjusted to less than six months.

Another form of misclassification bias in the current literature is the widespread use of "all accidents" (otherwise undefined) as the study outcome. This practice may mask the effect of risk factors that are concentrated on very specific external causes of injury such as "slips, trips, and falls." Although many risk factors are postulated to have effects on a broad spectrum of injuries, future research will need to study the effects of some risk factors that are unique to specific groups of injuries. A study of risk factors for injury to firefighters, for example, provides an example of segregating analyses by meaningful injury outcomes (e.g. falls from elevations, smoke inhalation, and burns) (27).

Measurement error is also likely when the classification of the study outcome requires an investigator or respondent to subjectively assign cause or responsibility to an injury event. The investigators in one study asked nurses to recall "accidents" they felt were caused by sleepiness (20). Thus, misclassification of outcome may have occurred if nurses who were exposed to the hypothesized risk factor, rotating shiftwork, were more likely to attribute their "accidents" to sleepiness even though they may suffer from the same injury rate as day-shift workers. Other examples of this problem are thc studies of "pilot error" mishaps in aviation (7) or the studies of industrial injuries comparing actively and passively involved victims (68, 69). The use of panels, which assign cause or responsibility based on specific criteria and are blinded to exposure status, could reduce this bias.

Selection bias was considered likely or possible in 31 percent of the studies and was suspected in 25 percent of the studies reviewed. Many of the cross-sectional studies were based on low response rates (e.g. 30 to 40 percent). In cohort studies, we suspect a form of survivor bias, or "safe worker effect". Some studies restricted their analyses to employees who were at risk throughout the entire study period and excluded those who left the company. If the probability of dropping out varied by both injury risk and level of the risk factor studied, the results of the study would be biased. Another problem noted in some epidemiological causality studies was the selection of noncomparable controls or comparison groups.

Selection bias is a definite concern when reports required by the Occupational Safety and Health Administration (OSHA) or workers' compensation systems are used to ascertain injuries. A report by the National Research Council documents concern regarding underreporting of injuries on the OSHA log that employers are required to keep (51). Studies of occupational deaths reported from multiple sources have shown that workers' compensation systems have a problem with underreporting (65). Cohort and casc-control studies using workers' compensation records to ascertain cases may suffer from severe selection biases if the probability of reporting an injury to workers' compensation varies by exposure status.

Measurement of Severity

The 16 studies we reviewed that did analyze injury severity usually used lost workdays as a measure of severity. Although this measure is an indication for cost of injury, it is less suitable as a measure of injury severity because it is not only a function of severity, but also of job demands, workplace policies, and disability qualification criteria that partly determine whether an injury results in lost work time. The development and evaluation of more accurate and interpretable measures of severity would be useful in studies of occupational injury.

The Abbreviated Injury Score (AIS) (42), the Injury Severity Score (ISS) (42), and the Anatomic Profile (AP) (14) are validated measures of severity that predict survival based on the degree of damage to the body, and to a lesser degree on other severity consequences. These measures should be incorporated more frequently into studies of acute, life-threatening occupational trauma in order to examine risk factors that affect the severity of injury. Unfortunately, AIS, ISS, and AP cannot precisely discriminate between severity levels among the relatively less severe occupational injuries on which etiologic research most commonly focuses. Mitchell and colleagues, for example, examined the severity of injuries treated in an industrial plant's medical department and found that most injuries fell within a narrow range of AIS scores (44a). More sensitive scales are required that can discriminate between different levels of anatomical damage among occupational injuries.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Relatively few (only 117) analytical epidemiological studies of occupational injury causality were published during 1970–1992 in the peer-reviewed literature that we surveyed. Some very high-risk industries have been the subject of few or no studies at all.

Evidence from the literature indicates that a large number of risk factors have been evaluated by epidemiologic research. Although most risk factors have been evaluated by only a few studies that appeared to be of higher quality (Tables 1, 2, 3), the contribution to injury risk of many factors was found to be significant.

The paucity of well-controlled analytical studies suggests that much still remains to be done in occupational injury epidemiology. Future research should encompass the following: (*a*) targeting of high-risk industries, including construction, agriculture, fishing, and logging; (*b*) employment of precise and appropriately restricted definitions of injury; (*c*) a focus on severe trauma, perhaps by greater reliance on hospital-based studies; (*d*) identification of the predictors of injury severity; (*e*) verification of some assumptions of behavioral strategics typically uscd in safcty management; and (*f*) evaluation of job content, environmental and human variables that may alter the risk of injury as predicted by research in human factors, ergonomics, occupational stress, and organizational behavior.

Important job content variables for future injury research include the design and scheduling of tasks and jobs, and how tasks are integrated into jobs. Environmental variables to be examined include psychosocial factors (e.g. worker control, social support, psychological demands) and organizational structure and change (e.g. continuous quality improvement, managcment commitment). Stressors in the physical environment (e.g. noise, lighting, heat) are also in need of investigation. Behavioral, psychological, and physiological responses to stressors on the job are categories of human variables that merit future consideration.

Significant methodological problems were found in 85 of the 117 studies reviewed. Future improvements in injury research methodology include: (*a*) use of appropriate study designs for rare events; (*b*) collection of situational data for workers at risk at the time workers were injured, and during injury-free reference periods; (*c*) development of appropriate methods to estimate the contribution of injury risk factors when some workers have recurrent injuries; (*d*) development of methods to estimate and control for exposure to safety hazards; (*e*) estimation of, and control for, rccall bias in studies of self-reported injuries and exposures; (*f*) use of longitudinal study designs or multi-firm national survcys to evaluate exposurcs that arc homogeneous at one point in time, but change over time; and (*g*) development of severity measures for occupational injuries.

CONCLUSIONS

While widespread application and evaluation of known strategies for occupational injury control should not be delayed, further advances are possible with a better understanding of how job design and the physical, psychosocial, and organizational environments influence the risk of injury. This will require tools to estimate the relative contribution of causal factors that cannot be ascertained from injury surveillance or mishap investigations alone. In conjunction with methodologies from other fields such as human factors, behavioral sciences, stress research, organizational behavior, and systems safety engineering, analytical epidemiology provides an important tool. Future etiologic research on occupational injuries must be multifactorial, which requires a multidisciplinary approach, and must begin to make wide use of advanced epidemiological methods.

While the public health model is well established in preventing disease through the application of descriptive epidemiology or surveillance, etiologic research, and experimental trials or intervention studies, the model needs to be applied more frequently to occupational injury. The success of future occupational injury research and the possibility of improved injury prevention efforts may lie in the ability of safety and public health disciplines to come together to more fully implement this model.

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