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Evaluation of Alternate Category Structures for the Strain Index: An Empirical Analysis

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Abstract

Objective—The purpose of this study was to develop alternative Strain Index risk classification categories.

Background—Strain Index scores are usually categorized into four Strain Index "risk categories." The "original" risk categories were developed in the meat-packing industry and may not be fully applicable to other industries.

Method—Daily Strain Index scores were estimated among 276 manufacturing workers participating in a cohort study of occupational risk factors for hand–arm musculoskeletal symptoms. Each score was categorized using the original method and a new method based on quartiles of Strain Index score values among symptomatic participants. Models examining associations between original Strain Index risk categories and incident hand–arm symptoms were compared to models examining associations between the alternative Strain Index risk categories and incident hand–arm symptoms.

Results—Compared to the respective referent categories, a twofold or greater increase in the risk of incident hand–arm symptoms was observed for the highest original Strain Index risk category (HR = 2.06, 95% CI = [1.08–3.92]) and for the second highest alternate Strain Index risk exposure category (HR = 2.21, 95% CI = [1.26–3.85]). Although significant associations between Strain Index risk category and incident hand–arm symptoms were observed for both Strain Index categorization methods, model fit statistics favored the alternate approach.

Conclusion—Results from this study suggests that the Strain Index risk category structure may need to be tailored to specific populations.

Application—If verified, results from this study provide a better way to identify hazardous manufacturing jobs and target them for exposure reduction.

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Keywords

epidemiology; cohort study; ergonomics; musculoskeletal symptoms; Strain Index

INTRODUCTION

The Strain Index (SI) is a widely used (Dempsey, McGorry, & Maynard, 2005) observation-based exposure assessment method that combines measures of biomechanical risk factors (forceful exertion, repetition, and nonneutral wrist postures) for upper extremity musculoskeletal disorders (UEMSDs) into a single numerical value or “SI score” (Moore & Garg, 1995). SI scores are then collapsed into “risk” categories for interpretation. Numerous methods of parameterizing SI categories exist, but based on the SI user guide four SI risk categories are often used: ≤3, >3 to <5, ≥5 to <7, and ≥7 (Bao, Spielholz, Howard, & Silverstein, 2009; Bernard, 2001; Moore & Garg, 1995).

The definitions (i.e., cut points) of the SI risk categories were developed using exposure and health outcome information obtained among pork processing workers and have been applied to both meat processing and other industries (Moore & Garg, 1995). Among non-meat-processing workers, an increased risk of UEMSDs has been observed when comparing those in the highest risk category to those in the lowest risk category (Drinkaus et al., 2003; Garg et al., 2012; Harris, Eisen, Goldberg, Krause, & Rempel, 2011; Hegmann, Garg, Moore, & Foster, 2006; Knox & Moore, 2001; Rucker & Moore, 2002). Some investigators have used SI scores as continuous measures as well and have observed associations between SI score and UEMSDs (Garg et al., 2012; Silverstein et al., 2006). Such an approach may be methodologically problematic, however, as it generally assumes that each unit change of the SI score results in the same change in risk regardless of whether it is at the higher or lower end of the SI score range. Although this problem can be avoided (e.g., by using spline terms), results can be difficult for practitioners to interpret and apply in the field.

Although SI scores of ≥7 were described as hazardous in the SI category structure, scores of >30 are not uncommon in many industries, and the theoretical maximum score is 1053 (Moore & Garg, 1995). Despite its wide acceptance, empirical verification of the SI category structure is sparse. A few studies examining associations between SI score and UEMSD risk suggest that the SI risk category structure (Moore & Garg, 1995) may not provide optimal risk stratification (Bao, Howard, Spielholz, & Silverstein, 2006; Drinkaus et al., 2003; Harris et al., 2011; Jones & Kumar, 2006). Thus, alternate SI classification methods may better characterize UEMSD risk than the original classification method (Rucker & Moore, 2002), at least in industries other than meat packing.

The purpose of the current project was (a) to develop an alternate *Empirical SI* classification method and (b) to compare the strength of associations between incident hand–arm musculoskeletal symptoms and job risk categories defined with the *Original SI* classification method to the strength of associations between incident hand–arm musculoskeletal symptoms and a newly developed set of SI job risk categories.

METHOD

Study Sample

From 2004 to 2008, we conducted a prospective cohort study of occupational risk factors for UEMSDs among 387 household appliance manufacturing workers in Iowa, United States (the Iowa Consortium Study). The participation rate was 52%. A brief description of the methods used to conduct the Iowa Consortium Study is provided later, and a detailed description of the methods is provided elsewhere (Gerr et al., 2014). All employees performing production work at a large appliance manufacturing facility were eligible to participate in the Iowa Consortium Study. Participants who were symptomatic at enrollment or who performed cyclic tasks with work cycles longer than 6 min were not included in the current analyses. Among 387 Iowa Consortium Study participants, 276 were included in the current analyses.

