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REVIEW

Review and Meta-analysis of Emerging Risk Factors for Agricultural Injury

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ABSTRACT
Agricultural injury is a significant public health problem globally. Extensive research has addressed this problem, and a growing number of risk factors have been reported. The authors evaluated the evidence for frequently reported risk factors earlier. The objective in the current study was to identify emerging risk factors for agricultural injury and calculate pooled estimates for factors that were assessed in two or more studies. A total of 441 (PubMed) and 285 (Google Scholar) studies were identified focusing on occupational injuries in agriculture. From these, 39 studies reported point estimates of risk factors for injury; 38 of them passed the Newcastle-Ottawa criteria for quality and were selected for the systematic review and meta-analysis. Several risk factors were significantly associated with injury in the meta-analysis. These included older age (vs. younger), education up to high school or higher (vs. lower), non-Caucasian race (vs. Caucasian), Finnish language (vs. Swedish), residence on-farm (vs. off-farm), sleeping less than 7–7.5 hours (vs. more), high perceived injury risk (vs. low), challenging social conditions (vs. normal), greater farm sales, size, income, and number of employees on the farm (vs. smaller), animal production (vs. other production), unsafe practices conducted (vs. not), computer use (vs. not), dermal exposure to pesticides and/or chemicals (vs. not), high cooperation between farms (vs. not), and machinery condition fair/poor (vs. excellent/good). Eighteen of the 25 risk factors were significant in the meta-analysis. The identified risk factors should be considered when designing interventions and selecting populations at high risk of injury.

KEYWORDS
Agricultural injury; emerging; meta-analysis; risk factors; systematic review

Introduction

Injury incidence

Since the 1990s, injuries to agricultural workers have been studied extensively, particularly in the developed countries, and high rates of mortality and morbidity have been reported. As an example, the incidence of fatal injuries was 24.1/100,000 full-time equivalent (FTE) workers in 2014, and the nonfatal injury rate was 5.7 injuries/100 FTE for hired farm workers in 2013 in the United States, according to the Bureau of Labor Statistics.[1,2] The fatality rate for agriculture was 8 times higher compared with all industries combined.[2,3] The high rates represent a hard pressing problem of unintentional occupational injury in modern agriculture. Further, the reported rates may underestimate the actual incidence, particularly among self-employed farmers, hired workers on small farms, and unauthorized workers.[4–8]

Injury sources

Injury sources are reported in many surveillance and insurance data sources. This information helps design source-specific interventions. Common sources of injury include machinery, animals, and falls. Machinery-related injury sources include tractors, combines, harvesters, planters, power take-off drivelines, augers, and all-terrain vehicles.[9–15] Tractors account for a large proportion of machinery-related fatalities.[13] Animal-related injuries occur frequently from handing horses, boars, bulls, and other livestock.[9,12,16–18] Many agricultural tasks involve working at heights, such as harvesting tree fruit. Fall-related injuries account for about 25% of total injuries on the farm.[7,19–21]

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Supplemental data for this article can be accessed on the publisher's website.

Injury characteristics

Injury characteristics are described in many surveillance systems and studies. This information can help develop strategies for prevention. Injury characteristics include physical nature: sprain, strain, fracture, laceration, etc.[10,11,21,22]; work activity: lifting, operating machinery, handling livestock, etc.[7,13,23]; worker situation: working alone, accompanied by others[24]; location: home, road, field, pasture, building, etc.[7,13,25]; and time: day, week, month, season.[7,13,23] Injury severity is defined by the level of medical treatment: no care, outpatient care, hospitalization[12,16,17]; economic loss: disability duration (lost time) and cost of medical care[7,26,27]; and prognosis: complete recovery, impairment.[7] Extremities were the most common body parts involved in injury.[6,24,28,29]

Recent research has addressed many risk factors for agricultural injury. However, the results vary from study to study and are contradictory in some cases. To enhance the success of injury prevention, evidence-based evaluation of risk factors is essential to understand the risk of injury in different agricultural worker populations.[30]

The risk factors for injury can be divided into individual-level or farm-level factors.[31] Individual-level risk factors include demographic or personal characteristics such as age, education, retirement status, race, marital status, native language, farming experience, on-farm residence, off-farm employment, and primary occupation. Farm-level risk factors include environment- and safety-related factors. Environment-related factors include farm size, use of tractors of different sizes, field crops harvested, farm sales, farm income, animal production, number of hired workers, and cooperation between farms. Safety and behavior-related factors include unsafe practices, receipt of safety training, alcohol use, smoking, sleep quantity and quality, perceived injury risks, and social conditions.

The objective of this study was to evaluate the weight of evidence for reported demographic, environment, safety, and behavior-related risk factors from the available literature using a systematic review and meta-analysis.

