Large Machinery-Related Agricultural Injuries Across a Five-State Region in the Midwest

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Objective: High agricultural injury related mortality and morbidity rates persist. This study addressed a knowledge gap regarding large machinery-related injury magnitude, consequences, and risk factors. **Methods:** From randomly selected Midwestern agricultural operations in 1999 and 2001, 7420 eligible households participated. Demographic, exposure, and injury data collected for four 6-month periods used a computer-assisted telephone interview. An a priori causal model enabled survey development, data analysis, and interpretation. Directed acyclic graphs, developed from this model, facilitated potential confounder identification for specific exposures in multivariate analyses. **Results:** The injury rate was 12.82 events per 1000 persons per year. Increased risk was associated with male gender, increasing age, state of residence, history of prior injury, and increasing hours worked per week. **Conclusions:** Large machinery-related agricultural injuries can result in significant consequences. Associated increased injury risks require further investigation and targeting of relevant interventions.

Agriculture has consistently ranked as one of the top three most hazardous occupations and is a lead sector in work-related fatalities.[1,2] According to the United States National Bureau of Labor Statistics, the preliminary report for 2012 indicated that, despite a 16% drop in the number of agricultural fatalities from 2011 ($n = 566$) to 2012 ($n = 475$), the agricultural sector has continued to have the highest fatality rate across all sectors with a rate of 21.2 fatal injuries per 100,000 full-time equivalent (FTE) workers.[2] The 2014 Injury Facts data for 2012 report agriculture as having the highest death rate of 20.8 per 100,000 FTE workers compared with 15.3 deaths and 2.7 deaths per 100,000 FTE workers for mining and all industries combined, respectively.[3] In addition to high rates of fatality, the agricultural sector has a high number of nonfatal injuries. In 2012, the rate of medically consulted injuries, based on hours worked in the agricultural, forestry, fishing, and hunting sector, was 1.5 times greater than for all occupations combined (120,000/4,327,000 and 4,930,000/264,374,000, respectively).[3]

Among agricultural-related injuries, machinery has been found to be the leading cause of fatal and nonfatal injuries, with tractors being involved in the vast majority of these.[1,4–9] However, the second largest group of machinery involved is considered ''large machinery'' such as augers, balers, and harvesting equipment.[5,8] Information on the magnitude of large machinery-related agricultural injuries as well as associated risk factors is lacking.

Despite these disconcerting statistics, there is likely serious underreporting of these injuries for the following reasons: (1) the United States lacks a unified reporting system for agricultural injuries; (2) case definitions for what constitutes an agriculture-related injury vary; (3) many reporting systems exclude children under age 14 years, as they do not have access to formal jobs despite the fact that they work in these settings, particularly those associated with their own household; and (4) reporting of injuries is not Occupational Safety and Health Administration–mandated if the operation employs fewer than 11 full-time individuals.[1,10]

The purpose of the current study was to utilize data collected from the Regional Rural Injury Study II (RRIS-II)[11,12] to better understand the magnitude and consequences of and the risk factors for large machinery-related agricultural injuries across the five-state Midwest region of Minnesota, Wisconsin, North Dakota, South Dakota, and Nebraska.

METHODS

Data for this study were obtained from the RRIS-II database, combining data for years 1999 (phase 1) and 2001 (phase 2), which is explained in detail elsewhere.[11,12] Phase 1 (1999 data) were collected as baseline data for defining incidence, consequences, and potential risk factors for injury in the sample population, whereas phase 2 (2001) involved the same type of methods and data collection in order to compare the results between phase 1 and phase 2, through a surveillance approach; comparable results were identified between these 2 years. The RRIS-II Study received approval from the Institutional Review Board, Human Subjects Committee, through the University of Minnesota.

