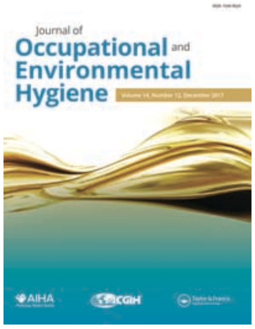

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Risk assessments using the Strain Index and the TLV for HAL, Part I: Task and multi-task job exposure classifications

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ABSTRACT

Background: The Strain Index (SI) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value for Hand Activity Level (TLV for HAL) use different constituent variables to quantify task physical exposures. Similarly, time-weighted-average (TWA), Peak, and Typical exposure techniques to quantify physical exposure from multi-task jobs make different assumptions about each task's contribution to the whole job exposure. Thus, task and job physical exposure classifications differ depending upon which model and technique are used for quantification. This study examines exposure classification agreement, disagreement, correlation, and magnitude of classification differences between these models and techniques.

Methods: Data from 710 multi-task job workers performing 3,647 tasks were analyzed using the SI and TLV for HAL models, as well as with the TWA, Typical and Peak job exposure techniques. Physical exposures were classified as low, medium, and high using each model's recommended, or a priori limits. Exposure classification agreement and disagreement between models (SI, TLV for HAL) and between job exposure techniques (TWA, Typical, Peak) were described and analyzed.

Results: Regardless of technique, the SI classified more tasks as high exposure than the TLV for HAL, and the TLV for HAL classified more tasks as low exposure. The models agreed on 48.5% of task classifications (kappa = 0.28) with 15.5% of disagreement between low and high exposure categories. Between-technique (i.e., TWA, Typical, Peak) agreement ranged from 61–93% (kappa: 0.16–0.92) depending on whether the SI or TLV for HAL was used.

Conclusions: There was disagreement between the SI and TLV for HAL and between the TWA, Typical and Peak techniques. Disagreement creates uncertainty for job design, job analysis, risk assessments, and developing interventions. Task exposure classifications from the SI and TLV for HAL might complement each other. However, TWA, Typical, and Peak job exposure techniques all have limitations. Part II of this article examines whether the observed differences between these models and techniques produce different exposure-response relationships for predicting prevalence of carpal tunnel syndrome.

KEYWORDS
Job evaluation; job rotation; MSDs; risk classifications; Strain Index; TLV for HAL

Introduction

The Strain Index (SI)[1] and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value for Hand Activity Level (TLV for HAL)[2] are two of the most commonly used index-based models to quantify occupational distal upper extremity (DUE) physical exposures.[3] These models quantify two or more biomechanical stressors (e.g., force, repetition) into a single score that represents the level of physical exposure a worker experiences while performing a task. Several epidemiological studies have shown associations between scores from these models and risk of work-related musculoskeletal disorders (WMSDs).[4–10]

The SI and the TLV for HAL use different constituent variables to determine physical exposure. Therefore, some disagreement in classifying physical exposures is expected.[9,11,12] For example, using the prescribed risk limits of these models, Bao et al.[11] and Speilholz et al.[9] found that the SI consistently identified more jobs as high exposure than the TLV for HAL. The Bao et al.[11] study

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was focused on a comparison of different methods to quantify the SI and TLV for HAL and thus had a limited direct comparison between the scores from these two models. Spielholz et al.[9] directly compared the SI and TLV for HAL scores, but the SI scores were based on subjective ratings for frequency of exertion and duty cycle, which was relevant to their study, but is inconsistent with the recommended approach of using time study data.[1]

Further, the above two studies[9,11] compared physical exposures at the task level, and did not compare differences in the classification of job physical exposure for those workers who perform multi-task jobs, sometimes referred to as job rotation. For these multi-task jobs, prior studies of WMSDs have relied mainly on three different techniques to determine a worker's job physical exposure: (i) Time-Weighted Average (TWA),[13–15] (ii) Typical exposure,[9] and (iii) Peak exposure.[4,13,16] An assessment of exposure classification agreement between the SI and the TLV for HAL, and a comparison of exposure classifications for multi-task jobs, using the three most commonly employed techniques to determine job physical exposure, would likely be beneficial to researchers and practitioners alike.

