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Structural Equation Modeling of Pesticide Poisoning, Depression, Safety, and Injury

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ABSTRACT. The role of pesticide poisoning in risk of injuries may operate through a link between pesticide-induced depressive symptoms and reduced engagement in safety behaviors. The authors conducted structural equation modeling of cross-sectional data to examine the pattern of associations between pesticide poisoning, depressive symptoms, safety knowledge, safety behaviors, and injury. Interviews of 1637 Colorado farm operators and their spouses from 964 farms were conducted during 1993–1997. Pesticide poisoning was assessed based on a history of ever having been poisoned. The Center for Epidemiologic Studies—Depression scale was used to assess depressive symptoms. Safety knowledge and safety behaviors were assessed using ten items for each latent variable. Outcomes were safety behaviors and injuries. A total of 154 injuries occurred among 1604 individuals with complete data. Pesticide poisoning, financial problems, health, and age predicted negative affect/somatic depressive symptoms with similar effect sizes; sex did not. Depression was more strongly associated with safety behavior than was safety knowledge. Two safety behaviors were significantly associated with an increased risk of injury. This study emphasizes the importance of financial problems and health on depression, and provides further evidence for the link between neurological effects of past pesticide poisoning on risk-taking behaviors and injury.

KEYWORDS. Agriculture, occupational health, occupational safety, pesticides

INTRODUCTION

Education-based agricultural injury interventions have not been effective at reducing farm injuries.[1,2] Although there is some evidence that farm safety training may help prevent injury,[3] fatal injury rates in agriculture have not decreased to the same extent that they have in mining and construction. A 2009 survey from the Bureau of Labor Statistics, US Department of Labor, showed that 2.7 animal-related injuries occurred per 100 full-time farm workers in 2009; the rate was higher for crop farmers at 3.6.[4] These injury incidence rates in 2009 for farm workers are higher than those for construction workers (2.3 per 100 workers) or the mining industry (1.5 per 100 workers).[4]

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In two previous studies of Colorado farm residents, pesticide poisoning was significantly associated with depression.[5,6] Additionally, depression was significantly associated with not exercising the safety behaviors of being calm around animals, reading instruction manuals for farm machinery, and keeping moving equipment parts shielded.[7] Structural equation modeling (SEM) showed that only when pesticide poisoning was antecedent to depressive symptoms did the data fit a model predicting exercising of safety behaviors.[8] In a cohort of Colorado farm residents with 2 years of follow-up, none of the safety behaviors were associated with injury, but being depressed increased the probability of an injury among those who scored low on safety knowledge.[9] Taken together, the evidence suggests that pesticide poisoning may result in depressive symptoms in susceptible individuals and may decrease farm residents' exercise of certain safety behaviors and, therefore, increase the risk of injuries. Previous studies have not assessed the relative importance of depression and safety knowledge, and their interaction, on the risk of injuries.

In this study, we combined two samples of farm residents to obtain a sufficient number of injuries to conduct SEM on cross-sectional data to examine the pattern of relationships between pesticide poisoning, depressive symptoms, safety knowledge, safety behaviors, and injury. Here, we test the hypotheses that (1) pesticide poisoning is as important a risk factor in depression as poor health and financial difficulties; (2) experiencing depressive symptoms is more likely to increase the odds of a farm-related injury than low safety knowledge; and (3) experiencing depressive symptoms is more likely to reduce certain safety behaviors than low safety knowledge.

METHODS

Study Participants

A total of 1637 principal operators and their spouses from two different Colorado study samples were combined and included in structural equation models of injury risk. The samples were similar in farm size and products produced and the large sample size provided ample power to simultaneously examine a number of risk factors for injury. All variables used in this study were asked identically in the two samples of farm residents.

