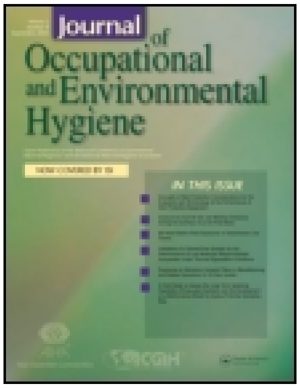

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This study evaluated two subjective assessment methods for physical work-related musculoskeletal disorder (WMSD) risk factors. A total of 567 participants from 12 companies in the manufacturing and health care industries were evaluated using the hand activity level (HAL) threshold limit value (TLV) and the Strain Index. Inter-rater reliability comparisons were performed on 125 selected cyclic tasks, with one novice and three experienced raters. Predictive validity was assessed by evaluation of relationships between measured exposure parameters and diagnosed WMSDs of the hand/wrist and elbow. HAL hand repetition ratings had a Spearman r value of 0.65 and a kappa value of 0.44 between raters. Subjective force (0–10 scale) estimates had a Spearman $r = 0.28$ and were not significantly different between raters ($p > .05$). The rating comparison for the four subjective components of the Strain Index had Spearman r correlations of 0.37–0.62 and kappa values of 0.25–0.44. The Strain Index and HAL TLV agreed on exposure categorization 56% of the time. Logistic regression showed, after adjustment for age, gender, and body mass index, that higher peak hand force estimates (odds ratio [OR] 1.14, confidence interval (CI) 1.02–1.27), most common force estimates (OR 1.14, CI 1.02–1.28), hand/wrist posture rating (OR 1.71, CI 1.15–2.56), and Strain Index scores ≥7 (OR 1.82, CI 1.04–3.18) were associated with distal upper extremity disorders in the dominant hand. HAL repetition ratings ≥4 (OR 2.81, CI 1.40–5.62) and hand/wrist posture ratings (OR 1.59, CI 1.01–2.49) were associated with disorders in the nondominant hand. These findings show moderate to good inter-rater agreement and significant relationships to health outcomes for the identified measures.

Keywords exposure assessment, hand activity level, musculoskeletal disorders, reliability, Strain Index, validity

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INTRODUCTION

Researchers and practitioners try to obtain the most accurate and precise exposure assessment measurements within time and money constraints to quantify putative risk factors for work-related musculoskeletal disorders (WMSD). Laboratory experiments may be suited to the use of direct measurement "gold standards," whereas practitioners, applied researchers, and epidemiologists often must rely on subjective and observational techniques to obtain data in large populations. Field-based exposure measurement methods have been developed to collect information and categorize jobs based on the level of exposure to a job's physical risk factors and the estimated risk of injury. The goal of scoring methods is to predict musculoskeletal disorder development risk based on scores calculated from rated observations of risk factors on the job. Several examples of these methods include the Strain Index,[(1)] RULA,[(2)] REBA,[(3)] and the American Conference of Governmental Industrial Hygienists' (ACGIH®) hand activity level (HAL) threshold limit value (TLV).[(4)]

Generally, direct measurements and video-based observation are assumed to have a higher level of precision and accuracy than subjective assessments and self-reports.[(5)] Many researchers, including Burdorf et al.,[(6)] believe that observational methods are subject to intra- and interobserver variability that can greatly decrease the level of accuracy and precision of measurements. This variability can lead to exposure misclassification and low validity when compared with health outcomes.

Some researchers have investigated inter-rater reliability and accuracy and validity of observational scoring methods and their components.[(7–11)] However, larger studies evaluating the efficacy of many of these methods have not been reported. This study presents an evaluation and comparison of the HAL TLV and the Strain Index. Cross-sectional data from a larger prospective study were used to evaluate the use of two commonly applied exposure assessment methods.