Methods

We conducted a systematic review and meta-analysis of risk factors for agricultural injury. The methods used in this review were similar to our earlier report,[32] with some modifications in the inclusion criteria and analysis. In this report, we expanded the inclusion criteria and accepted studies with unadjusted as well as adjusted odds ratio (OR) or relative risk (RR) estimates for agricultural injury. This enabled us to include emerging risk factors. We used unadjusted estimates for meta-analysis when adjusted estimates were unavailable. In some cases, we calculated crude OR estimates using descriptive data reported in the studies. In our earlier review,[32] we learned that different studies used very different combinations of confounders in their adjusted models. Therefore, adjusted estimates may not be robust, as different studies controlled for different sets of risk factors. In almost all cases, the risk factors found in adjusted models excluded hours spent in farm work and exposure time in different tasks conducted on the farm. This may lead to residual confounding effects, even when the risk factor variable was highly significant in adjusted analyses. For example, male gender is commonly found as a strong risk factor, but it may in fact merely reflect the division of work tasks and exposure durations in hazardous tasks. Typically risk factor variables with strong association with injury were significant in both unadjusted and adjusted models. In some cases, it is possible that adjusting for certain variables may also eliminate important risk factor variables from adjusted models. For practical purposes, knowledge of risk factors, confounded or not, can be used for selecting target audiences for interventions. Therefore, in this review, we accepted unadjusted as well as adjusted estimates to describe the association of risk factors and agricultural injury.

Definitions

There is no universally accepted definition of agricultural injury. The definitions vary from study to study. We included studies that used definitions relatively close to the following: an unintentional, sudden (vs. long-term exposure), forceful event with an external cause resulting in body tissue damage or unconsciousness (and possible medical care and/or lost work time), occurring to a person engaged in agricultural work activity at the time of injury. In some studies, the terms accident or incident are used instead of injury with the same meaning. Individual definitions prepared for the risk factors are summarized in Table 1 (see supplemental material).

Identification of studies

We used the following criteria for a study to be eligible for the systematic review:

(1). The study must focus on agricultural injury outcomes and report injury occurrences, such as incidence rate, cumulative incidence, or annual incidence—calculated using defined denominator populations.

AND

(2). The study must report adjusted or unadjusted point estimates, such as odds ratios, risk ratios, relative risks, rate ratios, hazard ratios, or incidence risk ratios.

We searched studies in PubMed and Google Scholar databases, published up to 2014. We identified 441 studies in PubMed and 285 studies in Google Scholar using the search process described in our earlier review.[32]

We then scanned titles and abstracts, removed duplicates, and shortlisted 210 studies that met our first eligibility criterion. Others were excluded because they focused on one of the following: agricultural diseases, nonoccupational injuries, road safety, farm practices, safety education to farmers, tractor rollover protection, interventions, pesticide use and its effect on farmer's health, farm animals, ergonomic issues in farm workers, and farm-vehicle/equipment accidents.

After evaluating the 210 studies, we identified 37 studies that met our second eligibility criterion. We excluded the remaining studies because they provided narrative reviews, reviews of interventions, covered nonagricultural activities, focused on causes or characteristics of injury, described risk factors already evaluated in our earlier review, or did not report adjusted or unadjusted point estimates for risk factors. After checking references of the 37 identified studies, we added 2 more studies that met our eligibility criteria, resulting in the inclusion of a total of 39 studies for the systematic review and meta-analysis. The included studies reported point estimates of injury for one or more risk factors. A total of 25 risk factors were described in the studies. The individual steps for selection of studies are illustrated in Figure 1.

Quality assessment

We evaluated the quality of the 39 selected studies using the Newcastle-Ottawa (NOS) checklist. We used commonly used cutoffs[33,34]: the scores of 6 out of 9 for case-control, 6 out of 10 for cross-sectional, and 5 out of 9 for cohort studies. One study from the total of 39 studies failed the quality assessment, resulting in the inclusion of 38 studies for the systematic review and meta-analysis. We

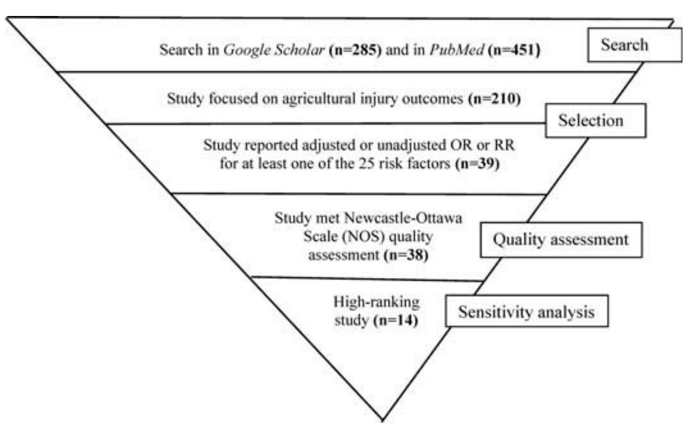

Figure 1. Schematic for identifying studies for systematic review and meta-analysis with measures taken during each stage.

calculated pooled estimates in the meta-analysis for the 25 risk factors from these 38 studies. Point estimates for three risk factors were reported in single studies. Estimates for age were evaluated differently (explained elsewhere).