Demographic, Personal, and Occupational Psychosocial Factors Data Collection

Demographic, personal, and occupational psychosocial information was collected on two self-administered questionnaires completed by participants at the time of enrollment. The Job Content Questionnaire (JCQ; Karasek, 1985; Karasek & Theorell, 1990) was used to estimate psychological job demands (i.e., demand), decision authority (i.e., control), coworker support, and supervisor support. A four-category *job strain* variable was created from JCQ results by splitting the demand and control score distributions at their respective median values (i.e., 1 = *low demand*, *high control*, 2 = *high demand*, *high control*, 3 = *low demand*, *low control*, and 4 = *high demand*, *low control*). Negative affectivity (a person’s tendency to experience unpleasant feelings) was assessed with the Positive Affectivity and Negative Affectivity Scales (Watson, Clark, & Tellegen, 1988).

Hand–Arm Symptoms Assessment

We dichotomized participants into hand–arm symptom categories using information about hand–arm symptom quality, severity, and duration recorded by participants on weekly diaries. Participants who (a) reported hand or arm pain, numbness, tingling, or burning for at least 30 min during the previous week with either a severity level of at least 5 on a 0 to 10 visual analog scale or reported use of analgesic medication and (b) denied acute trauma as an immediate cause of the symptoms were categorized as symptom positive (Sx+).

Physical Risk Factor Exposure Data Collection

On a weekly basis, participants recorded on preprinted logs information about (a) daily hours worked per task, (b) changes in work activities, (c) current work stress, (d) time spent performing non-work-related hand-intensive activities (e.g., gardening, playing video games), and (e) time spent working at a second job. In addition to the self-reported information, 10 to 20 min of simultaneous sagittal (side view) and frontal plane (anterior or posterior view) video was recorded of all study participants while performing each of their tasks. Because of time constraints, our research team did not collect video information for all tasks. The proportion of missing video data was relatively small (5% of total task hours) but affected 32% (*n* = 89) of the participants. For most participants with missing video data, SI physical and temporal task exposure ratings were imputed in accordance with the imputation procedures established for the Iowa Consortium Study (Gerr et al., 2014). Three representative work cycles were identified from the video of each cyclic task, and two trained observers, using standard SI methods (Moore & Garg, 1995), rated each task's overall intensity of exertion, hand–wrist posture, temporal exertion requirements (exertions per minute and percentage duration of exertion), and speed of work.

To maximize sample size, modified SI procedures were developed for rating noncyclic tasks in this study. Specifically, for noncyclic tasks, trained observers watched 20-min video segments to identify the work element (e.g., remove the clear film protective coating from door, move a door from the conveyor to a rack) with the longest total duration (the most common work element). The observers then viewed the most common work element and rated the overall intensity of exertion, hand–wrist posture, and speed of work using standard SI methods (Moore & Garg, 1995). When exposure estimates across noncyclic tasks in a particular work area (e.g., crating, brazing) were similar (i.e., had low coefficient of variation), the mean values for percentage duration of exertion and efforts per minute were assigned to all noncyclic tasks in that work area; otherwise, facility-wide mean values were assigned. Several other exposure assessment approaches (e.g., the Hand Activity Level, surface electromyography) were used to estimate exposure to physical risk factors in the Iowa Consortium Study, but those data were not used for the current study.

Homogenous Exposure Groups

A total of 886 tasks were observed among study participants. Because many participants performed the same task(s), repeated estimation of SI values for common tasks performed by multiple participants would have been redundant and was not feasible because of limited resources. Therefore, prior to data extraction, we collapsed the 866 tasks into 179 *task similarity groups* and 162 unique, solitary tasks. Tasks were grouped by similarity when they were located in the same area of the plant (e.g., basepan, crating, shelving), had the same function (e.g., assemble basepan, braze basepan, install gaskets, secure lids on crates), were characterized by the same intensity of exertion rating (using standard SI methodology), and were performed using the same dominant hand. Most participants with missing video data were assigned task similarity groups based on knowledge of the facility and task.

Calculating SI Scores

The two trained observers used a consensus approach to select the final SI physical and temporal exposure ratings (overall intensity of exertion, hand–wrist posture, exertions per minute, percentage duration of exertion, and speed of work). The remaining SI parameter, task duration per day, was estimated from daily task hours worked recorded by each participant on the daily task log. Procedures to calculate SI scores for multitask jobs vary somewhat among investigators (Bao et al., 2009; Garg, 2006). In this study, all SI scores for an entire shift were calculated for all participants according to Cumulative Strain Index (CSI) formulas developed by Arun Garg, codeveloper of the SI. SAS code used to calculate SI scores with the CSI method was adapted from Microsoft Excel macros developed at University of Wisconsin– Milwaukee by Jay Kapellusch and Arun Garg (personal communication, May 12, 2008). Task-level SI scores for single-task jobs calculated with the

CSI method are the same as SI scores calculated using standard SI methodology. A participant's peak daily SI score for the work week (Monday–Sunday) was used to assign weekly SI risk categories for each participant. All peak daily SI scores were calculated in SAS. More detailed documentation for the CSI calculation method used in this study is available elsewhere (Meyers, 2010).