METHODS

Subjects

The participants were volunteers from nine manufacturing and three health care sites. The jobs of 567 subjects were analyzed. The participants were 49% female and had a mean age of 39 (±11, range: 18–65). Approximately 5% were new hires (less than 1 month at company) and 7% worked a second job, whereas 88% reported working regular overtime. All subjects reported working one cyclic job during their regular work shift. The participants had a mean body mass index (BMI) of 27 (±6, range: 16–56), and 30% were current smokers. Approximately 13% of the subjects had previously filed a workers' compensation claim for an upper extremity injury. All subjects were provided informed consent as approved by the Washington State Institutional Review Board.

Materials and Procedures

Physical Exposure Assessment

The job evaluation was initiated with an informal subject interview to determine the number of distinct tasks associated with the job and duration of time per day. The workers were then videotaped from two different angles with hand-held video cameras synchronized with a light at the beginning of the recording. These mono-task, cyclic jobs were videotaped for 15 min during a typical workday while performing the normal job functions. The jobs at the health care sites included pharmacists, housekeeping, laundry workers, office workers, and laboratory technicians. Jobs at manufacturing sites included equipment assembly line, office workers, product testing, electronics assembly, sawmill line, machine operators, wood products finishing and assembly, and lead workers/supervisors.

Job information and observer ratings were recorded on an observation sheet during or immediately after the video recording. Objects believed to weigh more than 2 lb (8.9 N) were weighed, and any activity estimated to require a hand force of at least a 2 lb (8.9 N) pinch grip or a 10 lb (44.5 N) power grip was included as a "significant force" application. Push/pull forces estimated to be over 10 lb (44.5 N) were also rated. Hand force was estimated by the ergonomist using a CR-10 Borg Scale.[12]

A HAL rating was completed for each mono-task job using the 10-point scale developed by Latko et al.[7] Strain Index[1] observer-rated measures, Frequency of Exertion, Duration of Exertion, Hand/Wrist Posture, Speed of Work, and Hours per Day, were also rated (1–5) by ergonomists for both hands on the observation sheet. The data collection procedures and scales from Moore and Garg[1] were used.

Three ergonomists collected field data, with one "novice" partner completing duplicate observations for a subset of the population to evaluate inter-rater reliability. On a selected group of 125 cyclic tasks, two raters (either both ergonomists or novice-ergonomist) completed observational measurement information relating to the task variables used to compute the Strain Index and the HAL TLV. The "expert" ergonomists were all certified professional ergonomists (CPE) and had graduate training in ergonomic analysis at the master's degree level or above, with postgraduate field experience. The novice ergonomist was a master's degree student with no field assessment experience. The result was 66 expert-expert and 59 expert-novice pairwise comparisons.

Hand Force Measurement

The ergonomist hand force estimate was used in the analysis comparing the HAL TLV and the Strain Index. This was stated as the preferred method for the Strain Index calculation according to Moore and Garg.[1] Significant hand forces were rated on the Borg CR-10 scale, which was treated as a categorical exposure measure. The majority of tasks had either one or no significant forces. Jobs with no significant force ($n = 274$) were assigned a force of 0 on the CR-10 scale. The most commonly applied force, as determined from video-based hand exertion analysis and measured by ergonomist estimate, was used as the Intensity of Exertion task variable input for the Strain Index. The highest ergonomist force estimate for each subject was used as the peak force value for each hand in the analysis. Subject-estimated force and force matching was measured as part of the larger study but not used in the analysis.

The video recordings of work activities were digitized and analyzed using the MVTA system.[13] Five random 1-min intervals were designated for analysis of hand exertion and force on each 15-min video clip. Observed significant hand forces were marked on every frame during the analysis intervals using the MVTA system. Hand exertion or nonexertion was also marked for every frame in the analysis intervals. The exertion duration of the measured forces was then calculated for each job to determine the most common force. No other data were used from MVTA for the present analysis; additional measurements and exposure metrics were used and evaluated as part of the prospective study. A more detailed description of the larger study exposure assessment procedures and tools is provided by Bao et al.[14]

Health Outcome Assessment

Participants initially were given an oral interview detailing their job tasks, job history, health history, outside work activities, psychosocial factors, and functional physical and mental health. Participants then completed a body-discomfort interview that used a series of questions for each body region with reported pain. A standardized physical examination was then performed by either a trained occupational health physician, nurse, or physical therapist.[15,16] Nerve conduction velocity was measured in the dominant hand, and the nondominant hand if symptoms were reported or slowing was observed on the dominant hand, by a certified nerve conduction technician using a Cadwell Sierra II with review by a board-certified neurologist.