Sensitivity analysis

To determine the stability of measured associations of each of the 21 risk factors for injury outcomes, we performed sensitivity analysis of the measured associations. For this task, we ranked all 38 studies based on their scores on the NOS (described in our earlier review[32]). Studies that scored at least 1 point higher than the cutoffs (7/9, 7/10, and 6/9 or higher) were considered as "high-ranking," and the rest as "low-ranking." We determined that 14 of the total of 38 studies were high-ranking. Among these 14 studies, 4 were case-control, 4 were cohort, and 6 were cross-sectional studies. We then excluded the low-ranking studies and repeated the meta-analysis for all risk factors. The difference in the pooled estimates from the two rounds of meta-analysis (first with and then without low-ranking/nonsignificant confidence interval [CI] studies) reflected the robustness of association. The risk factors with highest risk difference in sensitivity analysis were considered least stable.

Data analysis

Point estimates for 25 risk factors were obtained from the 38 identified studies. All risk factors except one (age) were assessed in meta-analysis.

The meta-analysis of the 24 risk factors involved multiple steps. Relative risk (RR) estimates were converted into odds ratio (OR) estimates using a conversion method described in our earlier review.[32] When necessary, point estimates were adjusted for meta-analysis. The adjustments included inversion of the reference group in studies with opposite reference groups, and dichotomization of categories in studies that reported point estimates for more than two levels of the risk factor. We used CMA (Comprehensive Meta-analysis) program[35] for meta-analysis. All ORs were entered in the software program and pooled OR and CI estimates were generated using the inverse variance method for each of the 24 risk factors. The meta-analysis process is described in detail in our earlier review.[32]

Age could not be assessed in meta-analysis due to lack of universally accepted standards for categorizing age. Years of age intervals, numbers of levels, and referent groups differed greatly in source studies. To harmonize the differences in age categories, we assigned the reported point estimates for each age category to the midpoint of the interval of each age category. For example, one study reported OR of 2.16 for the category 50–60 years of age.[36] We assigned this OR to the midpoint of the category, 55 years. This method has been applied previously.[37] All non-OR point estimates were converted into ORs (explained in our earlier review[32]). We plotted age category midpoints on the x-axis and corresponding ORs on the y-axis in a scatter plot. Each reported OR was weighted by the corresponding study size. We quantified the correlation between age and injury risk using Pearson's r^2. Statistical significance was considered at $P \leq .05$. The trend of the correlation was visualized by drawing a regression line in the scatter plot using Statistical Analysis System (SAS).[38]

Results

Characteristics of studies included in the systematic review and meta-analysis

Location and sample size

The selected studies represented agricultural populations from the United States (n = 27) as well was from other countries (n = 11), including Australia, Belgium, Canada, China, and Finland. The sample size of the studies ranged from 113 to 274,797. Many studies had samples of less than 1,000 participants (n = 17), some had 1,000–3,999 (n = 12), and others (n = 9) had 4,000–99,000 participants. Further study details (study, location, design, sample size, target population, injury type, significant risk factors found, and confounders adjusted in multivariable model) for the included studies are available from the authors by request (13 pages).

Population

The identified studies used different populations drawn from national census (n = 1), insurance records (n = 3), and hospital records (n = 1), and used different data collection methods, including random sampling (n = 22), stratified sampling (n = 8), and other measures (n = 3). The populations were engaged in agricultural production work that is classified as codes 111 (Crop production) and 112 (Animal production) in the North American Industrial Classification System, and subcategories under these codes.[39] The subpopulations included principal owners/operators, regular or seasonal workers, migrant workers, farm residents, farm nonresidents, full-time farmers, part-time farmers, male farmers, female farmers, farmers of young, middle and older ages, farmers who had farming as their only income source, and farmers who also worked off-farm. Most participants were Caucasian. We included studies that were primarily focused on adults. Children and youth were not included because their injury characteristics, sources, and preventive strategies differ from those in adults.

Injury outcome

The vast majority of studies used self-reporting for data collection where the injury outcome was evaluated by asking farmers if they had an injury (or injuries) in the past 12 months. Other definitions included injury that required medical care (other than first aid) and/or lost work for half a day or more. Injury severity was measured by evaluating medical characteristics using Injury Severity Score[40] and the amount of compensation in insurance claims.[27] Injuries occurred in all areas of the farming operation, including animal facilities. Work tasks included transport of agricultural goods, operation and repair of machinery, mounting and dismounting of tractors, fieldwork, and animal-related tasks such as feeding, milking, herding, moving, and riding animals. Injuries resulted in lost work time, and medical care such as outpatient-level care and hospitalization. Common injury sources/causes included machinery, animals, and falls.