Thus, the objectives of this study were to examine: (i) differences in exposure classifications between the SI and the ACGIH TLV for HAL; and (ii) differences between the TWA, Typical, and Peak exposure techniques commonly used to determine job physical exposure for workers performing multi-task jobs.

Methods

This study combined physical exposure data of diverse jobs from three large-scale, prospective occupational studies of distal upper limb WMSDs. These studies were approved by the institutional review boards of the University of Wisconsin–Milwaukee, the University of Utah, and the State of Washington. All workers enrolled in these studies provided informed consent. The methods used to enroll workers and quantify physical exposures have been discussed in detail elsewhere.[10,17] The following is a summary of those methods.

Workers were recruited from 35 facilities representing 25 industries in the United States (U.S.) states of Illinois, Utah, Washington, and Wisconsin. Industries included manufacturing of: automotive parts, billboard signs, cabinets, clothing and apparel, commercial lighting, electronics and electric sensors, electric motors, exercise equipment, garage doors, generators, lawn equipment, medical equipment, pharmaceuticals, plastic bags, small engines, and windows, in addition to book printing/binding, warehouse distribution, hospital laundry, and meat and poultry processing.

For these analyses, baseline cross-sectional data were analyzed. Physical exposures were quantified for each task performed by each worker.[17,18] Exposures were collected for both right and left hands separately; however, only dominant hand exposures were considered for these analyses. Force for each sub-task[10,19] was rated by trained ergonomists using the Borg CR–10 scale.[20] Frequency of exertion, duty cycle (% duration of exertion), hand/wrist posture, and speed of work were quantified from video recordings and were later categorized using the Strain Index rating scales.[1] Hand activity level (HAL) was rated using a verbal anchor scale.[2,21] A minimum of three representative production cycles were used for video analyses. For cyclic tasks with cycle time less than 2 min, a minimum of 10 cycles—or, for very short cycle times, a minimum of 5 min of video—were analyzed at random. Force ratings for each exertion performed were used to determine: (i) peak force for TLV for HAL[2] and (ii) overall force for the SI.[1] Only those exertions rated as "very light" or greater (i.e., force rating ≥ 1) on the Borg CR–10 scale were used to determine overall force, frequency, duty cycle, and hand/wrist posture. For this study a given worker performed a single job consisting of one or more tasks, and each task consisted of one or more sub-tasks. Sub-tasks consisted of one or more exertions that had unique levels of force, duration of force, posture, and frequency.[18]

The SI scores for each task were calculated using: (i) overall force, (ii) frequency of exertion, (iii) duty cycle, (iv) hand/wrist posture, (v) speed of work, and (vi) an assumed 8-hr per day of exposure as described by Moore and Garg[1] and Garg et al.[12] The assumption of 8 hr per day of exposure was made to facilitate task-level comparisons with the TLV for HAL which does not explicitly account for hours per day of exposure. SI scores were then classified into low ($SI \leq 3.0$), medium ($3.0 < SI \leq 6.1$), and high ($SI > 6.1$) exposure categories using the recommended limits of Moore et al.[22]

The TLV for HAL scores for each task were calculated using the equation: Score = [Analyst Peak Force Rating on Borg CR–10 Scale/(10 – HAL Rating)].

Subsequently, these scores were classified into the ACGIH TLV for HAL exposure categories of: (i) below Action Limit (AL, score < 0.56), between AL and TLV ($0.56 \leq$ score ≤ 0.78), and above TLV (score > 0.78). These categories were considered "low", "medium", and "high" exposure, respectively.

For the purposes of these analyses, mono-task workers were excluded, leaving only tasks performed by workers with multi-task jobs (i.e., workers performing jobs with two or more tasks). Excluding mono-task jobs—where task level and job level physical exposure are identical—enables a direct, reasonably unbiased comparison of multi-task job physical exposure aggregation techniques.

Table 1. Descriptive statistics for the Strain Index, TLV for HAL, and their constituent variables for N = 3,647 tasks performed by N = 710 workers with multi-task jobs.