STUDY DESIGN AND POPULATION

The RRIS-II was a population-based study designed to analyze all agriculture and nonagriculture-related injuries experienced among farming and ranching operation households with children under the age of 20 years during 1999 and 2001. A validated telephone-based interview method for collecting injury, consequences, and exposure data was utilized.[11,12] Using the Master ListFrame of Farming Operations from the United States Department of Agriculture's National Agricultural Statistics Service (NASS), a total of 16,000 operations across multiple types of agricultural production were randomly selected to participate

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(3200 from each state) for both 1999 and 2001, resulting in a total of 32,000 operations selected. An introductory letter containing study information, informed consent information, and an invitation to participate was mailed to all selected operations, followed by a telephone interview conducted by a trained NASS-specialist to establish eligibility and obtain informed consent. During that interview, households were also invited to enter into a drawing to receive a $100 U.S. savings bond. To determine eligibility of nonresponder households, a one-page survey was mailed with a postage-paid return envelope.

Eligibility criteria required that the operation household (1) must have included at least one child under the age of 20 years as of January 1, 1999 or 2001; (2) sold or produced at least $1000 in agricultural goods or participated in a Conservation Reserve Program (CRP) in the previous year; (3) was actively farming/ranching as of January 1, 1999 or 2001, or maintaining CRP land; and (4) was willing to complete additional telephone interviews at 6-month intervals for both 1999 and 2001. All eligible participating households received a packet with information cards on which to record detailed injury information and agricultural operation exposure information, before the respective interviews.

NASS interviewers conducted supervised telephone interviews for eligible households during each 6-month period in 1999 and 2001. A computer-assisted telephone interview (CATI) instrument developed by the RRIS-II research team was utilized to obtain the following information: demographic characteristics; injury incidence and consequences; and other exposure information. Injury severity was measured by proxy variables such as self-reported severity, whether or not medical treatment was sought, and the duration of time for which normal activities were restricted. Results regarding mechanism (type of activity just before the event and how the incident happened) and the type of injury were recorded by the interviewers in a narrative form and then coded by two team members, independently, with the lead investigator finalizing any coding discrepancies.

DEFINITIONS

One or more of the following criteria needed to be met within the study periods to be defined as an injury: (1) normal activities restricted for a minimum of 4 hours; (2) loss of consciousness, loss of awareness, or amnesia for any length of time; and (3) care obtained from a health care professional. An ''agricultural'' injury was defined as any injury that occurred as a result of an activity or vehicle/source associated with an agricultural operation, including bystander injuries. All other injuries were classified as ''non-agricultural.'' In the current manuscript, ''injury'' refers only to large machinery-related injuries on one's own operation. A ''large machine'' is any machine identified as one of the following types of equipment: tillage; planting; harvesting; augers/elevators; feed grinder/mixer; irrigation equipment; wagons/trailers; chemical and fertilizer applicators; manure applicator; milking equipment; other farm equipment powered by an external source; other self-powered farm equipment; self-powered moving equipment; riding lawn mower; and other powered equipment.

DATA ANALYSIS

Injuries for these analyses were limited to those coded in the RRIS-II database as large machinery-related on one's own operation for both 1999 and 2001. Data were combined for both years as the populations and associated data were comparable.[11,12]

First, descriptive analyses were performed for the injury events, which included (1) socio-demographic information; (2) severity measures; and (3) the incidence of injuries based on type of large machine, body part(s) injured, type(s) of injury, and activity being performed at the time of injury. Rates were calculated as annualized rates, based on the number of injuries incurred per year per 1000 persons on their operation. In addition, rates of injuries per 100,000 hours worked were also calculated for males and females to identify any potential differences from the rates per 1000 persons; although injuries incurred among child bystanders near working activities were included in the numerator, it was not possible to establish bystander hours in addition to working hours in the denominator.[9,13]

Generalized estimating equations (GEEs) were used to adjust for within-household correlations, to address the nonindependence of multiple observations within the same household.[14,15] In addition, assessing for potential selection bias due to nonresponse was accomplished through inversely weighting observed responses against the probabilities of response[16] at the level of the household (unit nonresponse). The probabilities of response were estimated as a function of characteristics identified from the NASS Master ListFrame of Agricultural Operations: state of operation; type of operation; and quintile of annual revenue. The probability of eligibility for nonrespondents was also estimated on the basis of the same characteristics.[17]