Assigning SI Risk Categories

As previously mentioned, numerous methods of parameterizing SI categories exist. For this study the cut points for the four ordinal "Original" risk categories were ≤3, >3 to <5, ≥5 to <7, and ≥7. In this study, an alternate set of SI score cut points was defined based on quartile values of the distribution of SI scores calculated for the week during which Sx+ participants ($n = 97$) first reported symptoms. In this way, approximately equal numbers of incident Sx+ events were distributed across the four Empirical SI risk categories (Category 1_{EMP}–Category 4_{EMP}), resulting in the greatest estimated precision and stability. The specific SI values for these empirically obtained categories were ≤8.72, >8.72 to <13.5, 13.5 to <18.56, and ≥18.56. The cut points for both the Original and Empirical SI risk categories were used to categorize weekly SI scores for each participant.

Statistical Analyses

Descriptive statistics—Gender-stratified means and standard deviations or frequency distributions were calculated for all non-time-varying demographic, personal, and psychosocial/work organization variables for all participants ($N = 276$). Similarly, gender-stratified descriptive statistics were calculated for all time-varying measures (weekly SI score, Original SI risk category, Empirical SI risk category, and the work organization covariates) for all participant weeks of follow-up ($N = 8{,}826$).

Unadjusted associations with hand–arm Symptoms—Separate unadjusted survival analyses were performed for the full sample and samples stratified by gender to estimate hazard ratios (HRs) and 95% confident intervals (CIs) for associations between incident hand–arm symptoms and (a) relevant covariates (demographic, personal, and psychosocial/work organization) and (b) SI risk category for the two SI risk category classification methods (i.e., Original and Empirical). The proportional hazards assumption was tested for all time-independent covariates.

The two independent SI exposure variables compared in this study, Original SI risk category and Empirical SI risk category, were time-varying, ordinal, categorical variables with four levels (Category 1–Category 4). For the current study, relative risk (i.e., relative hazard) was calculated using survival analysis methods (Kalbfleisch & Prentice, 2002). Survival time was taken as time from enrollment to outcome. Symptom-free participants were censored at the end of the study or at the time of loss to follow-up. Weeks to hand– arm symptom outcome was used as the dependent variable of the unadjusted and multivariable survival analyses. Cox regression models (Kalbfleisch & Prentice, 2002) were used to accommodate time-varying independent variables, which allowed individuals whose weekly SI risk category varied over the course of the study to contribute person-time to more than one SI risk category (Kleinbaum & Klein, 2005). Dummy variables were created for Original and

Empirical SI risk category metrics to allow for estimation of nonlinear associations. Category 1_{ORIG} and Category 1_{EMP} were used as referent categories in the respective analyses.

Covariate selection for multivariable survival analyses—Because of the relatively large number of covariates, initial screening of covariates was performed with the goal of including only those that (a) were actual con-founders of the association between an SI risk category and incident symptoms or (b) accounted for substantial variance in the model.

Specifically, demographic, personal, and psychosocial/work organization covariates associated with hand–arm symptoms with a p value of <.2 were identified and included (with SI risk category) in an initial fully saturated multivariable model. The covariates were then removed sequentially from the full model, starting with the least statistically significant covariate. All covariates were subject to removal. Covariates were retained in the final multivariable model if their removal resulted in either (a) a change of 15% or greater in the HR of any of the SI risk categories (Kleinbaum & Klein, 2005) or (b) a poorer fitting model. The Akaike information criterion (AIC) value (Akaike, 1973) was used to quantify fit for the multivariable proportional hazard survival models.

Multivariable survival analyses—Once the covariates were selected for inclusion in each of the multivariable analyses, separate final multivariable proportional hazard models were constructed to examine associations between time to onset of hand–arm symptoms and each of the two biomechanical exposure categorization metrics, Original SI risk category and Empirical SI risk category. To address the specific aim of the current study, the multivariable models using Original and Empirical SI risk categories were compared using two criteria. First, models were compared for adequacy of fit using the absolute difference in AIC between the two models (Akaike, 1973), and, second, linear hypothesis tests were conducted to test the null hypothesis that the parameter estimates for Categories 2, 3, and 4 were not dissimilar for each of the two SI risk category methods. The null hypothesis was rejected when $p < .05$, meaning observed differences in parameter estimates for Category 2, 3, or 4 compared to Category 1 were not likely the result of chance alone.

After analyses of data from the entire study sample were completed, gender-stratified multi-variable analyses of the association between incident hand–arm symptoms and SI risk category were conducted for the Empirical category structure, but not for the Original structure, because of sparse (<5) numbers of Sx+ participant weeks for some SI risk categories. Tests for interaction showed statistically significant modification of the effect of several covariates on hand–arm symptoms by gender. Therefore, procedures analogous to those described previously were used to build separate multivariable models using the Empirical SI structure for male and female participants.