Hand-arm disorder symptoms were classified as positive if pain, numbness, tingling, aching, or burning in the elbow/forearm, or hand/wrist was reported in the past 7 days *and* (1) it occurred at least three times in the previous 12 months or lasted more than a week, *and* (2) it did not start as the result of acute trauma.

Clinical cases were defined as positive symptoms of upper extremity during the week of the examination *and* at least one physical finding in the symptomatic joint area, except for carpal tunnel syndrome. The case definition did not include an indication of work relatedness by the participants. Specific clinical diagnoses included were carpal tunnel syndrome, lateral and medial epicondylitis, and forearm/elbow tendonitis. Carpal tunnel syndrome was diagnosed only if the symptoms questionnaire criteria were met (pain, numbness, or tingling in the median nerve distribution) along with one of the following conditions: median motor latency (8 cm) >4.5 ms; or median sensory latency >3.5 ms (14 cm), or >2.2 ms (8 cm); or median-ulnar nerve sensory difference >0.5 ms (14 cm) or >0.3 ms (8 cm).[16]

Evaluation Parameters

Logistic regression was performed using SAS 9.1 (Cary, N.C.) to assess the cross-sectional association between the upper extremity clinical cases and the physical exposure parameters, adjusting for age, gender, and body mass index. The Spearman rho statistic was calculated for observed exposure parameters to compare correlation as a measure of precision between observers. The weighted kappa, with equal weight given to each category, was used as a reliability statistic and as a surrogate for agreement.[17] The chi-square statistic was used to evaluate statistically significant differences between raters. Kappa and Spearman rho values were also calculated for expert-expert and expert-novice rater pairs. Sensitivity and specificity for the Strain Index were calculated for varying exposure level cut points, as compared with identified clinical cases.

RESULTS

Measurements of Physical Variables

The HAL ratings had a mean value of 3.9 (±1.5) for the dominant hand and 3.6 (±1.5) for the nondominant hand. Figure 1 shows the distribution of HAL ratings over the 567 jobs. The mean Strain Index score was 15.8 (±29.0) for the dominant hand and 13.1 (±28.0) for the nondominant hand, with median values of 6.0 and 3.4 for the dominant and nondominant hands, respectively. The mean peak force estimates for the dominant and nondominant hands were 2.2 (±2.5) and 1.7 (±2.4), with median values of 2 for the dominant hand and 0 for the nondominant hand. The most common force estimate was 2.0 (±2.4) and 1.6 (±2.3) for the dominant and nondominant hands, also with median values of 2 and 0, respectively. Table I summarizes the individual characteristics of the study population for the dominant hand.

Inter-Rater Reliability

Strain Index task variables and score, HAL, and ergonomist hand force estimates were compared between observers. Results are shown for the dominant hand only, as rater differences between the left hand and right hand were not significant for all of the task variables ($p > 0.05$). The ordinal values were used as categories for the physical exposure variables, and the three defined risk levels of "safe," "action limit," and "hazardous" were defined as exposure categories for the HAL TLV and Strain Index. Table II summarizes inter-rater reliability results.

