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ADVANCING ANALYTIC EPIDEMIOLOGIC STUDIES OF OCCUPATIONAL INJURIES

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Abstract–The overall incidence rate of occupational injuries in the United States has increased 10% from 1983 to 1992. The improved understanding of the causes of these injuries is necessary for the selection and implementation of future interventions. The causes of many occupational injuries are often categorized simply as manual materials handling, falls, and struck by/against/caught. Injury events like illness outcomes have multiple antecedents that can only be determined by repeated analytic studies of risk factors for injury. This paper describes the rationale for using analytic epidemiological studies of the causes of occupational injuries. It describes both case–control and prospective study designs including some of the methodological problems in conducting such studies at the worksite. It introduces a new study design to occupational injury researchers: the case-crossover study. The case-crossover design may be used to assess acute events in relation to intermittent exposures that have transient effects such as physical exertion or unusual work practices. A hypothetical epidemiological study of low back pain disability using both prospective and case-crossover study designs is discussed. Further work is needed to plan and conduct these studies with the help of safety professionals and epidemiologists from industry, academia, labor and government. © 1997 Elsevier Science Ltd.

1. Introduction

The overwhelming majority of reported United States workplace health problems among the employed population are either acute traumatic or cumulative musculoskeletal in nature (Leamon and Murphy, 1994; Murphy et al., 1996). The overall trend in incidence rates for occupational injury cases showed a gradual increase of about 10% from 1983 to 1992 (US Department of Labor, Bureau of Labor Statistics, 1995a). There are in any given year an estimated 6 million reported occupational injuries. While recent fluctuations indicate a potential leveling in overall incidence rates (US Department of Labor, Bureau of Labor Statistics, 1995b), there remains a prodigious and relatively stable volume of occupational injury in the United States. This suggests that limited progress has been made in occupational injury prevention in the previous decade.

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It is not possible to discern at this point whether progress in reducing these injuries has been inhibited by the limited understanding of the etiology of injuries and illnesses, the selection of inappropriate interventions, or inadequate/incomplete implementation of selected interventions. Though all of these influences may be contributing factors, improved understanding of etiology may be considered a necessity for the selection and implementation of the next generation of interventions (Baker et al., 1992).

Epidemiologic research on injuries and illnesses forms the core of an improved understanding of etiology (Haddon et al., 1964; Guarnieri, 1992). Existing injury research has been largely descriptive or cross-sectional in design, resulting in uncertainty regarding potential risk factors. Etiologic research aimed at identifying risk factors for injuries and potential interventions may best be achieved using analytic epidemiologic methods (e.g. case–control and cohort studies).

In order to facilitate the use of analytic epidemiologic studies of occupational injuries, the objectives of this paper are to:

1. Present the rationale for conducting analytic studies of occupational injuries.
2. Briefly describe occupational case–control studies.
3. Introduce a new design: the case-crossover method for studying acute injuries.
4. Briefly describe prospective studies of low back pain disability.
5. Describe a hypothetical prospective study of low back pain disorder including a case-crossover design component.

2. Rationale for analytic epidemiologic study of occupational injury

Epidemiologic studies of occupational injuries have largely been descriptive in nature. These studies describe the distribution of injured persons (numbers and rates) usually in terms of person, place, and time characteristics and are useful for identifying hazardous industries, occupations and work situations (Justis et al., 1987; Sorock et al., 1993; Salminen, 1994). A frequent limitation of such studies is a lack of information on the total population exposed and/or the total time of exposure.

Injury is frequently an acute phenomenon requiring information about circumstances prior to the occurrence of injury. In the work setting, this means estimating the time spent exposed to various work practices and operations that can be measured in frequency and duration (in hours or even seconds).

Epidemiologic study designs usually progress from descriptive to analytic. Fig. 1 indicates an example of this progression for a given disease in which the causal relations between exposures and their effects become clearer as the study designs incorporate the temporal sequence between exposures and their effects (Sorock and Courtney, 1996).