All analyses were performed using SAS version 9.2.

RESULTS

Study Sample

Time-independent and time-varying demographic, personal health, and occupational characteristics for participants ($N = 276$) in the current study are presented in Table 1. The study sample mean age was 43 years, and the sample was nearly half female. Participants had long tenure at the facility (average 16 years employment).

Compared to participants, the mean age of nonparticipants in the parent study was 2 years younger, the mean number of years worked at the facility was about 4 years less, and a greater proportion were men (61% vs. 49%) and those who worked on the second shift (50% vs. 32%; data not shown).

Survival Analyses

Unadjusted associations with hand–arm symptoms—Unadjusted associations between hand–arm symptoms and demographic, personal, and psychosocial/work organization covariates are presented in Table 2 for the full study sample and stratified by gender. Variables meeting the a priori definition of a potential confounder ($p < .20$) were sex, height, comorbidities, previous hand–arm symptoms, hours worked at second job, hours per week of non-work-related hand-intensive activity, job strain quadrant, weekly job stress, and weekly job change. The overall risk of developing hand– arm symptoms was 77% higher for women compared to men ($p < .01$). Among men, although not statistically significant, age (HR = 0.98, $p = .13$) and years at facility (HR = 0.98, $p = .13$) appeared to be protective. Compared to female participants, men had weaker unadjusted associations between hand–arm symptoms and several demographic factors and stronger unadjusted associations between hand–arm symptoms and several psychosocial factors. For example, reporting of comorbid conditions was weakly and nonstatistically significantly protective among men (HR = 0.70, $p = .63$), whereas it was a statistically significant hazard among women (HR = 1.82, $p = .03$). Conversely, the relative hazard of being in the “low control, high demand” strain quadrant (compared to the “high control, low demand” strain quadrant) was substantially greater among men (HR = 6.21, $p < .01$) than among women (HR = 2.10, $p = .05$).

Unadjusted associations between weekly Original SI risk category and weekly Empirical SI risk category and incident hand–arm symptoms are presented in Table 3. Despite the use of quartiles, it was not possible to create equal numbers of participants in each of the four Empirical SI job risk categories because of clustering of SI scores.

A monotonic increase in the HR was observed across Category 2_{ORIG}–Category 4_{ORIG} when compared to Category 1_{ORIG} (Category 2_{ORIG}, HR = 1.19; Category 3_{ORIG}, HR = 1.39; Category 4_{ORIG}, HR = 1.80). For the Empirical structure job risk categories, a 70% increase in risk was observed among Category 2_{EMP} ($p = .08$) and Category 3_{EMP} ($p = .05$) participants compared to those in Category 1_{EMP}. However, the Category 4_{EMP} HR was lower (HR = 1.22, $p = .48$) than the HRs observed for Categories 2_{EMP} and 3 $_{\mathrm{EMP}}$. Despite the decline in risk among participants in the highest empirical exposure category, unadjusted models examining associations between the Empirical structure and incident hand–arm symptoms had better fit (lower AIC) than did models examining associations between the Original structure (AIC difference = 6.61) and incident hand–arm symptoms.

Multivariable models—Final multivariable models of associations between the two SI risk category structures and incident hand–arm symptoms were adjusted for sex, previous hand–arm symptoms, hours worked at second job, hours per week of non-work-related intensive hand activity, weekly job stress, and weekly job change (Table 4). The absolute difference in AIC was 1.57, which is generally considered a substantial difference in model fit and supports the model with the lower AIC value (Burnham & Anderson, 1998). In other words, empirical evidence supports the use of the alternate Empirical SI cut points compared to the Original SI cut points among the participants of this study. The strength of evidence provided by the AIC in support of the Empirical structure is consistent with the lower p value observed for the linear hypothesis tests (Empirical structure, $p = .05$; Original structure, $p = .14$).

HRs for Empirical SI risk categories are presented separately for males and females in Figure 1. A multivariable model examining associations between Empirical SI risk category and incident hand–arm symptoms among women (Category 2_{EMP}, HR = 2.11, $p = .08$; Category 3_{EMP}, HR = 2.65, $p = .01$; Category 4_{EMP}, HR = 2.06, $p = .07$) had higher HRs and lower p values than a model examining associations between Empirical SI risk category and incident symptoms among men (Category 2_{EMP}, HR = 1.73, $p = .31$; Category 3_{EMP}, HR = 2.04, $p = .14$; Category 4_{EMP}, HR = .68, $p = .07$; see Figure 1). In addition, the probability that chance alone accounted for observed differences between the parameter estimates for Categories 2, 3, and 4 was lower for the multivariable model among women ($p = .04$) compared to men ($p = .13$). However, assessment of model fit statistics favored using the empirically derived cut points of the Empirical structure. Although the SI was developed to evaluate tasks and jobs rather than people, results from multivariable analyses stratified by gender indicated that Empirical SI risk category structure was more predictive of hand–arm multi-variable model among women ($p = .04$). Because of small cell sizes, analogous stratification was not possible for the Original SI risk structure.