The Spearman correlation showed the highest value at 0.65 for the HAL ratings, followed closely by Speed of Work at 0.62, whereas the lowest correlation coefficient was associated with the hand force estimate at 0.28. All of these variables were not statistically different between raters ($p > 0.05$). The Strain Index score correlation coefficient was 0.57 and was significantly different between raters ($p < 0.05$). Duration of Exertion, Efforts per Minute, and Hand/Wrist Posture values were also different between raters ($p < 0.05$). Significant

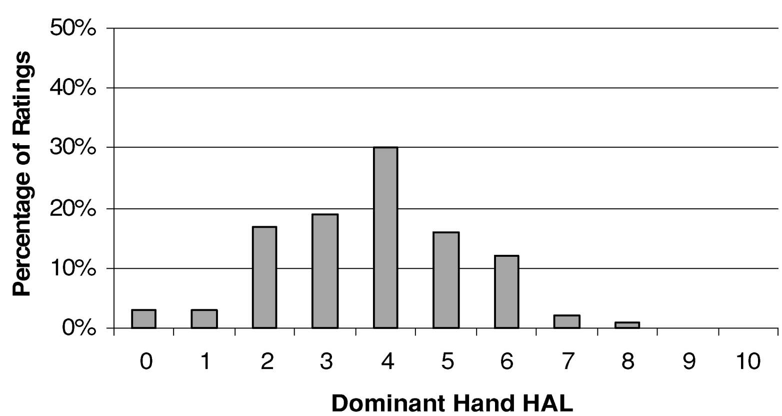

FIGURE 1. The percentage of job ratings by Hand Activity Levels for the dominant hand

TABLE I. Individual Characteristics of the Study Population, by Dominant Hand

Characteristics	All Subjects (N = 567)	Elbow/Hand/Wrist Clinical Cases (n = 86)	Non-Cases (n = 481)	p-value[A]
Age (mean ± SD)	38.8 ± 11.0	44.7 ± 9.9	37.8 ± 10.9	<0.0001
BMI (mean ± SD)	27.3 ± 5.8	29.4 ± 6.7	27.0 ± 5.0	0.0016
Gender (n, % male)	309 (54.5)	30 (34.9)	279 (58.0)	<0.0001
Duration of exertion rating, 1–5 (mean ± SD)	3.0 ± 1.1	3.0 ± 1.2	3.0 ± 1.1	0.54
Effort rating, 1–5 (mean ± SD)	2.7 ± 1.1	2.6 ± 1.0	2.7 ± 1.1	0.38
Speed of work rating, 1–5 (mean ± SD)	3.0 ± 0.7	3.0 ± 0.7	3.0 ± 0.7	0.69
Hand/wrist posture rating, 1–5 (mean ± SD)	3.2 ± 0.8	3.3 ± 0.7	3.1 ± 0.8	0.0512
HAL rating, 0–10 (mean ± SD)	3.9 ± 1.5	4.0 ± 1.5	3.9 ± 1.5	0.44
HAL rating categories (n, %)				
1: ≥4	345 (60.9)	55 (64.0)	290 (60.3)	0.52
2: <4	222 (39.2)	31 (36.1)	191 (39.7)	
Most common hand force, 0–max (mean ± SD)	2.0 ± 2.4	2.2 ± 2.4	2.0 ± 2.3	0.44
Peak hand force, 0–max (mean ± SD)	2.2 ± 2.5	2.3 ± 2.5	2.2 ± 2.5	0.56
Strain Index score—3 categories (n, %)				
1: ≥7	229 (40.4)	39 (45.4)	190 (39.5)	0.53
2: ≥3.1 to <7	140 (24.7)	21 (24.4)	119 (24.7)	
3: <3	198 (34.9)	26 (30.2)	172 (35.8)	
Strain Index score—2 categories (n, %)				
1: ≥7	229 (40.4)	39 (45.4)	190 (39.5)	0.31
2: <7	338 (59.6)	47 (54.7)	291 (60.5)	
ACGIH HAL TLV categories (n, %)				
Action	101 (17.8)	15 (17.4)	86 (17.9)	0.99
TLV	123 (21.7)	19 (22.1)	104 (21.6)	
Safe	343 (60.5)	52 (60.5)	291 (60.5)	

[A] p-value comparing clinical cases with the non-cases, Student's *t*-test, or chi-squared test.

differences between expert-expert and expert-novice values were found for each of the variables with differences between raters, with the exception of the Hand/Wrist Posture rating, for which there was no difference between the expert-expert pairs. Kappa statistic values ranged from a low of 0.22 for the hand force estimate to 0.44 for the Speed of Work variable. Duration per day was not included, as all workers worked the same shift length and no variation was present in the variable. A kappa statistic of 0.41 was found for risk categorization using the Strain Index.