Variable	Mean	SD	Min	Max	Median	IQR	N	%
Strain Index – Task Continuous	6.7	9.3	0.3	162.0	4.5	1.5–9.0	3647	—
TLVHAL – Task Continuous	0.57	0.54	0.00	5.00	0.50	0.33–0.67	3647	—
Peak Force[a] Continuous	2.4	1.2	0.0	9.0	2.0	2.0–3.0	3647	—
Overall Force[b] Continuous	1.8	1.1	0.0	9.0	2.0	1.0–2.0	3647	—
HAL[a] Continuous	4.7	1.8	0.0	10.0	5.0	3.0–6.0	3647	—
Frequency (F)[b] Continuous	19.7	18.2	0.0	111.3	14.7	5.4–30.0	3647	—
Duty Cycle (DC)[b] Continuous	46.0	29.0	0.0	100.0	48.6	20.0–73.0	3647	—
SI Posture[b]								
Very Good	—	—	—	—	—	—	1406	38.6
Good	—	—	—	—	—	—	1640	44.9
Fair	—	—	—	—	—	—	489	13.4
Bad	—	—	—	—	—	—	54	1.5
Very Bad	—	—	—	—	—	—	58	1.6
SI Speed[b]								
Very Slow	—	—	—	—	—	—	16	0.4
Slow	—	—	—	—	—	—	891	24.4
Fair	—	—	—	—	—	—	2464	67.6
Fast	—	—	—	—	—	—	272	7.5
Very Fast	—	—	—	—	—	—	4	0.1

[a]Constituent variable of the TLV for HAL, [b]Constituent variable of the SI.

In this regard, task-level exposures were aggregated into job physical exposure using three previously reported techniques: (i) Time-Weighted Average (TWA) exposure from tasks based on actual task hours per day;[13-15] (ii) typical exposure, defined as the task performed for the largest proportion of the work shift;[9] and (iii) peak exposure, defined as the task with the highest (i.e., worst) physical exposure.[4,13,16]

Agreements between the SI and TLV for HAL for low-, medium- and high-exposure were determined at the task level. The residual "disagreement" was further classified as low-medium (TLV for HAL = low and SI = medium or vice-versa), medium-high (TLV for HAL = medium and SI = high or vice versa), and low-high (TLV for HAL = low and SI = high or vice versa). Similarly, proportions of low-, medium and high-exposure agreements between each of the three daily exposure techniques (TWA, Typical, and Peak) were determined for both the SI and the TLV for HAL separately.

Descriptive statistics were calculated for all variables. Spearman's rank correlation coefficient (Spearman's Rho) was used to study correlations between (i) the task-level SI and TLV for HAL scores and (ii) the scores resulting from the TWA, Typical, and Peak multi-task aggregation techniques. Exposure category agreements were compared using Cohen's weighted kappa.[23,24] All statistical analyses were performed using R–64 for Macintosh version 3.3.0.[25]

Results

A total of 2,020 workers participated in this study and 1,885 of those workers had complete job physical exposure data. Of those, 710 (37.7%) workers performed multi-task jobs (i.e., had job rotation) and the remaining 1,175 workers performed only one task for their job (i.e., performed mono-task jobs). The 710 workers with multi-task jobs performed a total of 3,647 tasks, i.e., they rotated to an average of 5.1 tasks/worker (median = 4, range: 2–12) during their work day, with a large majority (81%) rotating to between two and six tasks per day.

Description of constituent variables, SI and TLV for HAL Scores, and exposure classifications

A summary of the SI and TLV for HAL variable distributions at the task-level are provided in Table 1. Physical exposures (SI and TLV scores) ranged from very low to very high; however, most individual tasks exposed workers to relatively low force (median peak force rating = 2.0), moderate repetition (median HAL = 5, median exertions/min = 15), and good to very good hand/wrist posture (83.5% tasks). The median duty cycle was 49%. As a result, large percentages of tasks were classified as "low-exposure" using the SI and the TLV for HAL models (44% and 64% of tasks, respectively, Table 3).

Descriptive statistics for job-level SI and TLV for HAL scores, after applying each of the three techniques used for aggregating multiple tasks into job physical exposure (i.e., after accounting for job rotation), are summarized in Table 2. The TWA exposure technique resulted in the lowest SI and TLV for HAL scores and most closely resembled the distributions of task-level SI and TLV for HAL scores. The Typical and Peak exposure techniques resulted in

Table 2. Descriptive statistics for TWA, Typical, and Peak Strain Index, and TLV for HAL for N = 710 multi-task jobs.