DISCUSSION

SI Classification Methods

One or more categories of both the Original and the Empirical SI risk category classification systems were statistically significantly associated with incident hand–arm symptoms, indicating that both have utility for examining exposure–effect associations, especially among female participants.

Results from the current study provide some empirical evidence to support the Original SI highest exposure strata, Category 4_{ORIG}, as recommended by Moore and Garg (1995). In particular, we observed a monotonic increase in risk across the four Original SI risk categories. More than 70% of weekly SI scores observed in the current study were 7 or higher and were therefore assigned to Category 4ORIG using the Original SI cut points. Thus, when using the Original SI cut points it was not possible to explore differences in risk that might exist across more than two thirds of the exposure since it was collapsed into a single category.

In contrast, the Empirical SI cut points were all higher than 7, enabling more precise estimation of associations between SI risk category and hand–arm symptoms across the large proportion of exposure samples that were classified in the highest SI risk category under the Original categorization system. Among the participants in this study, elevated risks were observed among the higher Empirical SI risk categories relative to the referent category. But in contrast to the Original structure, a monotonic increase was not observed across the Empirical SI risk categories. Furthermore, the only HR for the Empirical structure that was statistically significant was a twofold increase in risk for the second highest category.

Associations With Health Outcomes

Direct comparisons with previous studies using the SI as an exposure metric are difficult because health outcomes, study design, industry sector, SI score calculation methods (for multitask jobs), and cut points vary across studies. Similar to those for the current study, investigators for several studies have reported associations (although not always statistically significant ones) between various SI metrics and distal upper extremity musculoskeletal symptoms (Knox & Moore, 2001; Moore & Garg, 1995; Moore, Rucker, & Knox, 2001; Moore, Vos, Stephens, Stevens, & Garg, 2006), wrist tendonitis (Harris et al., 2011), rotator cuff tendonitis (Hegmann et al., 2006), or carpal tunnel syndrome (Garg et al., 2012; Silverstein et al., 2006).

One unexpected observation of the current study was that the highest strata of Empirical SI scores did not have the highest risk of hand–arm symptoms. The same pattern of lower observed risk among higher SI scores was observed in a recent study using the SI as an exposure metric among manufacturing workers (Garg et al., 2012). A possible explanation for the lower HRs observed among the highest Empirical SI risk category is the selection bias called selective survival. Specifically, because participants in this study had been working at the facility for many years (*M* = 16 years), it is possible that the workers most susceptible to hand–arm symptoms were underrepresented among the highest exposure strata because, after experiencing intolerable musculoskeletal effects, they self-selected into jobs with lower exposure levels or left the facility entirely (i.e., selective survival).

Gender Effects

For members of this study sample, the association between Empirical SI risk category and hand–arm symptoms was modified by gender. In particular, a statistically significant difference in the strength of the association between Empirical SI risk category and hand–arm symptoms was observed between men and women, especially for the highest exposure strata. Specifically, compared to the referent category, the risk of hand–arm symptoms among the highest strata of Empirical SI scores was doubled in comparison to the referent group among women, whereas a nonsignificant risk of less than unity was observed among men. Prior research has shown that men underreport upper extremity musculoskeletal symptoms compared to women, which could account for some of the observed gender effects (Silverstein et al., 2009).

Limitations

The findings of this study suggest that the SI score category may predict incident hand–arm symptoms among workers performing single-task and multitask manufacturing jobs similar to those performed by the study sample. However, about 90% of tasks at this facility were rated as “light” or “somewhat hard” on the SI “intensity of exertion” task rating subscale (a subscale intended to capture the forcefulness of hand– arm exertions). Observed associations between hand–arm symptoms and the SI metrics may have been attenuated because of the limited range of exposure to forceful hand–arm work performed at this facility.

Nondifferential sources of error in SI scores may have affected the results of this study. One source of nondifferential error in the SI scores was the use of task similarity groups for assigning a common SI score to similar tasks rather than conducting separate assessments for each task. This practice introduced some error into both Original and Empirical SI risk categories by artifactually reducing the observed exposure variability in comparison to the true variability. Another source of nondifferential error was using the most common work element for noncyclic tasks to assign SI scores. In both cases, nondifferential error in exposure estimation will attenuate observed associations between exposures and health outcomes (Jurek, Greenland, & Maldonado, 2008), which would not have affected comparisons between the Original and Empirical multivariable survival analysis models.

Only manufacturing workers were included in this study; therefore, it is uncertain whether the Empirical SI risk category cut points used in this study can be generalized to other industries. However, compared to the Original SI cut points, using the higher Empirical SI cut points presented in this study may provide a better way to identify hazardous manufacturing jobs.