TABLE II. Inter-Rater Comparison of Spearman Correlation and Kappa Agreement Values for Dominant-Hand Strain Index and HAL TLV Variables

	Spearman r			Kappa Value		
Exposure Variable	Inter-rater Overall	Expert-Expert	Expert-Novice	Inter-Rater Overall	Expert-Expert	Expert-Novice
Hand force estimate	0.28	0.38	0.46	0.22	0.31	0.19
Duration of exertion[A]	0.37	0.50	0.34	0.27	0.34	0.21
Efforts per minute[A]	0.40	0.49	0.34	0.26	0.35	0.16
Hand/wrist posture[A]	0.49	0.64	0.26	0.34	0.42	0.26
Speed of work	0.62	0.57	0.64	0.44	0.41	0.48
Hand activity level (HAL)	0.65	0.67	0.39	0.34	0.43	0.25
Strain Index score[A]	0.57	0.68	0.41	0.41	0.49	0.27
Mean	0.48	0.56	0.41	0.33	0.39	0.26

[A] Significant difference between raters ($p < .05$).

		ACGIH HAL TLV			
		Safe	Action	TLV	Total
	Safe	186 33%	10 2%	2 0%	198 35%
Strain Index	Action	113 20%	20 4%	7 1%	140 25%
	Hazardous	44 8%	71 13%	114 20%	229 40%
	Total	343 61%	101 18%	123 22%	567 100%

FIGURE 2. Comparison of ACGIH HAL TLV and Strain Index risk categorization for the dominant hand

Expert ergonomist ratings agreed more with other ergonomist estimates than with those of the novice ($p < 0.05$). The overall mean Spearman correlation coefficient and kappa statistics were 0.56 and 0.39 for expert-expert rater pairs, whereas they were 0.41 and 0.26, respectively, for expert-novice rater pairs (Table II).

Strain Index and Hand Activity Level TLV Comparison

The Strain Index scores were categorized based on Moore and Garg[1] into three categories: <3, 3–7, and >7, for comparison with the HAL TLV. The resulting risk classifications by category for both methods for the dominant hand are presented in Figure 2. Results for the nondominant hand gave comparable results. Overall, the two methods agreed on categorization for 320 out of 567 of the workers, or 56% agreement. Categorization by the two methods was significantly different ($p < 0.05$) overall. The HAL TLV categorized more jobs (61%) as safe compared with the Strain Index (35%). The Strain Index categorized more jobs (40%) as hazardous compared with the HAL TLV (22%).

The sensitivity and specificity of the Strain Index score were calculated for safe vs. hazardous cut points from 3 to 30 in multiples of 3 using any diagnosed disorder of the hand/wrist or elbow for the dominant hand as the health outcome. Sensitivity and specificity were equal at a Strain Index score cut point of approximately 7.5 (Figure 3).

Exposure Relationship to Health Outcomes

A total of 86 distal upper extremity musculoskeletal disorder cases were identified in the study population. Upper extremity disorders of the hand/wrist or elbow in the dominant hand were significantly associated with peak hand force estimates (odds ratio [OR] 1.14, confidence interval [CI] 1.02–1.27) and most common force estimates (OR 1.14, CI 1.02–1.28) after adjustment for age, gender, and BMI. Dominant hand/wrist posture rating (OR 1.71, CI 1.15–2.56) and Strain Index score ≤7 compared with ≤3 (OR 2.33, CI 1.20–4.53) or Strain Index score ≤7 compared with <7 (OR 1.82, CI 1.04–3.18) were also associated with upper extremity disorders. Nondominant hand HAL repetition rating category ≤4 (OR 2.81, CI 1.40–5.62) and hand/wrist posture ratings (OR 1.59, CI 1.01–2.49) were significantly related to health outcomes. A HAL cut point of 4 was chosen as the center of the distribution shown in Figure 1. Odds ratios were based on 1-unit scale increases except for those where the comparison category is defined. A multivariate model is not presented due to the levels of correlation between variables. Tables III and IV present adjusted odds ratios for the evaluated physical risk factors for the dominant and nondominant hands.