There is recent evidence of an increase in the number of analytic studies being reported in the occupational health literature over time. It is uncertain, however, how many of the reported papers were related to occupational injury compared with disease. Between 1980 and 1993 the proportion of cohort studies increased from 5% (2/42) to 23% (48/210) of published epidemiologic papers in eight selected occupational health journals (Takahashi et al., 1996). Case–control studies increased only slightly during the same time period from 12% to 14%. Cohort studies, in which the exposure is measured before the occurrence of the study outcome, is often the best approach for inferring a cause and effect relation.

The case–control design is one of the more common types of analytic epidemiologic study

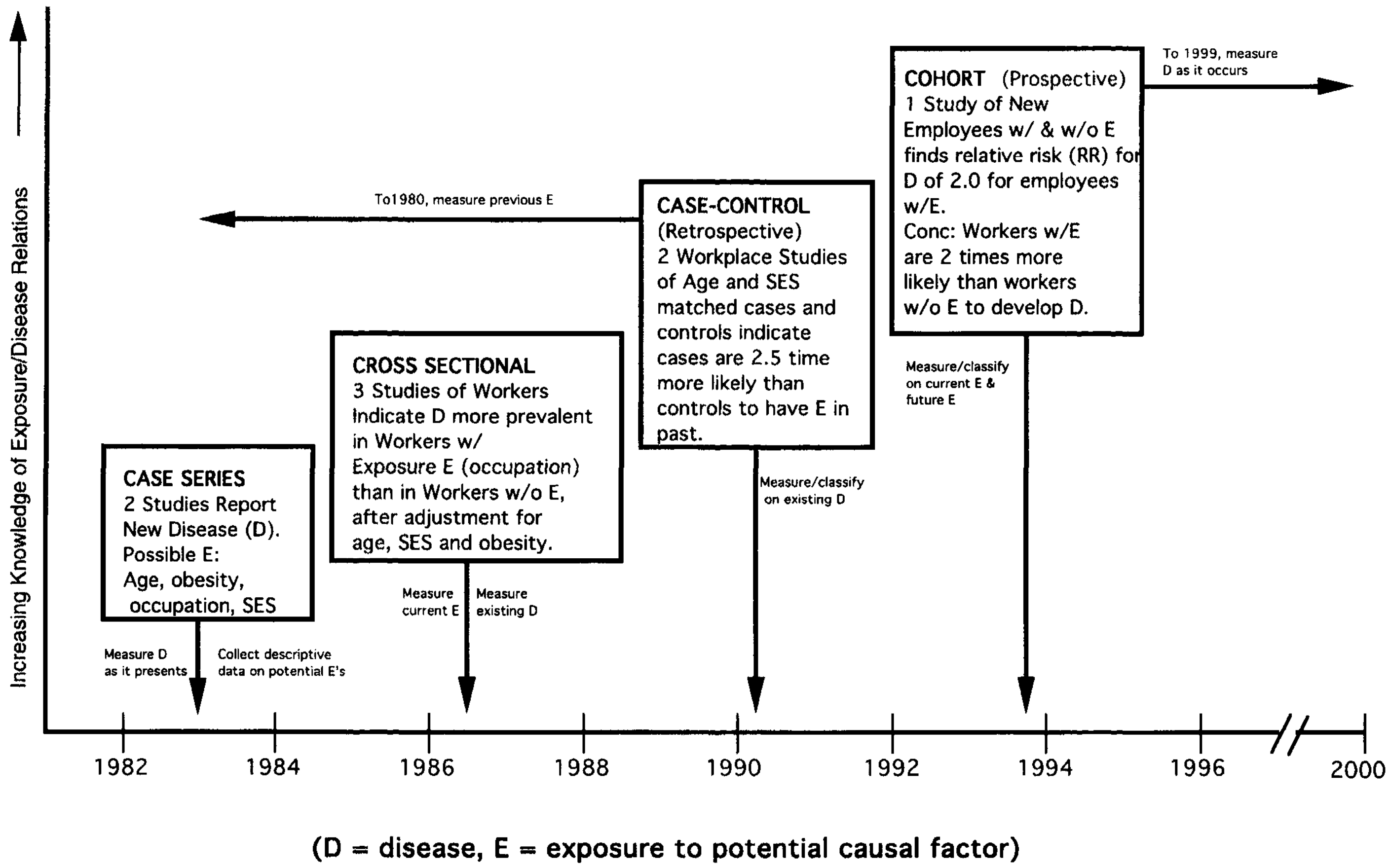

Fig. 1. Typical progression of epidemiologic research for a given disease illustrating the temporal nature of each fundamental study design. Reproduced from Sorock, G.S. and Courtney, T.K., 1996. Epidemiologic concerns for ergonomists: Illustrations from the musculoskeletal disorder literature. *Ergonomics* **39**(4), 562–578 with permission. Copyright (1996) Taylor&Francis.

methods. In this design, the cases are chosen as a group of persons with a clearly defined type of injury (Sorock and Courtney, 1996). The control group is selected to be representative of the population that produced the cases but does not have the injury under study.

For example, in tabular form, one can imagine the results of a descriptive study of alcohol use among injured persons as follows:

	Alcohol Use: Moderate-Heavy	Alcohol Use: Light	
Injured Persons	30	70	100

What is *unknown* is the exposure status of the population that gave rise to the cases, but whom did not get injured. Completing this table by adding a second row for a comparison group (sample of entire population that was uninjured) is:

	Alcohol Use: Moderate-Heavy	Alcohol Use: Light	
Injured Persons	30	70	100
Uninjured Persons	5	95	100

These results permit calculation of the hypothetical odds ratio as an estimate of the relative risk, which is $(30 \times 95)/(5 \times 70) = 8.1$. Hypothetically then, moderate-to-heavy alcohol users would be eight times more likely to be injured than light alcohol users.