Another limitation of the current study was its sample size. Among published epidemiologic studies of musculoskeletal outcomes among manufacturing workers, a sample size of 276 is not considered small. Regardless, statistical power in this study was limited because of sparseness of information within some strata of categorical variables. Estimates of association for the Original SI cut points were unstable because of sparse numbers of Sx+ participants in Original SI risk Categories 2 and 3. In addition, analyses by gender were especially limited by sample size considerations.

The modest participation rate of 52% may have resulted in distortion of the study sample. It is possible that the associations between exposure and outcome among participants were different than among nonparticipants. However, a participation rate of 52% is consistent with the experience of many investigators conducting prospective occupational cohort studies. Furthermore, because differences in associations between the Original SI risk category structure and hand–arm musculoskeletal symptoms and the Empirical SI risk category structure and hand–arm musculoskeletal symptoms were observed among the same set of participants, we have no reasons to believe that they were an artifact of differential participation.

Practical Applications and Future Research

Future research is needed to test the Empirical SI cut points presented in this paper (a) when assessing single-task jobs, (b) when multitask SI scores have been calculated using alternate methods, and (c) among other populations of both manufacturing and nonmanufacturing industries.

In addition to future research, future software development could be another way to make the use of multitask SI computation methods such as the CSI more accessible to practitioners. Until CSI calculation software becomes available, widespread use of the CSI is unlikely because manual calculation of more than a few multitask SI scores may be too time-consuming.

CONCLUSION

This study provides empirical evidence of associations between SI risk category structure defined in two distinct ways and incident hand– arm symptoms. These results (a) allow occupational health practitioners to better identify hazardous tasks to target them for exposure reduction efforts and (b) provide epidemiological researchers with an alternate method of categorizing SI scores that may permit more powerful modeling of exposure–effect associations. However, until further research is conducted, it is uncertain whether the performance of the Empirical SI classification method used in this study (or alternate SI classification methods) will be associated with incident hand– arm symptoms among workers in other industries.

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KEY POINTS

- The originally proposed SI job risk categories (cut points) may not be fully applicable to all industries.
- This study provides empirical evidence of an association between SI risk category and incident hand–arm symptoms.
- The overall strength of the evidence supported the use of the Empirical SI classification method over the Original SI classification method for associations with incident hand–arm symptoms among manufacturing workers.
- If verified, the results of the current study will allow researchers and occupational health practitioners to better identify hazardous jobs and target those jobs for exposure reduction efforts.