Statewide Survey Participants

A total of 876 farm operators and their spouses representing 485 farms were recruited in 1993 from a Colorado Department of Motor Vehicles list of farm truck registrations. Stratified probability sampling was used to determine the number of farm operations to be included in the sample. Inclusion criteria required that the farm have at least $1000 USD in production sales in a normal year using the US Bureau of Agriculture definition of a viable farm. A detailed description of the procedure has been previously published.[10] The initial response rate for farms based on total contacted minus refusals and procedural interview failures (could not understand the interviewer or questions) was 62%. The response rate based on contacted households minus outright refusals to participate was 70%. The telephone survey took approximately 20 minutes per respondent and was conducted during November to March, the slow months of agricultural production in the region.

Eight-County Survey Participants

Principal farm operators and their spouses ($n = 761$) representing 479 farms in one of eight counties in northeastern Colorado were identified from property value assessments lists or from rural directories. Eligible farms, based on the US Bureau of Agriculture definition, were enrolled in 1993–1997. Participants were interviewed in person at their farm by trained study personnel. Interview duration varied from 45 minutes to 2 hours depending on the extent of personal histories. Interviews were conducted during November to March of the study years.

Study Variables

Outcomes Measured

The primary outcome of interest was whether a farm resident had experienced an injury resulting in losing at least 1 day of work in the past year (0 = no injury, 1 = injury). Information was collected on each injury occurring in the past 12 months, beginning with the most recent and working backwards in time. Respondents were asked when the injury occurred, the body part affected, the type of injury, the farm activity at the time the injury occurred, how the injury happened, and whether the injury resulted in medical attention and lost work time. The second outcome of interest was the frequency of exercising 10 safety behaviors (0 = always, 1 = most of the time, 2 = sometimes, 3 = rarely, 4 = never). Respondents were asked which category best describes what they do in each of 10 situations. Each situation described 1 of the 10 safety behaviors.

Independent Variables

The Center for Epidemiologic Studies—Depression (CES-D) scale was used to determine the frequency of 20 depressive symptoms the farm residents experienced in the week prior to the interview (0 = none of the time, 1 = some of the time, 2 = occasionally, 3 = nearly all or most of the time). The CES-D scale covers four underlying latent constructs representing negative affect, somatic/retarded activity, positive affect, and interpersonal problems.[11] Study participants answered 10 questions concerning safety knowledge, with possible responses being true, false, or don't know; a correct answer was coded as 0; incorrect/don't know response was coded as 1 to reflect an increased risk of injury for those answering incorrectly. The safety knowledge scale was developed specifically for the Colorado Farm Family Health and Hazard Survey in 1992. Although the psychometric properties of the scale were assessed in a previous report,[12] no independent studies have been undertaken to assess its validity.

Covariates Assessed

The three primary covariates of interest were having a history of pesticide poisoning, past-year financial problems and self-perceived health. Positive responses to ever having become ill from exposure to pesticides were used to assess pesticide poisoning (0 = no, 1 = yes). Financial difficulties were assessed by asking the farm residents if they experienced an increase in debt or a decrease in income in the past year (0 = no, 1 = yes). Self-perceived health was an ordinal measure ranging from poor to excellent health (0 = excellent, 1 = very good, 2 = good, 3 = fair, 4 = poor). Control variables included sex (male = 0, female = 1) and age categorized into three groups (<45, 45–64, 65+) because younger farm residents were at higher risk of injury than those in the older category in this sample and because safety knowledge differed by age.[12]

Statistical Analysis

Descriptive Statistics

Descriptive statistics were used to summarize the characteristics of the sample. These analyses were done in SAS version 9.2 (The SAS Institute, Cary, NC).