An a priori causal model or directed acyclic graph (DAG) (Fig. 1), depicting potential causal associations between the large machinery-related injury outcome and environmental and socio-demographic variables, was used to identify potential confounders for each exposure of interest in multivariate models and to exclude other variables that may introduce bias if included in the analyses.[18] Some causal links shown in the DAG have been well established while others are hypothesized, based on expert investigator knowledge. The category within each exposure variable with the greatest number of respondents was selected as the referent group to increase power, with the exception of state of residence and gender. Rate ratios (RRs) and 95% confidence intervals (CIs) were calculated using multivariate Poisson regression models.[19]

RESULTS

A total of 7420 households participated in study phase 1 (1999) and phase 2 (2001). This represented 84% of eligible households, which included 32,598 persons.[11,12]

INJURY FREQUENCIES

Of the 405 reported large agricultural machinery-related injury events, 355 events (88%) occurred in males. Frequencies of injury events, reported by state, were North Dakota, $n = 109$ (27%), followed by South Dakota, $n = 97$ (24%), Nebraska, $n = 75$ (19%), Minnesota, $n = 64$ (16%), and Wisconsin, $n = 60$ (14%).

Harvesting equipment accounted for the greatest proportion of injury events (Table 1). The two most frequent activities performed at the time of injury were general repairs and adjusting machinery. Finger/thumb and back injuries resulted from the greatest proportions of injury events (Table 2). The most common injury types related to large machines were cuts/lacerations/scratches, sprains/strains, fractures/dislocations, and bruises/contusions. Of note, there were a total of 452 injured body parts and 472 injury types for the 405 reported injury events, accounting for the fact that one injury event could have involved more than one body part and injury type.

Self-reported severity measures showed 81% of injury events to be either minor or moderate in severity (Table 3). Treatment by a health care provider occurred for 326 of the injury events (80%), of which only 224 (70%) had health care covered by any percentage of insurance. In addition, 209 events (52%) resulted in lost farming or ranching work time. Of these 209 events, the amount of lost work time was at least 1 day for 129 events (62%), at least 1 week for 52 events (25%), at least 1 month for 16 events (8%), and at least 3 months for six events (3%). Also, 238 events (59%) resulted in at least 1 day of activity restriction and 79 injury events (20%) resulted in persistent symptoms.

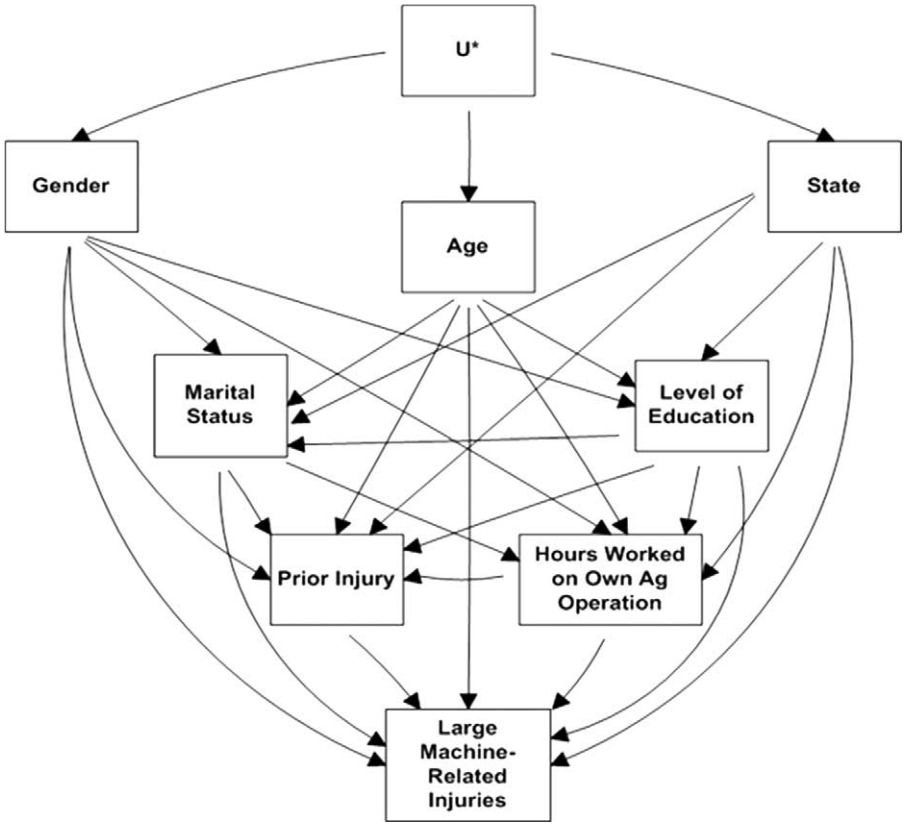

FIGURE 1. Directed acyclic graph for large machinery-related injury analysis.