Variable	Mean	SD	Min	Max	Median	IQR
Strain Index – TWA[a] Continuous	6.0	6.9	0.3	68.3	3.8	1.7–7.5
Strain Index – TYP[b] Continuous	10.4	12.4	0.3	117.0	6.0	2.3–13.5
Strain Index – PK[c] Continuous	11.7	12.7	0.3	117.0	6.8	3.0–18.0
TLVHAL – TWA[a] Continuous	0.49	0.35	0.00	5.00	0.41	0.40–0.80
TLVHAL – Typ[b] Continuous	0.77	0.66	0.00	5.00	0.60	0.28–0.63
TLVHAL – Pk[c] Continuous	0.84	0.73	0.00	5.00	0.60	0.40–0.83

[a]Time-Weighted-Average exposure of tasks performed by N = 710 workers; [b] Typical (i.e., longest duration per day) exposure of tasks performed by N = 710 workers, assumes the typical task is performed for an 8-hr day regardless of actual task duration; [c] Peak (i.e., highest exposure task) exposure of tasks performed by N = 710 workers, assumes the peak task is performed for an 8-hr day regardless of actual task duration.

median SI and TLV for HAL scores that were between 46% and 79% higher than the corresponding TWA score (Table 2).

Both at the task-level (N = 3,647) and job-level (N = 710), and regardless of the technique used to assign job physical exposure from multi-task jobs (i.e., TWA, Typical, and Peak), the TLV for HAL model classified a greater percentage of jobs as low-exposure than did the SI (Table 3). Conversely, the SI classified more jobs as high-exposure than did the TLV for HAL (Table 3). The SI consistently showed about one in five jobs as medium risk, whereas for the TLV, medium risk classification ranged from about one in eight jobs for the TWA technique to more than one in four jobs for the Peak technique. Overall, the three job-level aggregation techniques did not show a consistent trend between the SI and TLV for HAL for classification of tasks as medium-exposure (Table 3).

At the job-level, the TWA aggregation technique classified more jobs in the low-exposure category and fewer jobs in the high-exposure category, as compared to the Typical and Peak exposure techniques (Table 3). Among the three techniques, the Peak exposure technique had the lowest percentage of jobs in the low-exposure category and the highest percentage of jobs in the high-exposure category for both the SI and the TLV for HAL models (Table 3). The exposure classification differences between Peak and Typical exposure techniques were much smaller (Table 3).

Between model differences in risk classifications at the task- and job-level

Task-level exposure classification agreement between the SI and TLV for HAL was fair (kappa = 0.28). The two models agreed in exposure classification for slightly less than half of the tasks (48.5%) (Table 4). Most of the task-level disagreement was between low- and medium-exposure classifications (48.2% of disagreement, 24.8% of total classifications) or medium- and high-exposure classifications (21.7% of disagreement, 11.2% of total classifications). The remaining disagreement (30.1%, 15.5% of total classifications) was between low- and high-exposure categories (Table 4). Where disagreements occurred, the TLV for HAL provided the lower of the two exposure estimates for 73.4%, 60.0%, and 77.3% of the low-medium, medium-high, and low-high disagreements, respectively.

Figure 1 reveals that point estimates of exposure (i.e., scores) from the two models tended to vary widely (Spearman's Rho = 0.50, Table 4), and the exposure category disagreement between the two models would not be substantially resolved simply by adjusting the categorization cut points for one or both models.

At the job-level, exposure-classification agreement between the SI and TLV for HAL reached a consistent albeit modest majority (total agreement ≥ 56%, Table 4). The exposure-classification agreement between the SI and TLV for HAL remained generally fair for all three

Table 3. Risk category distributions for the SI and TLV for HAL at the task-level, and job-level using TWA, Typical, and Peak daily exposure aggregation techniques.

	Task-Level Exposure *N = 3647 tasks*	TWA Exposure *N = 710 workers*	Typical Exposure *N = 710 workers*	Peak Exposure *N = 710 workers*
Strain Index				
Low	44.0%	42.5%	32.8%	27.5%
Medium	28.7%	21.0%	22.0%	22.1%
High	27.3%	36.5%	45.2%	50.4%
TLVHAL				
Low	64.1%	71.0%	45.5%	41.8%
Medium	19.3%	12.7%	26.3%	27.2%
High	16.6%	16.3%	28.2%	31.0%

Table 4. Summary of risk category agreement and disagreement between the SI and the TLV for HAL at the task-level, and for the TWA, Typical, and Peak daily physical exposure aggregation techniques.