Exploratory Factor Analysis

Exploratory factor analysis (EFA) using robust weighted least squares was used to estimate the factor loadings. The EFA model fit was evaluated using the Tucker-Lewis index (TLI), the comparative fit index (CFI), and the root mean squared error of approximation (RMSEA), and by examining the eigenvalues in a scree plot. The models are considered to adequately fit the data when TLI and CFI are greater than .95, RMSEA is less than .06,[13] and eigenvalues are at least 1 and level off in a scree plot. Oblique rotation (quartimin) was used to rotate the factor loadings for improved interpretability.[14]

Confirmatory Factor Analysis

Multiple indicator multiple cause (MIMIC), a confirmatory factor analysis (CFA) with covariates, was used to identify significant covariates associated with the latent depression factor and the latent safety knowledge factor. We did two sets of MIMIC analyses. First, we identified the best-fitting CFA model using all three latent depression factors and the covariates age, sex, health status, financial problems, and history of pesticide poisoning. Second, we tested the same covariates to determine whether they were significantly associated with the safety knowledge factor and should therefore be retained in the SEM model. CFA model fit was assessed using the likelihood-ratio test (LRT), Akaike information criterion (AIC), and sample size–adjusted Bayesian information criterion (BIC). The LRT is chi-square distributed with degrees of freedom equal to the difference in the individual model degrees of freedom; smaller AIC and BIC values indicate a better fit of the data to the model than larger ones.

We tested for significant direct effects of pesticide poisoning on each of the latent depression factors identified in the EFA and compared the influence of pesticide poisoning on each of the depression dimensions of the CES-D scale. Results are reported as odds ratios (ORs) and 95% confidence intervals (CIs) for a 1-unit increase in frequency of a CES-D symptom when pesticide poisoning changes from 0 to 1.

Structural Equation Modeling

SEM was used to individually model the relationships between significant covariates, the latent depression factor, the latent safety knowledge factor, and injury. We then added the safety behavior variables in 10 separate models to determine whether they mediated the relationship between the depression and/or safety knowledge factors and injury. We tested for a significant interaction between the depression and safety factors on odds of injury.

All models were run in MPlus version 5.1.[15] All tests are two-sided and results were considered significant at the $p = .05$ level of significance. We allowed residual variances to be estimated for all latent variables, safety behaviors, and injury. Standardized estimators are presented as follows: (1) path coefficients for the binary and categorical variables were standardized using the applicable variance of the continuous latent depression or latent safety factor; (2) path coefficients for latent factors predicting a categorical safety behavior or binary injury variable were calculated using the variances of the continuous latent variables and the variances of the behavior or injury variable. Path coefficients are partial regression coefficients and can be interpreted as regression coefficients; standardization means the regression coefficient represents changes in standard deviation units.

RESULTS

Description of the Farm Resident Sample

The farm resident sample ($n = 1633$) was 53.0% male, 98.9% white, 91.4% married, and 91.7% were high school graduates. The mean age was 48.9 ($SD = 13.2$). Fewer than 7% reported fair or poor health, 7.5% reported a past pesticide poisoning, 31.4% reported financial difficulties, 7.9% scored as depressed by the CES-D scale (score > 15), and 9.4% reported an injury that required lost time from work. A total of 154 injuries occurred in this sample in the year prior to the interview. Depression data were missing for 13 farm residents, 15 did not answer the financial difficulty question, 14 did not report whether they had a pesticide poisoning, and 2 individuals did not report their health status. Although some attrition occurred at each step of the modeling, only 29 individuals (1.8% of the original 1633) were lost in the modeling process due to missing data.

Exploratory Factor Analysis

In 1624 individuals who had complete CES-D information, a three-factor model adequately fit the data (Table 1). The negative affect/somatic/retarded activity items loaded onto a single factor and separate factors were identified for positive affect and interpersonal problems, replicating previous results in a single sample.[8] Feeling like life had been a failure showed the weakest factor loading (.38) and enjoying life showed the highest factor loading (.86).