INJURY RATES

The overall rate of large machinery-related injuries incurred on the agricultural operations was 12.82 injury events per 1000 persons per year. This rate was much higher (21.80) for males than for females (3.26); however, when an exposure time denominator was used, the differences in rates between genders was greatly reduced (1.50 and 0.69 injury events per 100,000 hours worked for males and females, respectively). The highest injury rates were seen among men and women 20 years or older, compared with those 19 years and younger. By state of residence, North Dakota had the largest injury rate (18.11 per 1000 persons per year) among the five states. Injury rates for graduates of high school, technical school, and college were higher than those for participants with lower education levels at the time of the study. Married participants had a higher injury rate than those who were never married; however, injury rates for the remaining marital categories revealed unstable CIs due to small numbers. A positive association between injury rate and number of hours worked per week was identified, where those working 1 to 19 hours had a rate of 4.3 compared with those working 40 hours or more with rates of over 40 injuries per 1000 persons per year (Table 4).

MULTIVARIATE ANALYSES

The results for the multivariate analyses are found in Table 5. Males, compared with females, demonstrated a risk of injury seven times greater from large machinery. Compared with the referent group of 10 to 19 years, age groups 35 to 44 years and older had risks ranging from 4.8 to seven times greater. Having an agricultural operation in North Dakota, compared with the referent state of Minnesota, was associated with a 1.7 times greater risk. History of a prior versus no prior agricultural injury was associated with an injury risk 2.5 times greater. As one's hours worked per week increased, so did the risk of injury; compared with the referent group of working 1 to 19 hours per week, working at least 20 hours per week was associated with risks of injury ranging between 4 and 11 times greater.

DISCUSSION

This study provided new information on the importance of agriculture-related injuries. It addressed the magnitude, consequences, and risk factors associated with large machinery-related injuries on one's own agricultural operation in the Midwest five-state region, which had not previously been investigated in depth.

Several studies have shown that large machinery was related to injuries in 12% to 43% of cases,[5,20–24] with only one study citing a percentage as low as 5%;[25] great variations in populations and methodologies used were evident among these studies, however. Waggoner et al[26] who studied farmers and all causes of death reported a Standardized Mortality Ratio of 4.15 for machine-related deaths compared with 2.80 for motor vehicle non-traffic incidents, 2.12 for collisions with objects, and less than one for cancers, heart disease, and diabetes, respectively, indicating the risk of machinery-related exposures. Other studies have shown that harvesting equipment, alone, accounted for 31% of injury events.[27–29] In addition, the primary types of activity associated with injury, in the current study, were general repairs (22%) and adjusting machinery (14%), findings similar to Gerberich et al,[5] although the primary activity in that study was lift/push/pull (21%). The consistency in these findings suggests the need for activity-specific interventions. In contrast, other studies in which the subjects included were hospitalized patients, instead of a population of all farmers and ranchers who could have incurred any level of injury, found that entanglement, being pinned by or struck by machinery, and falls were common mechanisms of injury.[22]

TABLE 1. Frequencies of Large Agricultural Machinery Type and Activities Performed at Time of Injury: Regional Rural Injury Study

Exposure	Number of Injury Events	Percentage
Machine type		
Harvesting equipment	126	31
Wagons	53	13
Tillage	50	12
Augers/Elevators	47	12
Planting	25	6
Other	80	20
Missing/Unknown/Refused	24	6
Activity		
General repairs	89	22
Adjusting machinery	55	14
Handling/Transporting equipment	31	8
Handling/Transferring feed/grain/hay/straw	29	7
Hitching/Adjusting load	29	7
Mounting/Dismounting	25	6
Lifting	15	4
Making hay	15	4
Other	106	26
Missing/Unknown	11	3