Estimated effect of risk factors on agricultural injury

The correlation between age and injury is illustrated in a weighted scatter plot in Figure 2. Also, a bubble plot indicating weights of the point estimates based on the size of the corresponding studies is depicted in Figure 3. The regression line reflected an increasing trend in injury risk by age. The correlation between the risk of injury and age was relatively weak but statistically significant (Pearson's correlation P value = .03, r^2 = .21). Further, without weighting by study size, the effect was in opposite direction (P = .34, r^2 = .01).

Pooled risk estimates were calculated for the remaining 24 variables in separate meta-analyses using two or more studies. Different studies adjusted for different sets of confounders. The most common confounders included in the multivariate models were age (n = 29), work hours (n = 17), education (n = 14), gender (n = 14), marital status (n = 10), health- and safety-related factors (n = 23), and farm-related factors (n = 23). The results for the 24 risk

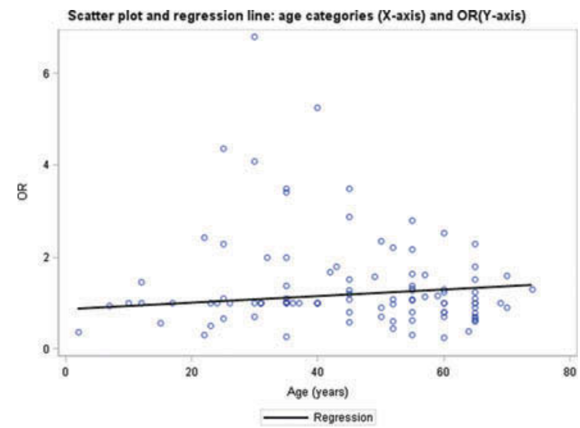

Figure 2. Weighted scatter plot with reported risk estimates of agricultural injury for age.

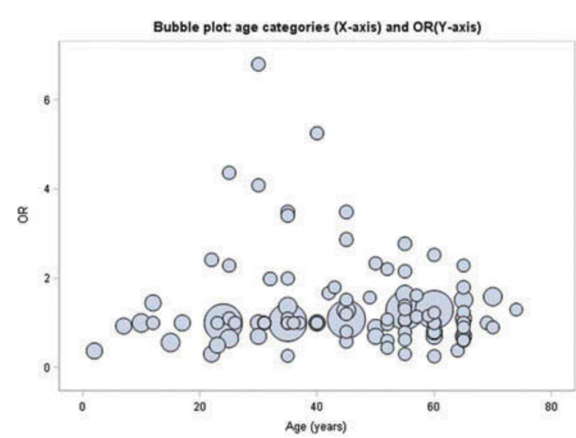

Figure 3. Weighted bubble plot with reported risk estimates of agricultural injury for age.

factors are illustrated in Table 2 (see supplemental material).The short descriptions are as follows.

Demographic risk factors

Pooled estimate calculated from eight studies showed that high school–level education or more (vs. less) increased the odds of injury (OR: 1.39; 95% CI: 1.21–1.59). Three studies reported married (vs. other) status as a risk factor, whereas five studies reported it as protective. The overall effect of marital status was inconclusive ($P > .05$). Four studies reported lower odds of injury for Caucasian farmers, whereas one study reported the opposite (OR: 0.76; 95% CI: 0.61–0.95). The pooled estimates for Finnish language (vs. Swedish) calculated from three Finnish studies showed that the odds of injury was 1.21 times higher in Finnish-speaking farmers compared with those who spoke Swedish as their native language (95% CI: 1.14–1.29). Experience in farming less than 20–25 years (vs. more experience) was protective in three studies and a risk factor in one study. The meta-analysis was inconclusive. Four studies reported higher odds of injury for those who lived on the farm compared with those who lived off the farm. Two studies reported the opposite (OR: 1.18; 95% CI: 1.08–1.29). Three studies concluded that the odds of injury were higher for those who worked off-farm than those who did not. One study showed contradictory results. The meta-analysis was inconclusive for off-farm work.