	Task-Level Exposures[a] N = 3647 Tasks	TWA Exposures[b] N = 710 workers	Typical Exposures[b] N = 710 workers	Peak Exposures[b] N = 710 workers
Strain Index vs. TLVHAL				
Spearman's Rho	0.502	0.694	0.635	0.553
Weighted Kappa	0.280	0.370	0.350	0.282
Total Agreement	48.5%	57.0%	57.5%	56.1%
Low-Low Agreement	33.9%	40.8%	25.9%	20.8%
Medium-Medium Agreement	6.0%	3.4%	8.9%	9.4%
High-High Agreement	8.6%	12.8%	22.7%	25.9%
Total Disagreement	51.5%	43.0%	42.5%	43.9%
Low-Medium Disagreement	24.8%	15.8%	14.5%	14.2%
Medium-High Disagreement	11.2%	11.1%	16.1%	16.3%
Low-High Disagreement	15.5%	16.1%	11.9%	13.4%

techniques (kappa = 0.28–0.37). Low-high disagreement remained large regardless of technique (i.e., ≥ 28%, and ≥ 11.9% of total classifications). The TWA technique yielded a modest increase in correlation between the SI and TLV for HAL (Spearman's Rho = 0.69) as compared to the task-level correlation (Spearman's Rho = 0.50) (Table 4).

Between daily physical exposure aggregation technique differences in risk classifications

The three, daily physical exposure aggregation techniques showed high between-technique correlations (Spearman's Rho ≥ 0.85). Between-technique exposure-classification agreement was good when the techniques were applied

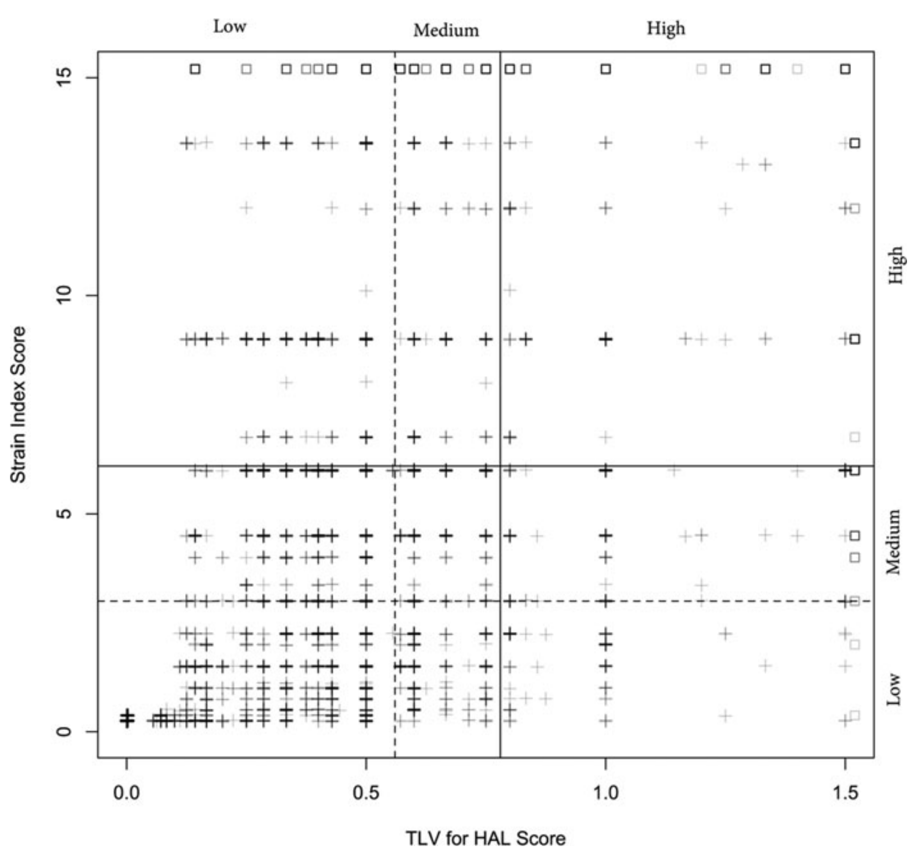

Figure 1. Scatter plot[a] of task-level SI and TLV for HAL scores. ([a] X and Y axes are truncated for clarity. Exposures that occurred outside the limits of the axes are represented by square symbols along the axes' upper limits. Darker and lighter markers reflect a relatively higher or lower concentration of data, respectively. Dashed vertical and horizontal lines reflect the low-exposure cut-points for the TLV for HAL and the SI.)