Numerous studies have looked at the most commonly injured body parts as well as the most common type of injury. The current study found that fingers/thumb and back accounted for 34% of injured body parts. Although injured body part classifications may vary among studies, in general, findings support those in the current study; injury, to hand structures whether whole hand or fingers,[21,29,30] is likely due to the activities involved in working with machinery. The most common injury types in this study were cuts/lacerations/scratches (23%) and sprains/strains (22%); most common injury types, reported from other studies, were fractures/dislocations and bruises/contusions.[20,21,23,25,29,30-34]

TABLE 2. Reported Injured Body Part and Injury Type Associated With Large Agricultural Machinery: Regional Rural Injury Study

Injury Characteristics	Number of Injury Events	Percentage
Injured body part*		
Fingers/Thumb	82	18
Back	72	16
Arm/Elbow/Wrist	41	9
Hand	35	8
Eye/Eyelid	29	6
Face	22	5
Spinal Cord/Spine	21	5
Head/Skull	16	4
Neck	13	3
Dental/Tooth	12	3
Other/Missing	109	24
Injury type†		
Cut/Laceration/Scratch	110	23
Sprain/Strain	105	22
Fracture/Dislocation	77	16
Bruise/Contusion	66	14
Foreign body in eye	16	3
Burn	16	3
Amputation	11	2
Concussion	11	2
Other/Missing	60	13

*Some injury events had more than one injured body part.
†Some body parts had more than one injury type.

TABLE 3. Measures of Severity Associated With Large Machinery-Related Injuries: Regional Rural Injury Study

Severity Measure	Number of Injury Events	Percentage
Severity (self-reported)		
Minor	136	34
Moderate	191	47
Serious	57	14
Severe	17	4
Life-threatening	4	1
Duration of activity restriction		
None	52	13
>0 to <4 hours	47	12
4 hours to <1 day	67	17
1 day to <7 days	120	30
7 to <14 days	43	11
14 days to <1 month	28	7
1 month to <3 months	26	6
3 months or more	21	5
Unknown	1	0
Lost farm work		
No	195	48
Yes	209	52
Unknown	1	0
Farm work time lost		
None	195	48
>0 to <4 hours	36	9
4 hours to <1 day	42	10
1 day to <7 days	77	19
7 to <14 days	19	5
14 days to <1 month	17	4
1 month to <3 months	10	2
3 months or more	6	1
Unknown	3	1
Persistent symptoms after injury		
No	325	80
Yes	79	20
Unknown	1	0
Treated by health care provider		
No	79	20
Yes	326	80
Health care costs covered by insurance		
None	98	24
<50%	20	5
50% to <100%	158	39
100%	46	11
N/A—No professional health care	79	20
Missing/unknown	4	1

Measuring injury severity is often incorporated into studies assessing agricultural operations, as the potential implications of injury can be devastating, financially. Because many farmers and ranchers are self-employed, they may or may not have health insurance, they often lack adequate back-up in the case of missed time from agricultural operation work, and do not have the ability to receive benefits from Workers' Compensation. Different indicators of severity have been used among studies, including self-reported severity, the use of the Injury Severity Scores (ISS)[28] as well as whether or not an individual sought medical care,[11,12,35,36] whether time was lost from agricultural work,[11,12,36] and if the injury resulted in permanent impairment.[11,12,25] In the current study, 81% of injury events were self-reported to be either minor (34%) or moderate (47%) in severity, whereas only 14% were reported as serious, 4% as severe, and 1% as life-threatening; yet, 80% received

TABLE 4. Large Agricultural Machinery Related Injury Rates for Multiple Characteristics and Exposures: Regional Rural Injury Study