2.1. Epidemiologic changes in heart disease incidence: a success story of analytic epidemiology

In the 20th century, epidemiologic research has expanded to include chronic diseases as well as infectious diseases. Perhaps the most influential work in modern epidemiology has been the cohort studies of risk factors for heart diseases, most notably the Framingham Heart Study (Dawber et al., 1951). These large prospective cohort studies, over time, have accumulated relatively consistent findings regarding the role of certain risk factors (high cholesterol/lipid levels, high blood pressure and cigarette smoking) for coronary heart disease (CHD). Results from cohort studies have improved our understanding of the risk factors for CHD, and thus provided the necessary information for intervention trials. Subsequent studies have shown that the control of such risk factors leads to the reduced incidence of CHD.

Between the years 1940 and 1991, in the United States, CHD mortality rates declined by 54% (American Heart Association, 1996). Changes in lifestyle, especially reduction in serum cholesterol levels and cigarette smoking, probably accounted for over 50% of the reduction in mortality between 1968 and 1976 (Goldman and Cook, 1984). In contrast, the sum of all medical interventions probably accounted for about 40% of the reduction. These included treatment of hypertension, ischemic heart disease and the increased use of coronary care units.

The declining trends in CHD incidence and mortality nationally were also seen in a large employed population (Pell and Fayerweather, 1985). Specifically, the male annual age-adjusted rate of CHD incidence in a large employed population, in the time period 1957–1959, was 3.19 per 1000, compared to 2.29 per 1000 in the 1981–1983 period, a 28.2% decline. This decline was attributed to greater control of high blood pressure and to reduced cigarette smoking, both established risk factors for CHD incidence.

The same analytic approaches applied to occupational injury may be expected to yield similar dividends for understanding and controlling injuries. The magnitude of the benefit would vary as it depends on the size of the *relative risk* associated with an exposure, the *frequency* of the exposure in the population, and the modifiable nature of the exposure.