TABLE 1. Geomin-Rotated Factor Loadings and Standard Errors From a Factor Analysis of 20 CES-D Criteria in 1624 Farm Operators and Their Spouses in Colorado, 1993–1997

CES-D depression criteria	Negative affect + somatic/retarded activity (*SE*)	Positive affect (*SE*)	Interpersonal (*SE*)
Bothered by things	**.75 (.06)**	.03 (.05)	−.16 (.06)
Poor appetite	**.81 (.07)**	−.01 (.01)	−.41 (.09)
Felt blue	**.75 (.07)**	.24 (.06)	−.08 (.07)
Couldn't get going	**.68 (.05)**	−.04 (.05)	−.02 (.05)
Trouble concentrating	**.68 (.05)**	−.15 (.05)	.02 (.04)
Depressed	**.81 (.05)**	.09 (.05)	.03 (.05)
Everything was an effort	**.62 (.05)**	.03 (.05)	−.06 (.06)
Life had been a failure	**.38 (.07)**	.23 (.07)	.21 (.07)
Felt fearful	**.46 (.07)**	.18 (.06)	.13 (.07)
Slept restlessly	**.50 (.05)**	.02 (.05)	.04 (.06)
Had crying spells	**.69 (.08)**	−.03 (.06)	.09 (.09)
Talked less than usual	**.58 (.06)**	−.04 (.05)	.03 (.06)
Felt lonely	**.51 (.06)**	.07 (.05)	.21 (.07)
Felt sad	**.70 (.05)**	−.03 (.04)	.19 (.06)
Felt hopeful about future	.01 (.02)	**.62 (.04)**	.09 (.07)
Enjoyed life	.02 (.08)	**.86 (.05)**	.01 (.04)
Felt as good as others	−.09 (.07)	**.61 (.07)**	.12 (.08)
Felt happy	.06 (.07)	**.78 (.05)**	−.02 (.04)
Felt disliked by others	.01 (.03)	.07 (.09)	**.82 (.06)**
Felt people were unfriendly	.02 (.07)	−.02 (.06)	**.78 (.08)**
Model fit parameters			
CFI	.99		
TLI	.99		
RMSEA	.04		
Eigenvalues	8.57, 1.70, 1.26, 0.90		

Bolded items load significantly on respective factor.

Confirmatory Factor Analysis With Covariates

In a MIMIC model, the criteria associated with each of the three factors in Table 1 loaded significantly on their respective latent factor (range of regression coefficients: 1.14–3.51, all p values $< .0001$). Young farm residents and those with financial difficulties and/or health problems had higher scores on the negative affect factor of the CES-D scale ($p < .0001$), were significantly less likely to endorse the positive affect criteria, and were more likely to score high on the interpersonal latent factor (Table 2). Although pesticide poisoning was significantly associated with the negative affect factor ($p = .001$), it was not associated with the positive affect ($p = .16$) or interpersonal ($p = .08$) constructs (Table 2). Results from assessing direct effects of pesticide poisoning on each of the negative affect symptoms showed that in models that included financial difficulties, health, and age, pesticide poisoning was significantly associated with being bothered by things (OR = 2.08; CI: 1.30, 3.31), poor appetite (OR = 1.81; CI: 1.05, 3.12), depressed mood (OR = 2.18; CI: 1.08, 4.41), things being an effort (OR = 1.81; CI: 1.16, 2.82), feeling like a failure in life (OR = 2.68; CI: 1.46, 4.92), and feeling fearful (OR = 2.00; CI: 1.16, 3.43). With the same covariates in the model, pesticide poisoning did not influence any of the positive affect or the interpersonal constructs. Sex was not significantly associated with any of the three dimensions of depression (Table 2). Therefore, we retained the covariates financial difficulties, health, age, and pesticide poisoning in subsequent SEMs of the depression factors, but excluded sex.

In a separate MIMIC model, those who scored poorly on safety knowledge were less likely to report a pesticide poisoning, were in

TABLE 2. Association of Covariates With Latent Depression and the Latent Safety Knowledge Factors From Two Separate MIMIC Models in Colorado Farm Residents, 1993–1997

Covariate	Model 1: Latent depression factors (N = 1602)			Model 2: Latent safety factor (N = 1601)
	Negative affect β (SE) p value	Positive affect β (SE) p value	Interpersonal β (SE) p value	β (SE) p value
Pesticide poisoning	.33(.10).001	.17(.12).16	.23(.13).08	−.31(.12).01
Financial difficulties	.24(.06).000	.22(.07).003	.17(.08).03	−.13(.07).05
Self-perceived health	.24(.03).000	.25(.04).000	.15(.04).000	.09(.04).02
Age	−.25(.04).000	−.12(.05).03	−.31(.06).000	−.01(.05).80
Sex	−.03(.06).65	.06(.07).37	−.06(.08).44	−.12(.07).08

poorer health, and were less likely to have financial difficulties (Table 2). Age and sex were not significantly associated with safety knowledge. Therefore, we included pesticide poisoning, health status, and financial difficulties as covariates in subsequent SEMs. The latent depression factor was uncorrelated with the latent safety factor.