Characteristics/Exposures	Number Enrolled	Number Responded	Number of Injury Events	Injury Events per Year per 1000 Persons	95% CI
Total population	32,598	32,597	405	12.82	11.57–14.22
Gender					
Male	16,836	16,835	355	21.80	19.51–24.36
Female	15,762	15,762	50	3.26	2.47–4.30
Age (years)					
<10	5935	5935	22	3.67	2.41–5.59
10–19	10,608	10,607	38	3.67	2.67–5.06
20–34	3385	3385	51	15.89	12.06–20.95
35–44	7160	7160	171	24.43	20.85–28.63
45–54	4629	4629	101	22.23	18.05–27.38
55–99	833	833	22	30.07	19.12–47.30
State of residence					
Minnesota	6539	6539	64	10.29	7.98–13.27
Nebraska	6751	6751	75	11.03	8.65–14.07
North Dakota	6258	6258	109	18.11	14.84–22.10
South Dakota	7367	7366	97	13.68	11.14–16.81
Wisconsin	5687	5687	60	10.97	8.37–14.37
Educational status					
Eighth grade or less	8071	8070	26	3.19	2.15–4.72
Some high school	4218	4218	32	8.04	5.57–11.62
Highschool graduate/GED	6945	6945	136	20.05	16.91–23.78
Some technical school	786	786	11	13.92	7.72–25.11
Technical school graduate	1644	1644	36	22.88	16.15–32.40
Some college	4276	4276	83	20.76	16.33–26.41
College graduate	3272	3272	66	20.77	15.92–27.11
Graduate school	422	422	5	12.15	5.05–29.22
Prior injury					
No	25,915	25,915	172	6.69	5.72–7.82
Yes	6553	6553	232	37.06	32.37–42.42
Hours worked per week on own operation					
0	5918	5918	7	1.22	0.58–2.58
1–19	15,060	15,060	64	4.25	3.30–5.47
20–39	4479	4479	80	18.88	14.93–23.88
40–59	2693	2693	109	40.25	32.83–49.35
60–79	2322	2322	98	43.15	35.17–52.92
80 or more	861	861	36	43.19	30.56–61.05

CI, confidence interval.

treatment by a health care provider, a finding similar to that of other studies.[5,11,12,21,30,36,37] Although 93% to 95% of agricultural operations, in each study period, reported having health insurance,[12] only 70% of those who received health care following an injury event reported having any insurance coverage. Park and Hartley[38] found that those participating in a health insurance plan were at a lower risk for a work-related injury.

Any amount of lost time from agricultural operation work can result in financial hardship. In this study, 52% of injury events resulted in lost time from farm work, a smaller percentage than studies reporting on hospitalized patients, only, but similar to others investigating any type of injury incurred among agricultural households.[11,12,36] Of the 209 injury events that resulted in lost work time, the amount of lost farm work time ranged from at least 1 day (62%), to at least 1 week (25%), and from 1 month to 3 months or more (11%). In addition, 59% of all machinery-related injury events resulted in at least 1 day of activity restriction, while 29%, 11%, and 5%, respectively, involved at least 1 week, 1 month, or 3 months or longer, findings consistent with Gerberich et al (1998; 2001),[5,21] and Howell and Smith.[29] Ultimately, 20% of the injury events resulted in persistent, long-term symptoms, a finding noted to range from 10% to 25% in other studies.[5,25,27] Inoue[23] studied victims with injuries compensated by the Endowment Assurance by the Agricultural Cooperative Insurance Business Average to determine the average time lost from operation work following particular injuries; this varied according to the injury: arm or leg amputations (175 days); finger(s) amputation (52 days); fractures or contusions (140 days); and cuts or lacerations (40 days). Some of these findings, particularly lost-time from a cut or laceration, appeared quite lengthy; this may be partially explained by the potential for higher rates of infection from wound contamination due to the untidy nature of agricultural work, in general,[39] as well as possible delays in proper treatment of such wounds.[40]

The overall rate of large machinery-related injuries on one's own operation was found to be 12.82 injury events per 1000 persons per year, which was similar to the rate reported by Gerberich et al[5] from a similar population-based study (11.27 injury events per 1000 persons per year). Comparing these rates with those found from other studies is difficult, as denominators vary, sampled populations may differ in age, and most combined large machinery with either tractors or other smaller machinery.