3. Summary of case–control studies of occupational injury

Case–control or case-referent studies include injured persons as cases and uninjured persons as controls. By determining the percent of each group exposed to potential risk factors, one can estimate the relative risk of the injury under study given the exposure. Table 1 summarizes eight case–control studies of occupational injuries. The criteria used to select these studies were: (1) use of case–control methodology and (2) cases and controls selected among persons injured and uninjured at work. The study outcomes include: falls from ladders (Cohen and Lee-Jean, 1991), traumatic hand injury (Hertz and Emett, 1986), low back injuries (Zwerling et al., 1993), acute injury mostly to the upper extremities (Wohl et al., 1995), non-traumatic shoulder neck pain (Bjelle et al., 1981), truck crashes (Stein and Jones, 1988), saw mill injuries (Punnett, 1994), and aircraft crashes (Li and Baker, 1994). The array of these injuries suggests that the case–control methodology may be applied to cumulative onset as well as acute onset injury.

The results of these eight studies suggest that the work practices and behaviors just prior to the injury (or personal factors within 12 hours before the injury) may be most important from an etiological perspective. This is difficult to measure, however, because it entails interviewing the injured employee as soon after the injury as possible. It may also include an investigation at the worksite. The design and conduct of such a study should occur in active collaboration with the health and safety staff of the respective plants or job sites at which the injuries occur.

4. The case-crossover study design

The case-crossover design was originally developed for the study of triggers of myocardial infarction. (Maclure, 1991; Mittleman et al., 1993, 1995a). It has only recently been successfully applied to injury related to intermittent exposure to alcohol (Vinson et al., 1995) and child pedestrian–motor vehicle injury related to traffic patterns of roads crossed prior to the injury event (Roberts et al., 1995).

The case-crossover design may be used when the study outcome or condition has an acute onset and an exposure that is intermittently present and transient in its effects, such as alcohol

Table 1
Summaries of eight case–control studies of occupational injuries

Ref.	Case	Controls	Exposure measurements	Results–pos. assoc.	Comments
Cohen and Lee-Jean (1991)	Work-related fall from ladder. Hospital ER visit ($n = 123$) 2–4 weeks post fall	Random selection of ladder users at same company with no ladder fall at work or home; control ($n = 142$) refers to last time used ladder	150 fall site visits: personal, occupational, working, condition, ladder use variables	Ladder surface Unsafe ladder Difficult work posture Hours on job Evening/night shift	Ladder use factors most important; case-crossover study would refer to last time ladder was used
Hertz and Emett (1986)	Traumatic hand injury on job with > 1 day of work time lost. City workers reporting to occup. med. clinic ($n = 124$)	Pair-matched by gender, job, at work on same date and shift as case. All interviews within one week post index injury date	Personal and work activity variables	Non-usual task, defective/unusual material used, Sleep ≥ 9 hour on avg. per night	Many injury types, might need to focus on one, i.e. laceration. Separate laceration, sprain and fracture in analysis?
Zwerling et al. (1993)	Nested study of 154 postal employees with low back injuries and pre-employment physical exams	942 Randomly chosen subjects without low back injuries from 8029 in cohort	Age, gender, LBP history, disability, body mass index, injury history, psychosocial factors, job classification	History of disability (OR = 2.9), history of low back injury (OR = 1.3), manual labor (OR = 1.9)	Limited recall bias by design; disability vs. injury definition problems; no injury event information
Wohl et al. (1995)	Female mfg. workers-aerospace; who reported acute injury in 1989	2 Controls/case matched on LOE and dept. without report of injury	Age of women's children, age, LOE, BMI, ethnicity, marital status, injury history (records only)	Age of children under 6 (+) previous injury (+) obesity (+) LOE (−), age (−)	Type of injuries to women with and without children < 6 year is needed; In-person interviews needed