DISCUSSION

Inter-rater reliability of the measures was generally in the fair to moderate agreement range according to Landis and

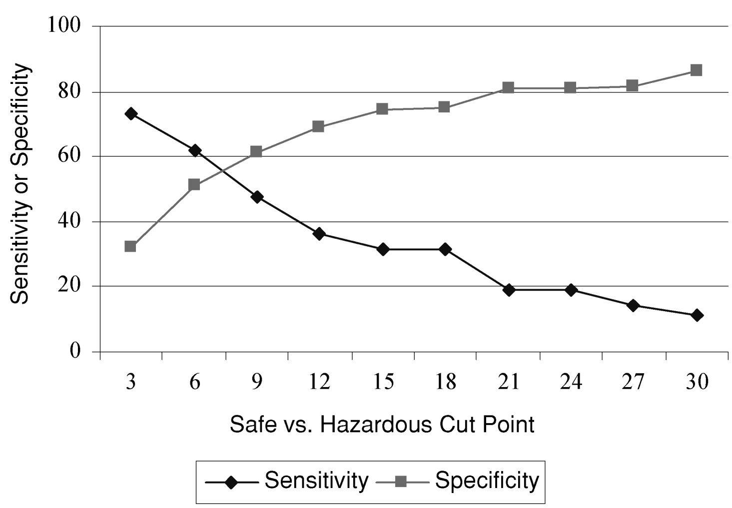

FIGURE 3. Sensitivity and specificity for Strain Index scores compared to diagnosed disorders of the hand/wrist or elbow for the dominant hand

TABLE III. Relationships Between Physical Risk Factors and Distal Upper Extremity Health Outcomes for the Dominant Hand (LCL/UCL: 95% Lower and Upper Confidence Limits) Controlling for Age, Gender, BMI

Exposure Parameter Comparison	Odds Ratio	LCL	UCL
Duration of effort	1.07	0.85	1.35
Efforts per minute	0.97	0.75	1.26
HAL (as continuous variable)	1.18	0.98	1.42
HAL category (≥4 vs. <4)	1.69	0.94	3.03
Hand/wrist posture	1.71	1.15	2.56
Hand force (most common)[A]	1.14	1.02	1.28
Hand force (peak)[A]	1.14	1.02	1.27
SI ≥7 vs. ≤3[A]	2.33	1.20	4.53
SI (3-7) vs. ≤3	1.80	0.83	3.88
SI ≥7 vs. <7[A]	1.82	1.04	3.18
Speed of work	1.39	0.92	2.10
ACGIH Action Level vs. Safe	1.86	0.95	3.65
ACGIH TLV vs. Safe	1.76	0.87	3.57
ACGIH TLV vs. Safe or Action	1.61	0.85	3.07

[A]Statistically significant odds ratio.

Koch.[18] It was apparent from the results that expert raters agreed more with each other than with the novice rater. The expert-expert kappa values were over .40 for the HAL rating and Strain Index score, showing moderate agreement, while expert-novice comparisons were on the lower end of the fair agreement range for these measures. The expert raters agreed with each other much more often and across all measures with the exception of Speed of Work. These data represent pairwise comparison of only one novice and three expert raters, so these results may not necessarily be generalized to a larger population of novice and expert raters. It should be noted that kappa values may be influenced by nonhomogeneous distributions between categories and, given the inherent variation that differences between categories, may have lowered the reported kappa values.