Personal or behavioral risk factors

High CAGE score or excessive drinking was reported as harmful in six studies, whereas one study reported a protective effect of excessive drinking. The meta-analysis was inconclusive. Two studies reported that current smoking was protective for injury. Smoking in the past was reported as harmful in one study and protective in two studies. The overall result was inconclusive. The pooled estimates calculated from two studies for sleep showed that sleeping less than 7–7.5 hours (vs. more) increased the risk of injury by 1.32 times (95% CI: 1.12–1.56). Pooled estimate from two studies showed that the odds of injury were 1.66 times higher in individuals who perceived high injury risk than those who perceived low risk (95% CI: 1.28–2.15). Two studies showed a very high risk of injury in those who had challenging social conditions such as tensions with neighbors or stress due to social situations; pooled estimate indicating 3.49 times greater injury risk (95% CI: 1.81–6.75).

Farm-related risk factors

The pooled estimates for farm size calculated from six studies indicated that greater farm size (vs. small) increased the odds of injury by 1.14 times (95% CI: 1.11–1.17). Three studies reported higher odds of injury in farmers who produced livestock compared with those who produced other commodities. One study reported the opposite. The overall effect was OR: 1.71 (95% CI: 1.04–2.79). The summary effect for gross sales calculated from two studies showed that the odds of injury were 1.33 times higher in those with greater sales versus those with smaller sales (95% CI: 1.28–1.39). The pooled estimates of injury for higher income earned from farming (vs. lower income) reflected 2.33 times higher risk of injury among higher income farmers (95% CI: 2.22–2.44). Higher number of workers employed on the farm (vs. lower) increased the odds of injury (OR: 1.92; 95% CI: 1.32–2.79).

Safety-related risk factors

Four studies reported higher odds of injury in farmers who employed unsafe practices such as not turning off machinery regularly, accidental exposure to alkalis/acids on the skin, frequently hurrying during farming, and unsafe lifting of heavy objects (OR: 1.67; 95% CI: 1.34–2.09). Not attending safety training or quality management courses or instructions was reported as harmful in three studies, whereas it was reported as protective in one study. The meta-analysis was inconclusive for attending safety training courses or instructions. The pooled estimate calculated from two studies for computer use for farm management (vs. not) indicated 1.35 times higher odds of injury (95% CI: 1.10–1.65). Overall effect of accidental exposure to pesticides and/or chemicals to the skin obtained from three studies showed that the odds of injury were 1.71 times higher in those who had accidental exposure to pesticides and/or chemicals to the skin than those who did not (95% CI: 1.35–2.16).

Sensitivity analysis

All measured associations remained stable during sensitivity analysis. The change in the strength of association was minimal and ranged from 0.00 to 0.43. A change in the direction of the association was observed in only two cases—smoking and off-farm work. However, the pooled estimates for these risk factors were not significant. The results of sensitivity analysis are illustrated in Table 3 (see supplemental material).

Discussion

Reported reasons for risk differences

The systematic reviews reported in this and our earlier report,[32] to our knowledge, provide the first pooled estimates quantifying risk factors for agricultural injury. Based on evidence found in the current literature, several risk factors emerged significant whereas others require further research to confirm their role. Of the 25 potential risk factors that we evaluated, 17 increased the risk of injury whereas 1 decreased the risk. Two out of the 18 significant risk factors were derived from single reports. The pooled odds ratio estimates ranged from 0.76 to 3.49. Significant factors included age, education, native language, race, on-farm residence, sleep, perceived injury risk, social conditions, farm size, sales, income, livestock production, number of workers employed, cooperation between farms, unsafe practices, poor maintenance, computer and/or Internet use, and accidental exposure to pesticides or chemicals. Injury was not significantly associated with marital status, experience, principal occupation, alcohol use, smoking, and safety training. In our earlier report,[32] we established male gender (vs. female), full-time farming (vs. part-time), owner/operator status (vs. family member or hired worker), regular medication use (vs. none), prior injury (vs. none), stress or depression (vs. none), and hearing loss (vs. none) to be significant factors whereas health problems (vs. none) was inconclusive.

Intervention programs should consider targeting populations with elevated risk of injury. The pooled estimates calculated in the meta-analysis indicate the magnitude and direction of the association. Some source studies suggested causal mechanisms related to the identified risk factors, which are discussed in the following sections.

Demographic risk factors

The current study showed that higher education was a risk factor. Studies suggested that farmers with higher education may be able to recall injuries better than those with less education.[18,22,41] Research also suggests that higher education and knowledge of farm safety are two different things. Therefore, higher education does not help reduce the risk of injury, which is contrary to workers from most other industries; less educated workers from most other industries tend to have high risk of injury.[42]

Marital status is yet to be fully explored in injury risk research. Gerberich et al.[12] reported that those who were married had the higher risk of injury but that the effect could be confounded by age and work exposures. Other studies found marital status as a significant risk factor in their univariate analyses but failed to achieve significance in multivariate analyses.[25,43] Our meta-analysis was inconclusive for marital status.

McCurdy et al.[44] showed race as an independent risk factor for injury, and that Caucasian farmers were at higher risk than other races. McGwin et al.,[45] on the other hand, reported a greater risk of injury in non-Caucasian (African American workers, in particular). The meta-analysis showed that the Caucasian race was protective for injury risk.