Bjelle et al. (1981)	20 Workers mfg. plant w/non-traumatic shoulder-neck pain	Paired sampling from employment records by age, gender, worksite and absence of symptoms	Medical, electromyography, anthropometric, muscle strength, biomechanical film analysis factors	7/20 cases had disease diagnosis; strength differences seen; high load on shoulder for non-disease patients vs. matched controls	Post injury measurement bias in cases not controls
Stein and Jones (1988)	Trucks that crash > 10000 lbs and property damage > $1500 or personal injury ($n = 604$)	Three randomly selected trucks at same site of crash for each crash-involved truck ($n = 1812$)	Brakes, steering, tire check, truck weight, size, configuration, driver age, driver experience and type of trip	Double trailer trucks were over-involved in crashes regardless of driver age and hours of driving (which also were independent risk factors)	Exactly similar conditions for assessment of control trucks was not possible compared to crash-involved trucks. Study looked at case–control pairs that were a reasonable match
Punnett, 1994	Injured workers from saw mills in Maine determined from First Report of Injury ($n = 157$)	Controls randomly selected from payroll at site where case was injured; telephone interview ($n = 251$)	Items included work history, physical workload, specific activities at time of injury; controls asked about work on last full day worked	Three strongest risk factors were: processing hard wood, work in sawmills vs. wood products and high physical demands	Participating companies left study when worker names/telephone numbers were requested. Source of potential bias slight? Details of how specific injury happened is limited
Li and Baker (1994)	Pilots involved in commuter aircraft or air taxi crashes ($n = 725$) from National Transportation Safety Board data	Controls randomly selected from Federal Aviation Administration records ($n = 1555$)	Crash incident/violation record history, age, total flight time, flight time past 6 months	Either very small or very large recent flight time increased the risk of a crash. Violation records increase risk of crash too	Data linkage (NTSB& FAA) made study feasible. Co-pilot involvement in crashes was uncertain

LOE = length of employment; OR = odds ratio; BMI = Body Mass Index; (+) positive association; (−) negative association.

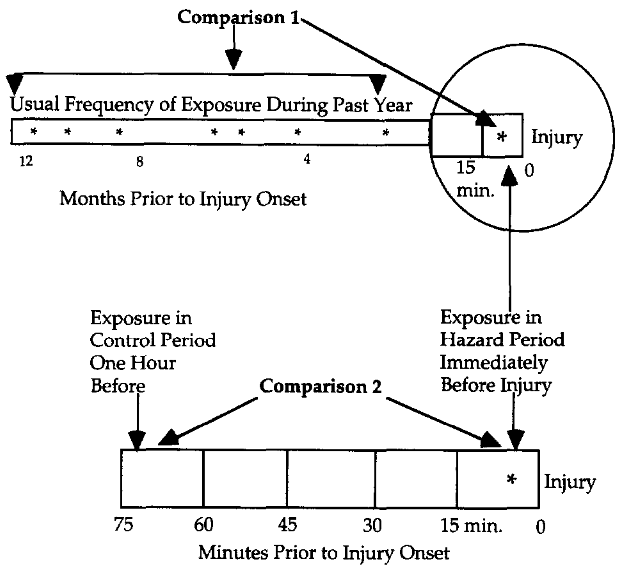

Fig. 2. The case-crossover design applied to the study of an acute injury. Adapted with permission from Mittleman, M.A., Maclure, M., Sherwood, J.B., Mulry, R.P., Tofler, G.H., Jacobs, S.C., Friedman, R., Benson, H. and Muller, J.E., Triggering of acute myocardial infarction onset by episodes of anger. *Circulation* **92**, 1720–1735. Copyright (1995) American Heart Association.

use (Vinson et al., 1995). The term case-crossover refers to a case (individual) with an injury that 'crosses over' from a period of time spent exposed to a potential risk factor to a time period unexposed to the same factor. This design assesses the change in risk of an acute event during a well-defined hazard period following exposure to transient potential risk factors. Control information for each injured subject is based on his/her past exposure experience.

Fig. 2 presents a schematic representation of the case-crossover study design. For the purpose of this illustration, the hazard period of interest is 15 minutes prior to injury onset. The hazard period length is arbitrary. It reflects the amount of time in which exposure may influence the injury of interest. Comparison 1 contrasts exposure to potential triggering activities (such as a specific work practice) during the hazard period with the frequency of that work practice based on its reported usual frequency over the year prior to injury. In Comparison 2, exposure in the hazard period is compared with exposure in a 'control period' at the same time one hour earlier.