Males have consistently been found to have higher per person rates of machinery-related injuries.[5,9,20,21,23,24,28–34,36,41–46] In the current study, males had an annualized rate seven times that of females, a finding that may partly be explained by the gendered role of females on agricultural operations, in general, as noted by

TABLE 5. Multivariate Analyses: Risk of Large Agricultural Machine Related Injuries on One's Own Agricultural Operation Associated With Characteristics and Exposures—Regional Rural Injury Study

Characteristics/Exposures	Responded (*n*)*	Number of Injury Events	Rate Ratio†	95% CI
Gender‡				
Male	16,836	355	6.95	5.15–9.37
Female	15,762	50	Referent	(—)
Age (years)§				
< 10	5935	22	1.01	0.60–1.71
10–19	10,607	38	Referent	(—)
20–34	3385	51	0.99	0.58–1.68
35–44	7160	171	4.77	2.87–7.92
45–54	4629	101	7.00	4.46–10.97
55–99	833	22	5.57	3.49–8.88
State of residence‖				
Minnesota	6517	64	Referent	(—)
Nebraska	6742	75	1.07	0.76–1.52
North Dakota	6247	109	1.73	1.26–2.39
South Dakota	7361	97	1.32	0.95–1.83
Wisconsin	5682	60	1.07	0.74–1.55
Educational status¶				
<Kindergarten	2881	10	0.88	0.21–4.72
Eighth grade or less	8063	26	Referent	(—)
Some high school	4216	32	1.14	0.27–4.72
High-school graduate/GED	6938	136	1.98	0.37–10.49
Some technical school	786	11	1.31	0.25–6.74
Technical school graduate	1642	36	1.12	0.20–6.32
Some college	4272	83	1.46	0.28–7.76
College graduate	3272	66	1.81	0.35–9.44
Graduate school	422	5	1.48	0.28–7.77
Prior agricultural injury#				
No	25,915	172	Referent	(—)
Yes	6553	232	2.55	2.04–3.20
Hours worked per week on own operation**				
0	5869	7	0.26	0.13–0.51
1–19	15,023	64	Referent	(—)
20–39	4471	80	3.87	1.96–7.65
40–59	2687	108	9.74	4.77–19.91
60–79	2321	98	11.65	5.57–24.36
80 or more	855	36	10.98	5.19–23.25

CI, confidence interval.
*Number of responders with nonmissing values for all variables included in final models.
†Adjusted for within-household correlation using GEEs and weighted for nonresponse.
‡Adjusted for age and state.
§Adjusted for gender and state.
‖Adjusted for gender and age.
¶Adjusted for gender, age, and state.
#Adjusted for gender, age, state, educational status, and marital status.
**Adjusted for gender, age, state, educational status, marital status, and prior injury.

McCoy et al,[47] for example, having greater involvement in working with animals, tending vegetable gardens, and performing general managerial tasks for the operation. However, it is important to note that when hours worked was used as a denominator, the rate for males decreased to three times that of females. This finding may be partly explained by gender differences in the types of interactions with machinery. For instance, although women may operate large machinery, males may be more likely to perform higher risk activities on this equipment, such as maintenance work, work on problematic machinery, or operate it on more uneven portions of the land. As noted previously, the two activities most frequently associated with injury were general repairs and adjusting machinery. Narasimhan et al[48] found a higher risk associated with both inadequate safety devices on machinery and increased routine maintenance, suggesting that any form of maintenance increases risk of injury. Also, the level and types of concern about safety may be gender-related, though this could not be analyzed in this study.

A second factor associated with an increased risk for injury is increasing age, particularly after the age of 34 years, which is consistent with many other studies.[9,22,23,32,36,38,41–43,49] Some studies have reported that children, in addition to the elderly, are at highest risk for injuries,[31,34,43,44] while others have reported that the fatal injury rate increases while the nonfatal injury rate decreases with age.[8,42,50] Pickett et al[9] retrospectively reviewed coroners' files and hospital discharge data for farm children ages 0 to 19 years in Ontario, Canada, and found that the younger the child, the higher the fatality rate. From many of the studies reported, it is very difficult to differentiate between injuries in children that result from work-related interaction with a large machine versus exposure to agricultural hazards as a bystander. Findings may differ, based on the goals of the specific study, highlighting the importance of creating standard criteria for defining circumstances surrounding injury events as well as operator characteristics.[29]

The finding of an increased risk for large machinery-related injury in North Dakota, compared with Minnesota, is unclear, as it

was not found to be important in a previous study of machinery-related injuries, based on the RRIS-I population,[5] or a study of tractor-related injuries, using the RRIS-II data.[41] However, this state has been identified among the top crop producers in the country that require large machinery for these operations.[51] It will be important to monitor this effect to determine whether there are opportunities for mitigation in the future.