TABLE IV. Univariate Relationships Between Physical Risk Factors and Distal Upper Extremity Health Outcomes for the Nondominant Hand (LCL/UCL: 95% Lower and Upper Confidence Limits)

Exposure Parameter Comparison	Odds Ratio	LCL	UCL
Duration of effort	1.14	0.87	1.51
Efforts per minute	1.04	0.77	1.40
HAL (as continuous variable)	1.17	0.95	1.44
HAL category (≥4 vs. <4)[A]	2.81	1.40	5.62
Hand/wrist posture[A]	1.59	1.01	2.49
Hand force (most common)	1.09	0.95	1.25
Hand force (peak)	1.10	0.97	1.25
SI ≥7 vs. ≤3	1.54	0.72	3.32
SI (3-7) vs. ≤3	1.61	0.73	3.58
SI ≥7 vs. <7	1.29	0.65	2.58
Speed of work	1.45	0.91	2.29
ACGIH Action Level vs. Safe	1.94	0.85	4.45
ACGIH TLV vs. Safe	1.67	0.68	4.09
ACGIH TLV vs. Safe or Action	1.77	0.79	3.95

[A]Statistically significant odds ratio.

The hand force estimate had a Spearman r value of 0.28 overall, showing a relatively low level of precision; however, this measure along with the HAL and Speed of Work ratings were not significantly different between raters. The HAL rating, when performed by experts, appeared to be the most robust individual exposure measure of those observed in terms of both precision and inter-rater reliability. The HAL method described by Latko et al.[7] involving two or more raters reaching consensus, achieved higher levels of precision and inter-rater reliability. Ebersole and Armstrong[11] found initial kappa values of 0.52 for HAL ratings and 0.26 for peak force estimates, both in the same agreement range as was found in the present study. They also determined that kappa values could increase to 0.60–0.70 for these measures after discussion between the raters.

Stevens et al.[19] previously found relatively high inter-rater reliability for Strain Index variables, ranging between .66 and .81. The overall Strain Index score was found to have an intraclass correlation (ICC) of .43. The individual variable reliability was higher than that found in this study; however, the inter-rater reliability for the overall score was actually lower. Some of the variation between these findings may be explained by differences in the statistics used and study design. The study by Stevens et al.[19] did not present kappa values or Spearman rank correlations for comparison and used more potentially monotonous jobs from videotape compared with simultaneous field assessment in the current study.

The data collection form in this study used the rating scale directly from Latko[8] and ACGIH,[4] which included verbal anchors at 2-point intervals on the 10-point scale. The HAL scores in Figure 1 shows a distribution skewed slightly toward the lower end of the scale, which may have been influenced partly by having verbal anchors at 2 and 4.

The two methods did not agree on categorization of almost half of the jobs workers were performing. The Strain Index classified more (40%) jobs as hazardous compared with the HAL TLV, and the TLV categorized more (60%) of the jobs as safe. This is consistent with the recommendation by Armstrong et al.[20] that the HAL TLV Action Limit be lowered in some situations. Another study by Bao[21] found 95% agreement between hazardous classifications by the Strain Index and HAL TLV when comparing assessments of 23 professional workshop participants of seven jobs. Bao et al.[22] found 75% agreement between the two methods using both the subjects presented in this article and additional subjects from the larger study.

The results of the present study appear to indicate that adjustment to each of the HAL TLV category cut points may improve the validity of the tool. The Strain Index categorized 106 more subjects as being in a hazardous level of exposure when compared with the TLV level of the HAL. This categorization level of the Strain Index was significantly related to health outcomes for the dominant hand, while the HAL TLV was not. In addition, the HAL TLV showed a greater odds ratio for the Action Level compared with Safe than for TLV compared with Safe (Tables III and IV). Though not statistically significant, the consistent finding between hands shows a potential for improvement in the categorization cut points for the HAL TLV.

The original paper by Moore and Garg[1] defines a Strain Index score of 7 or above as hazardous. The data from this study showed that the plot of sensitivity and specificity of the Strain Index by score cut point were equal between scores of 7 and 8. These results support a cut point of 7 for jobs with an increased risk of promoting the development of upper extremity WMSDs.