The case-crossover study does not eliminate recall bias which can occur if cases recall differentially more exposure during the 15 minutes before the injury than the other control periods. Recall bias may be estimated, however, by comparing the observed occurrence in the discrete control period one hour before the injury with the expected occurrence based on usual frequency during the year prior to injury (Mittleman et al., 1995a,b).

The primary advantage of the case-crossover design is that it controls all interpersonal potential confounders. However, within person confounding can occur if other intermittent exposures are correlated with the exposure of interest (Mittleman et al., 1995b). For example, risk-taking personality is probably mostly controlled by this design, whereas leisure time activities usually associated with alcohol use are not (Vinson et al., 1995). These leisure time activities might affect injury risk independently of alcohol use.

5. Summary of prospective studies of low back pain (LBP)

Prospective studies begin by classifying members of a population by level of exposure status and then observing the number of injuries in each exposure group over time. LBP is chosen here as the study outcome of interest because it is a costly and frequent type of occupational injury and further prospective research is needed (Riihimaki, 1995). In 1989, LBP accounted for 16% of all workers compensation and 33% of all costs or approximately one billion dollars for one large insurance company with about 100000 claims per year for LBP (Webster and Snook, 1994). LBP is complex because the original injury has cumulative and recurrent aspects, as well as acute onset causes. Improved understanding of the causes of LBP can help direct intervention studies and reduce the frequency and costs of these injuries.

Five prospective studies of LBP are summarized in Table 2. Three criteria were used to select these studies: First, work tasks and LBP as the study outcome were the independent and dependent variables, respectively. Second, the studies had to be conducted at an industrial worksite. Third, the work tasks had to be assessed prior to the measurement of the study outcome (prospective study design).

Though considered 'stronger' studies due to their prospective designs, conclusions from the combined studies reviewed are limited by their lack of a common protocol to measure job characteristics and a standardized LBP definition. Each lacks controls for job changes, lacks reliability estimates of both exposure and outcome measurements, and largely disregards non-occupational exposures (Mundt et al., 1993). Also, the recurrent nature of LBP is not addressed in data collection and analysis procedures. All five studies suggest that LBP occurs where the job demands exceed the physical capabilities of the worker.

Prospective study designs are prone to some potential methodological problems. These include measurement error and changing exposure over time. Because of the difficulty in defining some musculoskeletal disorders, the outcome may be defined hierarchically (definite, probable, and possible) and analyzed as separate strata. Adequate pilot testing and repeatability and validity checks of all field instruments should be conducted prior to data collection (Sorock and Courtney, 1996). Changes in worksite conditions over time should be assessed. Exit interviews to assess LBP occurrence might also be conducted during the course of the study to determine if people with work-related disorders are selectively leaving high exposure jobs.

6. Mixed prospective case-crossover design: study of risk factors for low back pain

Injury events can best be understood from an etiologic perspective if studied from two time dimensions. That is, prospectively beginning with suspected risk factors that are relatively stable over time (personality, muscle strength, weight and height) and retrospectively, as soon after the occurrence of injury as possible, to examine risk factors that are intermittent, such as change in work practices, recent alcohol use, distraction just prior to the injury, or change in work posture prior to lifting.

Unlike a typical prospective cohort study, the hybrid design would include a case-crossover component that would measure transient changes in exposure and other risk factors prior to the injury. This would be a nested study, that is, cases would be newly developed and chosen as they occurred from surveillance of employees already enrolled in the study. Detailed questions about work practices 15 minutes prior to the onset of pain would complement work practice information assessed at baseline.