Finnish language (vs. Swedish) was a risk factor among farmers in Finland. Language may reflect differences in culture, farming practices, and insurance utilization that could not be controlled for with available variables in the studies.[27,30] Swedish-speaking farmers may underreport their injuries; they filed fewer claims for minor injuries, but the rate of serious injury claims was similar in both groups.[30,46] However, it is also possible that Swedish-speaking farmers have safer farms and take fewer risks than Finnish-speaking farmers.[46]

Injury risk tends to be lower in farmers with longer farming experience. This may be due to adopting safer work practices compared with those with less experience.[11] Also, the effect of experience on injury may[10,12] or may not[43] be confounded with age and other factors. In this review, the overall effect of experience on injury was not significant. More research is needed to understand the effect of experience and its interaction with age.

Residence on the farm was a risk factor. Farmers who live on the farm have a greater exposure to farm work and farm environments, leading to increased probability of injury.[30] However, two studies[10,21] reported the opposite. It may be difficult to understand the occupational nature of injuries that occur to off-farm residents.[21] In conclusion, farm residents generally have a higher risk of occupational injury.

The meta-analysis was inconclusive for off-farm work. According to Sprince et al.,[18] farmers who hold off-farm employment spend fewer hours on the farm than those who work on the farm exclusively, indicating higher exposure to farm work and underlying risks to farmers. On the contrary, Xiang et al.[47] suggested that farmers who work off-farm experience more stress, which in turn increases their risk of injury. More research should explore the effect of off-farm work on injury.

Having farming (vs. other) as primary occupation was reported in one study, but the result was inconclusive. Farming is one of the most hazardous industries,[9] and those who are employed primarily in agriculture should have higher risk of injury. On the other hand, individuals who consider farming as a secondary business may pay better attention to safety due to lack of confidence and experience in agriculture.[48] The odds ratio from the single study was not significant for primary occupation. More studies should explore principal occupation as a risk factor.

Personal or behavioral risk factors

Excessive use of alcohol was associated with high risk of injury.[7,49] However, Rautiainen et al.[50] reported that moderate use of alcohol was protective compared with nonuse. Alcohol use was evaluated differently across studies. Some studies used the CAGE[22,25] questionnaire for the level of alcohol use, whereas others reported the amount of alcohol consumed in a day, week, month, or year. The meta-analysis was inconclusive for alcohol as a risk factor. More research is needed to examine the association between alcohol use and injury.

Crawford et al.[36] suggested that the stimulant effect of tobacco can induce alertness that can result in decreased risk of injury. The meta-analysis was inconclusive for smoking as a risk factor. The effect of smoking warrants further exploration.

Meta-analysis showed that inadequate sleeping (less than 7–7.5 hours) was associated with injury. Choi et al.[51] explained that adequate sleeping is required to maintain alertness to remain productive on the job. Sleeping more than 8.5 hours also elevated the risk of injury that could be indicative of underlying diseases.[51] Additionally, alcohol can cause changing sleeping patterns, daytime drowsiness, and loss of alertness.[25] Modification of the effect of inadequate sleep on injury by alcohol use should be explored further.

High perceived injury risk was a risk factor. Self-awareness of the risk of injury can increase the level of alertness towards imminent hazards and should result in a decrease of the actual risk of injury. However, the issue may arise from the existence of known hazards or taking risks knowingly. In one example, active safety and security monitoring reduced the risk of injury.[52] Further studies should explore how high perceived risk of injury could result in safety-enhancing behaviors among farmers.

Challenging social conditions was a risk factor. Studies reported high risk of injury in those with compromised interpersonal relationships or social situations.[53,54] Difficult social and economic conditions pose a barrier for promoting safety behaviors.[53] Programs to overcome these challenges could have health benefits, including reducing the risk of injuries.

Farm-related risk factors

Larger farm size was a risk factor for injury. Managing larger farms may require longer exposure hours to farm work and accompanying risks.[20,28] Larger farms may also have livestock operations that involve high workload year-round and added economic pressure.[55] However, long work hours may not explain the high rates of injury, as manual work may be done by hired employees on larger farms. They may also need to comply with safety regulations, which should improve their injury risk.

The meta-analysis result may be influenced by having a high proportion of very small part-time farm operations in the small farm category. More research is required to understand injury patterns on large farms that produce different commodities.

Animal (vs. crop) production was associated with high risk of injury,[29] particularly in female farmers.[56,57] According to a Belgian study,[48] crop farming involves less variety of tasks than mixed farming, which may reduce their injury risk. McGwin et al.[45] showed the association between animal production and injury while adjusting for work hours.