Study sites were included if jobs with at least 20 workers were identified that could be stratified into at least three different exposure-combination categories of low (0–3), medium (4–6), or high repetition (7–10) and low or high peak force. Despite these efforts, it was extremely difficult to find participants in high repetition-high force jobs. There was a near normal distribution of hand forces and repetition levels as shown in Figure 1, though slightly skewed toward low force and low to medium repetition jobs. The lack of higher levels of physical exposure could bias the relationship between physical job variables and health outcomes toward the null hypothesis. However, any associations between physical risk factors and outcomes might be strengthened given a relative lack of high repetition and high repetition-high-force jobs in the population.

Peak force (dominant hand) and HAL (nondominant hand) were both significantly related to distal upper limb health outcomes (Tables III and IV). However, the HAL TLV did not appear to be significantly related to morbidity. This outcome could be due partly to the lack of higher level exposures or because the TLV morbidity relationship is diluted in the combination of the HAL and peak force variables as compared with each used separately. Categorizing the TLV into three levels (TLV, Action Level, and Safe) from the two 10-point scales reduces the level of precision and may result in lower associations with negative health outcomes than the two variables taken separately.

Hand/wrist posture as categorized by the observer-rated Strain Index scale was the only physical exposure variable significantly related to clinical cases for both the dominant and nondominant distal upper extremities. The significant physical exposure variables were mutually exclusive to the dominant and nondominant hands. Reasons for this are not immediately clear. However, it is possible that a different exposure pattern may be related to disorder development in the dominant vs. nondominant hand. These results, and those of all observer ratings presented in this article could differ from future findings comparing risk factor parameters from detailed video analysis and multiple task jobs.

Franzblau et al.[23] found in a cross-sectional validity study that the TLV categories were positively associated with both elbow/forearm tendonitis and diagnosed carpal tunnel syndrome. In that study, a job-based exposure assessment was performed compared with individual exposure assessment in the current study. This may explain some variability in measurement of physical variables. However, both studies did find dose-response relationships between HAL variables and carpal tunnel syndrome clinical cases.

Wands et al.[10] found in a study of 34 jobs that a Strain Index score of 50 correctly categorized five out of six cases of self-reported symptomatic WMSDs, as opposed to the cut point of 7 used in this study as a hazardous exposure level. Even at the higher cut point, however, approximately 42% of the exposures were false-positives, identifying jobs as hazardous where there was no reported morbidity.

Rucker and Moore[9] found a statistically significant relationship between Strain Index hazard classification and morbidity in manufacturing jobs, with high levels of sensitivity, specificity, and positive and negative predictive value. This study and Wands et al.[10] used OSHA 200 logs to classify morbidity to the distal upper extremity on a general level. This outcome end point may result in some disease misclassification compared with more objective physical exam and nerve conduction findings. It is possible that the method of morbidity classification and potential false-positives in these two studies diluted the relationship found between the Strain Index and work-related upper extremity musculoskeletal disorders (UEMSDs) compared with other studies.

A previously published paper using the same study population but including other exposure measurement techniques and multiple task jobs found an increased risk for diagnosed carpal tunnel syndrome only associated with the Strain Index score (OR 1.35, CI 1.09–1.68) and with peak hand force (OR 1.18, CI 1.00–1.40).[24] These findings are consistent with the results from this analysis of all diagnosed upper extremity disorders in the dominant hand, although they do did not include the described hand/wrist posture and most common force variable relationships.

The accuracy of the exposure measures was not evaluated in this analysis. Future evaluation at completion of the prospective study will compare subjective exposure variables and UEMSD outcomes with detailed video observation and task analysis. The HAL TLV and Strain Index task variables also will be compared along with observational methods to health outcomes prospectively, which will give a greater understanding of the predictive value of different exposure measures as they relate to upper extremity musculoskeletal disorder development at work.

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