Table 5. Summary of risk category agreement and disagreement for the TWA, Typical, and Peak daily physical exposure aggregation techniques (N = 710 workers).

	TWA vs. Typical Exposures	TWA vs. Peak Exposures	Typical vs. Peak Exposures
Strain Index			
Spearman's Rho	0.901	0.916	0.851
Weighted Kappa	0.800	0.780	0.880
Total Agreement	*75.6%*	*74.0%*	*93.3%*
Low-Low Agreement	30.7%	27.5%	27.5%
Medium-Medium Agreement	10.4%	10.0%	20.6%
High-High Agreement	34.5%	36.5%	45.2%
Total Disagreement	*24.4%*	*26.0%*	*6.7%*
Low-Medium Disagreement	11.6%	12.1%	1.5%
Medium-High Disagreement	10.4%	11.0%	1.4%
Low-High Disagreement	2.4%	2.9%	3.8%
TLVHAL			
Spearman's Rho	0.873	0.919	0.934
Weighted Kappa	0.190	0.160	0.920
Total Agreement	*61.2%*	*60.5%*	*95.2%*
Low-Low Agreement	43.8%	41.8%	41.8%
Medium-Medium Agreement	3.0%	2.4%	25.2%
High-High Agreement	14.4%	16.3%	28.2%
Total Disagreement	*38.8%*	*39.5%*	*4.8%*
Low-Medium Disagreement	23.1%	24.8%	2.0%
Medium-High Disagreement	9.9%	10.3%	1.1%
Low-High Disagreement	5.8%	4.4%	1.7%

to the SI scores (kappa ≥ 0.78), but agreement tended to be poor when the techniques were applied to the TLV for HAL scores (kappa ≥ 0.16) (Table 5). The worst agreement was observed for Peak vs. TWA and Typical vs. TWA TLV for HAL scores (kappa = 0.16, and 0.19, respectively) (Table 5).

In terms of absolute exposure-classifications agreement, the Peak and Typical exposure techniques differed from TWA technique exposure classifications for about 25% of jobs using the SI model and 40% of jobs using the TLV for HAL model (Table 5). For the SI model, most of the disagreement between TWA and Peak, and TWA and Typical exposures was between low-medium and medium-high classifications (Table 5). For TLV for HAL, between-technique disagreement was mostly confined to differences in low-medium exposure classifications (Table 5). Low-high disagreement was less than 6% of all exposure classifications, regardless of technique and model used to quantify exposure.

Discussion

This large-scale study showed that the SI and TLV for HAL differ in exposure classification for more than half (51.5%) of the tasks studied. Similarly, the TWA, Peak, and Typical techniques to quantify physical exposure from multi-task jobs (i.e., job rotation) showed large between-technique variations in exposure categorization, particularly for the TLV for HAL model.

Exposure-classification disagreement

Consistent with the prior studies of Bao et al.[11] and Spielholz et al.[9] we found that the TLV for HAL tends to classify a much higher proportion of tasks as low-exposure than does the SI. This persistent finding is interesting given that the TLV for HAL penalizes based on peak force, whereas the SI considers overall force (which is often well below the peak force). In general, use of peak measures would be expected to inflate, or overestimate the summary exposure measure. However, within the TLV for HAL construct this overestimation does not appear to be occurring. One possible explanation is that the Action Limit (AL) for the TLV for HAL model is too high and is thus artificially over-classifying tasks as low-exposure. This concern has been raised in a few recent epidemiological studies.[4,7,26] These studies reported that the workers with exposures above the AL, but below the TLV, were at arguably too high a risk for CTS. Lowering the AL in the TLV for HAL model would reduce the proportion of tasks classified as low-exposure by shifting them to medium-exposure.