Higher farm income was a risk factor. High farm income commonly implies higher exposure to farm work as well.[27,30] However, some studies reported high injury rates for low-income farmers.[25,58] Low income, along with debt,[25,58] stress, and depres sion[25] may increase the risk of injury. More efforts are needed to evaluate income in greater detail.

Higher farm sales can be an indicator of greater exposure to farm work, similar to income and farm size mentioned above.[5] A Canadian agricultural census–based study[59] found the opposite. They explained that farmers who accumulated high sales tend to know prevention of injury better than those with lower sales.[59] More studies are needed to understand the risk-taking behaviors in farmers relative to sales, income, and farm size.

Greater cooperation between farms (vs. low) was a risk factor. The high risk may be due to borrowing malfunctioning machinery from other farmers without the knowledge of its condition, and such machinery could pose a high risk of injury.[60] More research could reveal mechanisms for high risk of injury resulting from cooperation between farms.

Larger number of employed workers on the farm was a risk factor. Zhou and Roseman[7] reported that the risk of injury increased with the number of hired workers. Crawford et al.[36] suggested that the ability to employ workers indicates larger farm size and greater exposure time. On the other hand, lack of hired help can also lead to a higher risk of injury, if owners/operators overextend their working capacity.[48]

Safety-related risk factors

Reporting unsafe behaviors was a risk factor. The risky behaviors included unsafe lifting of heavy objects, frequently hurrying when performing tasks, less frequency of turning off machinery, and accidental exposure to acids/alkalis. Some behaviors considered unsafe may be unintentional due to lack of awareness, or intentional in many cases. Safe behaviors such as using seatbelts frequently have shown to reduce transportation-related injuries among farmers.[4] Unsafe practices such as lifting of heavy weights could be reduced by mechanization or management or organization of work.[50]

Safety training courses and material were found inconclusive in the meta-analysis. Training in one study included safety information embedded into chemical handling, animal husbandry, pasture management, machinery and equipment operation, and wool classing course components.[40] It is likely that agricultural training courses do not have enough safety-related content to make an impact on injuries.[52] The evaluation of farm safety training warrants further research.

Computer use for farm management was a risk factor. A high percentage of farms in the United States had computer(s) (70%) and Internet (67%) access in 2013.[61] Taattola et al.[60] explained that operators on modern farms may work longer hours, thereby having a greater exposure to farm-related activities. Farmers with advanced equipment may have higher levels of stress and urgency to get jobs done in spite of the availability of better management tools. More research is required to understand the association of injury and use of advanced technologies, and the effect of confounding factors such as farm size, number of workers employed, income, age, race, and native language of workers.

Accidental pesticides/or chemicals exposure to the skin was a risk factor. High doses of pesticides or chemicals can be hazardous to health. However, this exposure may be an indicator for the general level of safety precautions on the farm, rather than an independent risk factor due to toxicity of the chemical. Further research is needed to understand these mechanisms.

Poor maintenance of machinery was a risk factor. Poorly maintained machinery tends to be unreliable and also requires frequent repairs compared with adequately maintained machinery.[45] Injuries often result from situations where the normal process of work is disrupted by malfunction. Machinery maintenance may also be an indicator of general attention to safety on the farm.

Age as a risk factor

One of the unique aspects of the current study was the assessment of the effect of age on injury using a correlation metric, adjusted for study sizes. The source studies used different categorizations for age. It was not possible to dichotomize or reclassify age categories uniformly between studies. Instead, we constructed a data set assigning each reported risk estimate (OR) to the corresponding midpoint year of each age category. This data set enabled calculating the correlation between OR and age in years, and showing the result graphically in a weighted scatter plot with a regression line. We found that older farmers were at high risk of injury compared with their younger counterparts. The risk of injury increased with age only slightly, and the correlation was weak (r^2 = .21). When the ORs were not weighted by study size, the association was reversed: older farmers had fewer injuries. The majority of studies in fact showed higher risk of injury in younger farmers.

Many explanations have been offered in support of younger farmers having a higher injury risk. Younger farmers tend to be less experienced in farming, and tend to engage more in risk-taking behaviors compared with older farmers.[5,7,18,22,44,48] Also, younger farmers may remember their injuries better compared with older farmers.[18,22,36] Younger farmers may have high stress from increasing production and expanding the business.[60] Working long hours, on and off the farm, can lead to high frequency of risk-taking behaviors.

Other explanations were offered as to why older farmers may have a higher injury risk.[31,47] Older farmers continue working on the farm because there are limited retirement options in farming in many countries. Although they may reduce their farming activity,[31] possibly due to health ailments, medication use, and other issues, they still participate in farm work by helping other operators such as a son, daughter, or other relative.[47]

We base our conclusion that older age is a risk factor for injury on the analysis where the sizes of the studies were considered, giving more weight to findings from largest studies. However, this conclusion should be interpreted with caution, as the majority of (smaller) studies show the opposite. Several confounding factors may also play a role, such as hours spent on individual tasks, commodities produced, operator status, gender, race, farm size, income, availability of assistance for work, medication use, health issues, hearing loss, and others.