Structural Equation Modeling

Neither the positive affect depression construct nor the interpersonal depression construct significantly predicted injury (positive affect: regression coefficient (β) = .00, SE = .01, p = .86; interpersonal: β = .02, SE = .01, p = .23). The best-fitting SEM of injury showed that pesticide poisoning, financial difficulties, and health problems preceded the negative affect/somatic depression construct, which preceded and was significantly associated with injury (Figure 1). The standardized path coefficient of injury on the depression factor can be interpreted as the odds of 1 standard deviation of change in the depression factor resulting in injury risk changing from 0 to 1. Safety knowledge was not significantly associated with injury (Figure 1). Age, health status, financial difficulties, and pesticide poisoning were significantly associated with higher negative affect construct scores when safety knowledge and injury were in the model (all $p < .0001$); pesticide poisoning had the largest path coefficients to injury in the model.

FIGURE 1. Structural equation model of the effects of significant covariates on the latent depression dimensions of the CES-D scale, the latent safety knowledge factor, and injury.

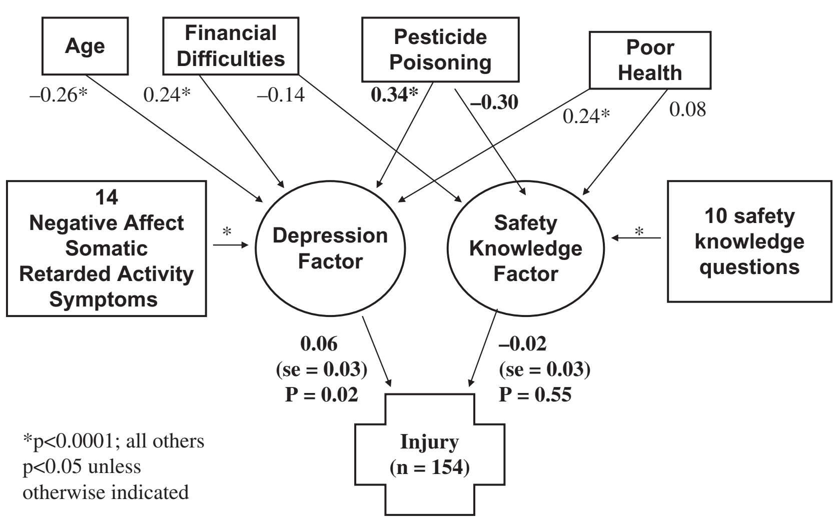
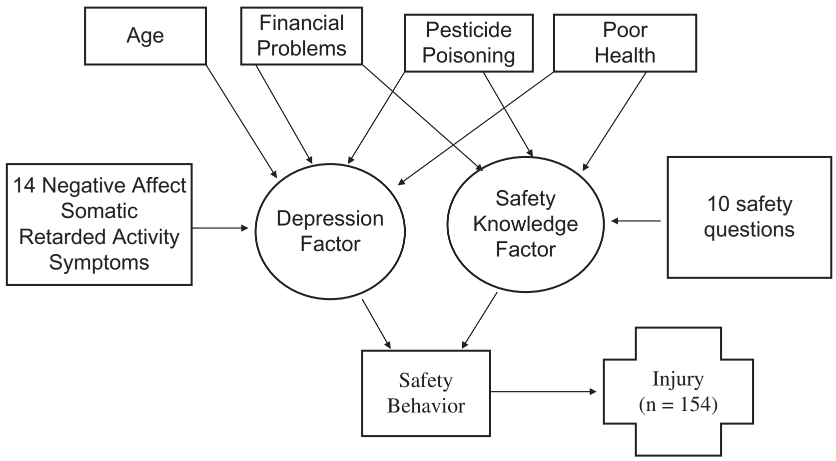


FIGURE 2. Structural equation model used to evaluate path coefficients for the latent depression factor and the latent safety factor predicting exercising a certain safety behavior and how this safety behavior impacts the odds of injury.