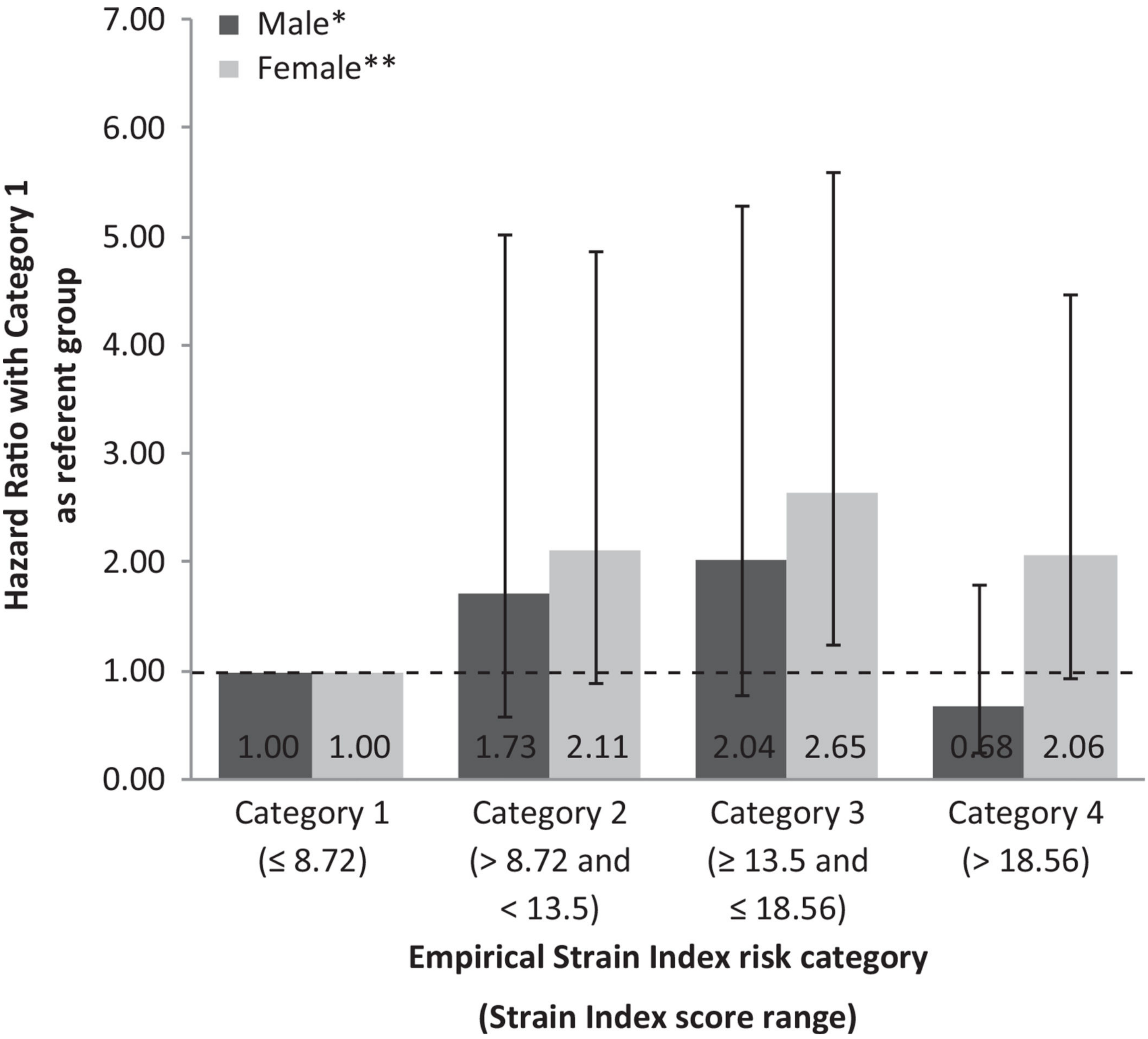

Figure 1.

Hazard ratios of association between hand–arm symptoms and Empirical SI risk category stratified by gender. Error bars represent the 95% confidence interval.

*Associations between Empirical SI risk category and hand–arm symptoms for men were controlled for job strain quadrant, weekly job stress, weekly job change, and coworker support. The p value = .13 for linear hypothesis test that $\beta_{\text{Category2}} = \beta_{\text{Category3}} = \beta_{\text{Category4}} = 0$.

**Associations between Empirical SI risk category and hand–arm symptoms for women were controlled for nonwork hand-intensive activity, weekly job stress, supervisor support, and previous hand–arm symptoms. The *p* value = .04 for linear hypothesis test that $\beta_{\text{Category2}} = \beta_{\text{Category3}} = \beta_{\text{Category4}} = 0$.

TABLE 1

Descriptive Statistics of Time-Independent and Time-Varying Demographic, Personal Health, and Occupational Characteristics ($N = 276$)

Characteristic	*M*	*SD*	*n*	%
Time-independent characteristics				
Age	42.8	10.0	—	
Female sex	—		133	48.2
Height males (cm)	179.2	9.1	—	
Height females (cm)	165.6	6.6	—	
BMI	27.4	5.5	—	
Education beyond high school	—		80	29.0
Proportion right handed	—		241	87.3
Non-White ethnicity	—		23	8.3
Annual household income ≥ $50,000	—		112	40.6
Hormone medication (% of women)	—		29	10.5
Currently smoke	—		94	34.1
Hand outcome comorbidity	—		38	13.8
Past history of hand–arm pain	—		50	18.1
Second shift	—		69	25.0
Years at study worksite	16.3	11.2	—	
Time-varying characteristics[a]				
Hours per week at second job	1.2	4.7	—	
Hours per week upper-extremity-intensive activities	2.3	3.8	—	
Hours per week nonwork aerobic activity	0.4	0.9	—	
Hours per week primary assembly job	36.9	8.2	—	

[a] Time-varying characteristics are averages of more than 276 weekly observations.

TABLE 2

Unadjusted Associations Between Hand–Arm Symptoms and Potential Demographic, Personal, and Psychosocial/Work Organization Confounders by Gender

	Facility-Wide (*N* = 276)		Male (*n* = 143)		Female (*n* = 133)	
Variable	**Crude HR**	***p***	**Crude HR**	***p***	**Crude HR**	***p***
Age (years)	0.99	.57	0.98	.13	1.00	.93
Female gender	1.77	<.01	—	—	—	—
Height						
Lower tertile	1.40	.16	0.98	.96	1.56	.39
Middle tertile	1.00	—	1.00	—	1.00	—
Upper tertile	0.84	.50	0.54	.11	0.69	.74
Body mass index (kg/m^2)	1.02	.40	0.99	.81	1.03	.17
Education beyond high school	0.96	.86	0.72	.34	1.80	.06
Right handed	0.97	.91	0.82	.65	1.05	.90
Non-White ethnicity	0.84	.65	0.68	.47	3.18	.05
Income ≥ $50,000	0.86	.46	0.77	.46	0.82	.47
Current smoker	0.87	.52	0.77	.47	1.02	.94
Comorbidity (RA, DM, thyroid med, prior CTS)	1.80	.02	0.70	.63	1.82	.03
Past history arm pain	2.99	<.001	2.50	.02	3.05	<.001
Hours/week in second job	1.05	<.01	1.46	.43	1.94	.13
Hours/week upper-extremity-intensive nonwork activities	1.04	<.01	1.04	<.01	1.04	.11
Some nonwork aerobic activity (vs. none)	1.19	.44	0.83	.64	1.19	.52
Second shift (vs. first shift)	1.10	.71	1.42	.91	1.13	.75
Years worked at the study facility	1.00	.26	0.98	.13	1.00	.88
Hours worked each week	1.01	.50	1.01	.60	1.01	.40
Psychosocial risk factors						
Coworker support	1.02	.70	1.14	.11	0.97	.55
Supervisor support	0.96	.27	1.03	.67	0.94	.15
Negative affectivity	1.02	.25	1.05	.12	1.00	.99
Positive affectivity	0.98	.27	0.98	.44	0.99	.42