Table 2
Summaries of five prospective workplace studies of low back pain disability

Ref.	Study	n	Variables studied	Case definition	Results
Cady et al. (1979)	Firefighter	1652	Flexibility, isometric lifting, strength, recovery heart rate, diastolic blood pressure, energy, expenditure	Workers compensation, claims and costs	(Total cases = 57) 0.9 cases per 100 persons per year; least fit had 10× higher incidence than most fit
Bigos et al. (1992)	Boeing	3020	Anthropometry, back exams, flexibility, strength, aerobic capacity, demographics, med. history, workplace factors, job perceptions, psychological factors	LBP incident reports or claims	(Total cases = 279) 2.3 per 100 persons per year; LBP history, job dissatisfaction and psychosocial responses on MMPI most predictive of LBP
Rossignol et al. (1993)	Aircraft assembly	205	Pain symptoms, activity of daily living, LBP history, use of LBP services, age, body mass index, smoking, sports, caring for children, work satisfaction	LBP compensation, LBP complaints at med. dept., absenteeism, work limitations	(Compensated cases = 16, 6.0% per year) 16.0% absent from work due to LBP per year; history of LBP was important predictor
Chaffin and Park (1973)	Electronic manufacturing plants	411	Maximum weight lifted, frequency of lift, age, weight, height, LBP history, isometric lift strength	LBI complaint at med. dept.	(Total cases = 25) 6.1 per 100 persons per year; LBI incidence increased as lifting strength rating increased (↑ weight and ↓ strength)
Herrin et al. (1986)	Large industrial plants	6912	Type of task, force required, posture, vertical hand location, horizontal hand position, travel distance, body movement frequency, lift-strength ratio	Med. dept. visits for LBI, over-exertion (sprains and strains, degenerative disc disease, and ill-defined pain), and lost work time	Back over-exertion associated with job stress indices (severity more so than incidence)

LBI = low back injury; MMPI = Minnesota Multiphasic Personality Inventory.

6.1. Issues of sample size

A prospective study is necessarily a significant investment in time and resources. A sample size estimate indicates the needed number of subjects given study specifications in advance so that time and resources can be adjusted accordingly (Statistics and Epidemiology Research Corporation, Egret SIZ, 1992).

The following are specifications for a hypothetical study of risk factors for low back pain disability. The purpose of the study would be to determine whether a physical load index can predict an increased risk of LBP (Waters et al., 1993). Being above the *a priori* index threshold is hypothesized to increase the risk of low back pain.

For purposes of this simulation, the specifications are as follows:

- The primary exposure is the lifting index value (LI).
- The outcome is medically attended and recorded low back pain.
- The regression analysis for the study is the Cox Proportional Hazards Regression. This analysis takes into account different amounts of follow-up times for groups of persons followed since baseline exam.
- The study is expected to take one year to enroll study participants and then follow people for a period of two years for the study outcome.
- The potential confounding variables may include age, gender, low back pain history and job satisfaction.
- It is assumed that 60% of the workforce would be above the safe lifting index limit (Karwowski and Brokaw, 1992).
- Five percent of people are expected to have the study outcome over a one-year period (see Table 2, 5% is approximately the average annual frequency of LBP in the populations studied).
- Fifteen percent of workers would be lost to follow-up.

Figure 3 depicts the relation between power (study's ability to reject a true null hypothesis) and the sample size required for the study. This assumes an alpha (the study's given error of

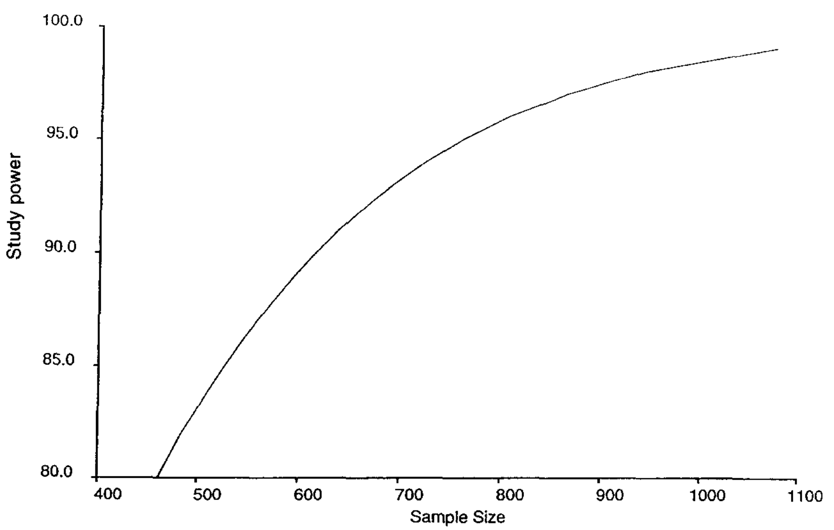

Fig. 3. Power vs. sample size for a hypothetical study of LBP (alpha level = 0.05).