We next tested models with each of the 10 safety behaviors as mediators of the association between depression and safety knowledge and injury, hypothesizing that lower safety knowledge results in not exercising safety behaviors, which in turn, increases the odds of injury (Figure 2). The results in Table 3 show that the safety behaviors related to the use of personal protective equipment and farm maintenance were significantly related to the safety knowledge factor (all $p \leq .01$). However, the only safety behaviors that were associated with injury were keeping chemicals out of the reach of children and keeping passageways clear of slippery substances. Use of personal protective equipment was not significantly associated with injury. Keeping passageways clear was significantly associated with the depression factor, the safety knowledge factor, and increased odds of injury. Safety behaviors related to animals and machinery were significantly associated with the depression factor (all $p < .01$), but were not significantly associated with the safety knowledge factor or with injury. The depression factor did not interact with the safety knowledge factor to increase the odds of injury.

DISCUSSION

Pesticide poisoning had a greater influence on the negative affect components of depression than did health status and financial difficulties. The significant direct effects of pesticide poisoning on individual CES-D negative affect symptoms suggests that these dimensions are more severely affected than positive affect and interpersonal depression constructs and may suggest a neurological target of pesticide poisoning. These results are supported by biological evidence that depression is a sign of increased cholinergic activity relative to adrenergic activity, the imbalance hypothesis.[16] Depressed humans administered a cholinergic agonist had an increase in depression, negative affect, hostility, and anxiety.[17] The cholinesterase inhibitor diiosopropylfluorophosphate (DFP) and organophosphate insecticides cause a similar decrease in appetite, cause a change in rapid eye movement (REM) sleep patterns, increase lethargy, and can rapidly induce a depressed mood in rats as well as in humans.[18]

The negative affect and somatic symptoms of the depression scale were significantly associated with injury; however, the positive affect and interpersonal dimensions of depression were not. Depression has been reported previously as a risk factor for injury in farmers.[9,19–22] The question that remains to be answered is whether farm residents with a family or personal history of depression are more at risk of depression following a high exposure to organophosphate pesticide or whether the exposure can induce a

TABLE 3. Relationships Between Latent CES-D Factor*, Latent Safety Knowledge Factor, Safety Behaviors, and Risk of Injury (Figure 2) in 1604 Colorado Farm Residents, 1993–1997

Safety behavior	Latent construct	Safety behavior β (*SE*), *p* value	Safety behavior and injury β (*SE*), *p* value
Safety behaviors: personal protective equipment and maintenance			
Wearing a respirator	Depression	.11 (.06), $p = .08$	−.00 (.01), $p = .57$
	Safety	**.19 (.08), $p = .01$**	
Wearing hearing protection	Depression	.09 (.05), $p = .08$	.00 (.01), $p = .95$
	Safety	**.17 (.07), $p = .008$**	
Wearing a dust mask	Depression	**.11 (.06), $p = .04$**	.00 (.01), $p = .95$
	Safety	**.23 (.06), $p < .0001$**	
Keeping chemicals away from children	Depression	.03 (.02), $p = .09$	**.03 (.01), $p = .02$**
	Safety	**−.08 (.03), $p = .01$**	
Keep passageways clear of slippery substances	Depression	**.11 (.02), $p < .0001$**	**.02 (.01), $p = .03$**
	Safety	**−.10 (.03), $p < .0001$**	
Safety behaviors: animals			
Calm around animals	Depression	**.10 (.03), $p < .0001$**	−.01 (.03), $p = .07$
	Safety	−.04 (.03), $p = .19$	
Use gates for handling animals	Depression	**.10 (.04), $p = .006$**	.01 (.01), $p = .43$
	Safety	.05 (.05), $p = .25$	
Safety behaviors: machinery			
Replace protective shields on machinery	Depression	**.11 (.03), $p = .001$**	.01 (.01), $p = .32$
	Safety	.07 (.04), $p = .10$	
Keep equipment parts shielded	Depression	**.09 (.02), $p < .001$**	.02 (.01), $p = .21$
	Safety	.01 (.03), $p = .77$	
Read instruction manual for machinery	Depression	**.17 (.03), $p < .0001$**	.00 (.01), $p = .97$
	Safety	−.01 (.04), $p = .86$	