Strengths

Risk factors for agricultural injury have been studied fairly extensively. Many studies were consistent, showing similar effects of risk factors. However, there were also contradictory findings. The evidence from all available studies can be analyzed in a systematic review, and a quantitative summary can be generated using meta-analysis. This method allows creating a common understanding of risk factors from individual studies that may not show similar results. Similar systematic reviews have been done frequently for evaluating the effectiveness of interventions to reduce injury.[62–66] To our knowledge, this is the first systematic review of risk factors for agricultural injury.

Numerous studies have addressed common risk factors such as gender, age, education, health problems, medication use, hearing loss, farm size, and type of commodity produced. Other risk factors have been reported less frequently. For instance, computer and/or Internet use, language, social conditions, and cooperation between farms have been identified in small numbers of studies. Therefore, this review is timely and provides useful insights into well-established as well as emerging risk factors from available studies published to date.

The effect of age on injury has been investigated in many studies. Age is one of the most commonly used variables for adjustment in multivariate models as well. The effect of age is challenging to summarize from different studies. Different categorizations are used for age to fit the population, study design, data source, and sample size. We developed a method correlating midpoints of age categories with injury risk estimates for those categories. This is a unique contribution from this study.

The selected studies were diverse in terms of geographic locations, study designs, sample sizes, sampling schemes, populations, methods of data collection, and factors used for adjustment of multivariate models. Our review included cross-sectional (n = 20), prospective cohort (n = 7), and case-control (n = 11) studies. The studies used various data sources such as mail surveys, interviews, and insurance or hospital records.

Of some of the methods available for quality assessment of research studies, such as Critical Appraisal Skills Program,[67] Strobe,[68] and the Downs and Black Checklist,[69] we used the NOS[70] for the current study. The NOS is an appropriate tool for assessing the quality of nonrandomized studies, with the capability of generating numerical scores. These scores can be used for determining the eligibility for inclusion of the studies for the systematic review. Although we used adjusted risk estimates for risk factors from most studies, we also used unadjusted risk estimates when adjusted estimates were not available. In some cases, we also calculated crude ORs using reported frequencies. We included unadjusted estimates because adjustment of confounders varies with studies, and this observation resulted in waiving the requirement of adjustment for confounders. Only one study did not meet our predetermined NOS score for quality. Sensitivity analysis showed that eliminating the low-ranking studies did not make much impact on the pooled estimates calculated in the meta-analysis; the pooled estimates for risk factors were stable even with 14 high-ranking studies used for the meta-analysis.

Limitations

The study had some limitations. The overall quality of systematic reviews depends on the quality of source studies. We selected studies of high quality using the predetermined quality criteria, and this measure might have helped overcome this limitation. As with all reviews, our study is subject to publication bias. Studies with nonsignificant findings are difficult to get published.[71] We addressed this issue by allowing inclusion of nonsignificant point estimates of injury for risk factors from published studies. However, often the nonsignificant associations are not mentioned, or if they are, usable nonsignificant estimates are not included in the reports.

Self-reporting was used in many source studies, and this can introduce recall biases. It is possible that farmers with any or severe injuries remembered more about exposures than those with no injury or nonsevere injury. Also, insurance claims may include some underreporting due to high requirements for accepting claims. On the other hand, insurance systems create a "moral hazard"[50] where claims are filed fraudulently for economic gain.[27,46] In one insurance system, both over- and underreporting were relatively low.[30] Information bias could have also resulted due to failure to interpret survey questions correctly. The selected studies used data sources such as administrative records, and data collection methods such as structured questionnaires and computer-assisted interviews. These measures help reduce the possibility of recall bias to a certain extent.

All case-control studies had differential response rates between case and control/comparison groups, and that could have led to selection bias. Selection bias results in over- or underrepresentation of one or both groups (cases, controls/comparison group). However, studies sampled their populations using random sampling, stratified sampling, regional government survey records, sampling of all individuals from a defined population, or using total population-based administrative records (hospital or insurance). These measures may have reduced the effects of selection bias.

Although some studies reported adjusted risk estimates, they did not adjust the association between risk factor and injury for individual tasks. Adjustment for tasks could have revealed actual risk differences among populations.

We modified some of the risk estimates reported in the source studies to maintain consistency among studies for the type of risk estimate (OR or non-OR estimates), referent group, and number of categories used. The modified risk estimates may not be absolute estimates. However, modification of risk estimates many not have affected the overall summary effect. On the contrary, the modified estimates may have increased the stability and precision of measured associations.

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