Variable	**Facility-Wide (*N* = 276)**		**Male (*n* = 143)**		**Female (*n* = 133)**	
	Crude HR	***p***	**Crude HR**	***p***	**Crude HR**	***p***
Job strain by quadrant						
High control, low demand	1.00	—	1.00	—	1.00	—
High control, high demand	2.61	<.01	4.92	<.01	1.66	.24
Low control, low demand	2.22	.02	3.81	.03	1.49	.35
Low control, high demand	3.50	<.001	6.21	<.01	2.10	.05
Strain ratio (job demand/decision latitude)	11.69	<.01	12.03	.02	8.93	.07
Decision latitude	0.98	.01	0.97	.07	0.98	.17
Job demand	1.07	.02	1.10	.02	1.03	.44
Stress (from task log VAS, time-varying)	1.17	<.01	1.18	.04	1.15	.04
Job change (from task log, time-varying)	4.07	<.001	4.76	<.001	3.39	<.001

Note. CTS = carpal tunnel syndrom; DM = diabetes melltus;HR = hazrd ratio; RA = rheumatoid arthritis; VAS = visual analog scale.

TABLE 3

Unadjusted Associations Between SI Risk Category and Hand–Arm Symptoms for the Original and Empirical Structures

SI Risk Category	**Weeks**						
Classification Method	**Score Range**	**Sx+**	**Sx–**	**HR**	**95% CI**	***p***	**AIC**
Original structure						.27*	983.26
Category 1	≤3	11	1,630	1.00	—	—	
Category 2	>3 and <5	4	319	1.19	[0.38–3.75]	.77	
Category 3	≥5 and <7	6	619	1.39	[0.51–3.77]	.52	
Category 4	≥7	76	6,161	1.80	[0.96–3.40]	.07	
Empirical structure						.17*	
Category 1	≤8.72	26	2,907	1.00	—	—	976.65
Category 2	>8.72 and <13.5	18	1,405	1.71	[0.94–3.12]	.08	
Category 3	≥13.5 and ≤18.56	27	1,849	1.70	[0.99–2.91]	.05	
Category 4	>18.56	26	2,568	1.22	[0.71–2.10]	.48	

Note. AIC = Akaike information criterion; CI = confident interval; HR = hazard ratio; SI = Strain Index; Sx+ = symptom positive; Sx– = symptom negative.

[*] Overall *p* value is for the result of the linear hypothesis that $\beta_{Category2} = \beta_{Category3} = \beta_{Category4} = 0$.

TABLE 4

Final Multivariable Models of Association Between SI Risk Category and Hand–Arm Symptoms for the Original and Empirical Structures

SI Risk Category	**Weeks**						
Classification Method	**Score Range**	**Sx+**	**Sx–**	**HR**	**95% CI**	***p***	**AIC**
Original structure						.14[*]	883.32
Category 1	≤3	11	1,630	1.00	—	—	
Category 2	>3 and <5	4	319	1.25	[0.39–4.01]	.71	
Category 3	≥5 and <7	6	619	1.57	[0.56–4.42]	.39	
Category 4	≥7	76	6,161	2.06	[1.08–3.92]	.03	
Empirical structure						.05[*]	881.75
Category 1	≤8.72	26	2,907	1.00	—	—	
Category 2	>8.72 and <13.5	18	1,405	1.57	[0.83–2.96]	.18	
Category 3	≥13.5 and ≤18.56	27	1,849	2.21	[1.26–3.85]	<.01	
Category 4	>18.56	26	2,568	1.42	[0.80–2.50]	.23	

Note. AIC = Akaike information criterion; CI = confident interval; HR = hazard ratio; SI = Strain Index; Sx+ = symptom positive; Sx– = symptom negative. Associations between Original and Empirical SI risk category and hand–arm symptoms controlled for sex, hours per week of nonwork hand-intensive activity, hours per week at second job, weekly job change, previous hand–arm symptoms, and weekly job stress.

[*] Overall *p* value is for the result of the linear hypothesis that $\beta_{\text{Category2}} = \beta_{\text{Category3}} = \beta_{\text{Category4}} = 0$.