History of prior agricultural injury was associated with an increased risk for subsequent injury, which is consistent with findings from previous studies.[36,37,41] The reason for this is not completely clear; however, there are a few potential contributors to this finding. First, the prior injury may have resulted in impairment. If disability results from inability to properly accommodate the impairment, the injured person may be at an increased risk for subsequent injury. Second, prior injury may be an indicator of the general safety mindset of that individual. Third, depending on the financial stability of the agricultural operation, an operator may feel pressured to produce beyond the capabilities of that operation, potentially leading to an increased risk in injury. The fourth factor associated with an increased risk for injury is the positive relation with increasing number of hours worked per week. With the exception of one study reported by Howell and Smith,[29] which showed that none of the included injuries were thought to be secondary to long hours, all other studies addressing the number of hours worked noted that fatigue from either poor sleep or simply working more hours is associated with an increased injury risk.[5,23,38] Potential reasons for working more hours may include (1) nearly 90% of agricultural operations are family-owned and operated, likely with few additional employees,[50,52] thus, increasing the work burden on each individual worker; (2) an increased need for production; (3) farmers and ranchers tend to have the reputation of being hard workers; and (4) weather often forces operators to work more quickly during good weather to make up for lost time during poor weather conditions.

The level of highest education achieved by the injured individual showed a trend in the univariate analysis toward decreased injury risk with less than a high school degree and increased risk with at least a high-school degree. However, this trend was no longer present when controlling for gender, age, and state, likely indicating that the trend was mediated through one of these covariates; the most likely would be expected to be age, as those in categories with less than a high school degree would tend to include younger persons who had a lower rate of injury, findings consistent with Carlson et al.[41] One study from India reported that those with an education less than a high-school degree versus college graduates were more likely to be injured[24]; however, that study included all workers on an operation, versus those working on only their own agricultural operation, and who likely encountered more hazardous working conditions. Bancej and Arbuckle[20] investigated children ages 0 to 18 years living on a full-time operational farm in Ontario and found that they were at an increased risk for injury if they had even one parent with an education level greater than high school, compared with some postsecondary education.

There are limitations to this study that warrant consideration. Although the participation rate for eligible households was relatively high (84%), there could have been some selection bias, meaning the nonresponders were different from the participants and may account for some of the findings, though nonresponse and eligibility adjustments were made.[16,17] Recall bias may have been present, although the 6-month recall periods used in this study have been found to increase reliability.[11,12,53] Also, households were supplied with forms on which injury events and details could be recorded at the time of injury, thereby, likely decreasing recall bias. For reasons stated previously, rates were calculated using a person-year denominator as well as hours worked; however, it was not possible to adjust for working hours associated with different exposures. Further, given that the target population was limited to households with children under the age of 20 years within the five-state Upper Midwest region, such results may not be generalizable to other populations. It is also possible that there are other unidentified confounders not controlled for that could have affected the results.

In summary, this comprehensive study provided information to increase understanding of the magnitude and consequences of, and the risks for large machinery-related agricultural injuries across the five-state Midwest region. Although much attention has been focused on tractor-related injuries, large machinery other than tractors clearly deserves more attention in an effort to decrease the morbidity and mortality associated with agricultural operations. The primary factors found to increase one's risk of injury from large machinery were gender, age, state of agricultural operation location, prior agricultural injury, and number of hours worked. Prior agricultural injury and the number of hours worked are potentially modifiable risk factors. Through future research, there is a potential to further investigate factors associated with prior and subsequent injury and mitigation of extended working hours. Although gender, age, and state are nonmodifiable risk factors, more research and education regarding how to target prevention efforts, based on these risk factors, is also needed.

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