*Latent variable includes negative affect, somatic, and retarded activity symptoms of CES-D scale.
Results significant at $p < .05$ are in bold.

depressive state in a farm resident who has no previous history of depression.

Depression significantly impacted most of the safety behaviors in the study. Increased negative affect and somatic depressive symptoms were associated with not exercising animal- and machinery-related safety behaviors; two of the most common causes of farm-related injury.[3] With the exception of wearing a dust mask, depression was not associated with the use of personal protective equipment and keeping chemicals away from children. In contrast, safety knowledge had minimal impact on most safety behaviors and was not associated with increased odds of injury.

Scoring low on safety knowledge was associated with not wearing a respirator, not wearing hearing protection, and not wearing a dust mask. Not wearing a dust mask or respirator may be more likely to result in an increased risk of lung disease, but reduced hearing has been associated with an increased risk of injury.[23,24,25,26] Those with high safety knowledge were less likely to keep chemicals away from children and keep passageways clear of slippery substances; both of these safety behaviors were associated with an increased odds of injury. Keeping passageways clear of slippery substances was the only safety behavior that was significantly associated with depression, safety, and injury. Since falls are a major cause of unintentional injury on farms,[3] this is an area that should be addressed in farm safety training programs.

Screening for and treating depression in farm residents prior to implementing a safety training program may improve a farm resident's ability to incorporate safe behaviors on the farm. The present study adds to previous reports by highlighting safety behaviors that can be addressed by safety training and those that need to be addressed from a behavioral health perspective. Farm safety training programs have not fully addressed increasing awareness of the role of fatigue and the lack of concentration, which can lead to increased risk of injury and underscore the link between these symptoms and depressed mood. The somatic effects associated with depression, including changes in sleep patterns, can compromise vigilance in hazardous situations and reduce reaction time. The results from this study suggest that increasing safety behaviors requires improving mental states. Further, the results reinforce the importance of stressors such as financial difficulties, poor health, and pesticide poisoning in injury risk and in behavioral health among farm residents.

The strengths of this study include the large sample of similar types of Colorado farms, and the detailed questionnaires allowing assessment of safety behaviors, safety knowledge, and injury. Although the CES-D scale asks only about the frequency of symptoms experienced in the past week, it has been shown to be a valid and reliable tool for community-based research and produced consistent results with excellent psychometric properties.

Limitations of this study include the lack of validation of the safety knowledge questions. Future studies assessing the validity of safety behavior and safety knowledge scales would be useful for agricultural research. Pesticide poisoning was based on self-reported illness and symptoms of exposure. Financial difficulty was asked as a subjective, qualitative question; however, how a farmer interprets his or her financial situation maybe what is meaningful.

Causation cannot be determined because this was a cross-sectional study and path coefficients in SEMs must be interpreted with caution. The results do, however, emphasize the importance of mood on the odds of injury and provides direction for improved farm safety training programs. Although research on stress among farmers often highlights the financial difficulties inherent in the occupation of farming and the devastating impact health problems have, it often fails to take into account the neurological effects that can result from a high pesticide exposure. Farm safety training should target increasing awareness that a pesticide poisoning may put a farmer at an increased risk of farm injury and that behavioral medicine should be incorporated into comprehensive health and wellness programs for farming communities.

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