rejecting a true null hypothesis as non-null) of 0.05. With a sample of about 550 workers, the study has about 85% power to reject the hypothesis that being above the lifting index makes no difference in LBP risk.

The precise measurement method for the exposure of interest (exceeding the lifting index) is beyond the scope of this paper (see Winkel and Mathiassen, 1994 for a review of issues related to exposure assessment for LBP). The outcome is best assessed with the cooperation of the medical department within a plant and may include various levels of outcome severity. The primary outcome would be lost work time for an acute LBP episode that can reasonably be associated with an occupational exposure.

7. Discussion

Most current epidemiological studies of occupational injuries have significant methodological problems (Veazie et al., 1994). To address the challenges of doing high quality research in this area more attention needs to be given to modern epidemiologic research methods. Some new approaches like the case-crossover study need to be tested in the workplace.

Since the nature of injury at the workplace is diverse in severity, agents and causes of injury, the best approach may be to focus on one industry and one injury type. For example, non-fatal machinery-related injury on farms may be one area of focus (Layde, 1990). Detailed descriptive studies of how injuries occur might be discussed at first in an open-ended format with farmers. A survey instrument might then be developed to assess the rate of injury and exposures to various hazardous machines. Either a prospective multi-site study with a case-crossover component or a case-crossover study alone might be planned next. A broad examination of environmental, equipment, medical and behavioral factors and their temporal relationships with respect to injury might be used (Feyer and Williamson, 1991).

The above process could be applied to any other type of occupational injury. However, only after repeated analytic studies of the same injury type will risk factors be confirmed or refuted and intervention studies planned. In this regard, interventions following analytic (case–control and cohort) studies have begun to show an effect in reducing the frequency of falls in the elderly (Tinetti et al., 1996). There is every reason to assume that analytic studies, over time, can improve our understanding of the etiology of occupational injuries, and lead to interventions that can help reduce specific types of these injuries.

8. Conclusion

Study designs will invariably benefit from challenges by and contributions from a variety of professions including the injury prevention disciplines (occupational safety, occupational hygiene, industrial ergonomics), sociology, psychology, epidemiology, engineering, and medicine. Complementing this approach, the degree of successful cooperation between government, academia, industry and labor sectors will likely influence the efficacy of the next generation of analytic and intervention studies.

Attention should be given to the development of opportunities which facilitate the broad exchange and challenge of ideas in injury research. Such opportunities might include electronic exchanges, small cooperative study groups, focused conferences and workshops, and other activities intended to foster long term cooperative partnerships among researchers in safety science.

An example of one such opportunity is provided in Courtney et al. (1997) which documents an international injury epidemiology methods workshop held in June 1996. Participants agreed to collaborate with one another on the development of original manuscripts concerning research methods and challenges, the results of which were published along with recommendations emerging from the workshop (Burdorf et al., 1997). Subsequently, several participants have extended the collaboration to participation in and review of one another's studies. This increased interaction between professionals in various public health specialties is desirable if our understanding of injury and injury prevention is to progress.

Analytic epidemiology studies have demonstrated utility in identifying the causes of diseases and injuries. Interventions based on the accumulated findings of numerous analytic studies in a personal health area (cardiovascular disease) have been shown to reduce disease rates. Similarly, it is reasonable to assume that interventions based on the accumulation of analytic studies of occupational injury could have similar effects on occupational injury rates. If this proves to be the case, then these efforts will leave a legacy of safer, more competitive workplaces to future generations of workers and their organizations.

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