Although a reduction in the AL would likely resolve the potential problem of classifying too large a proportion of tasks as low-exposure, it would not address the relatively low proportion of tasks classified as high-exposure by the TLV for HAL. Increasing the high-risk proportion would require a lowering of the threshold limit value (TLV) which would move a portion of tasks classified as medium-exposure into the high-exposure category. However, it is unclear whether lowering the AL and TLV would produce superior exposure-response relationships between the TLV for HAL and WMSDs, especially given that some studies have reported a marked increase in risk of WMSDs to workers exposed to high-risk jobs as defined by the current TLV.[4,7,12,26–28]

Even if alternative AL and TLV thresholds were implemented, and proportions of low-, medium-, and high-exposure classifications between the SI and the TLV for HAL were made comparable (Table 3), the actual between-model agreement in risk classification for a given task would remain somewhat poor (Figure 1). The TLV for HAL is a simple two-variable model (peak force and HAL rating). Conversely, the SI is a somewhat complex, six-variable model (overall force, frequency of exertion, duty cycle, hand/wrist posture, speed of work, and hours per day of exposure). Thus, while the models share the same physical exposure domains of force and repetition, they do not share any constituent variables between them. Different variables will necessarily lead to different estimates of exposure. Because of these differences, it would take slightly longer time to complete a job assessment using the Strain Index method compared to the ACGIH TLV for HAL, although both methods are observation-based and, in general, relatively inexpensive to apply.

A further complication is that many modern tasks are complex (e.g., have widely varying levels of force being applied with diverse durations and frequencies of exertion), and this was reflected in the data used for this study. Measuring these complex task exposures is challenging and neither of the two models adequately address evaluation of these complex tasks.[18] The use of overall force in the SI model only partially addresses exposure from complex tasks and relies on analyst judgment. Thus, given the measurement difficulties and the fundamental differences in model constructs, some amount of differential exposure-classifications is seemingly unavoidable, and it is unclear if one model provides a better characterization of distal upper limb physical exposure than the other.

The few studies that have simultaneously evaluated associations between WMSDs and physical exposure quantified by the SI and the TLV for HAL, have reported broadly similar exposure-response relationships for the two models.[12,27,28] Given the large differences in exposure classifications between them (Table 4), it is plausible that the TLV for HAL and the SI are each quantifying different types of exposures or different aspects of the risks posed by a given task. If this is the case, then perhaps the two models could be somehow combined to create a superior assessment tool, or the combined results of the two models could be used to better classify task exposure.

Regardless, given a sufficient sample size the disagreements in exposure classifications from these two models—as they are currently designed—might be acceptable for epidemiological studies. However, a much more common use of these models is by practitioners (e.g., ergonomists, manufacturing engineers, health professionals) who often need to determine the risk of WMSDS from a single task, or the job of a single worker. A practitioner may arrive at different conclusions depending upon the model selected to evaluate the task's risk and this could have a profound impact on injuries to workers and/or resources spent by employers to manage risk and prevent WMSDs.

A more detailed, and robust job analysis method, that can more accurately and reliably quantify physical exposures, would be useful for job design and intervention. While models such as the Revised Strain Index (RSI)[29,30] show promise in this area, until such models are developed and proven, perhaps a reasonable approach for practitioners would be to use the TLV for HAL for large-scale surveillance—taking advantage of its simplicity and the speed of expert rating its variables—and the SI or RSI for job design and intervention, where detailed but often time-consuming, time-study-based analyses are more easily justified.

Quantifying physical exposure to workers with multi-task jobs

The results of this study show that the choice of technique (TWA, Typical, and Peak exposure) used to quantify physical exposure from multi-task jobs will have a profound effect in classifying risk posed to workers. The difference between the three techniques is most apparent when using the TLV for HAL, where TWA showed poor exposure classification agreement with both the Typical and Peak techniques (Table 5). The TWA technique creates a dubious mathematical equivalency between the biomechanical exposures of a task and the duration that the task is performed.[30] Thus, the TWA technique's averaging process may systematically dilute overall exposure.[30–32] Conversely, the Peak technique likely overestimates physical exposure unless the "peak" task is performed for a majority of the work day. The Typical exposure technique might accurately represent true exposure, or it might over or under estimate physical exposure depending on which tasks are ignored. Thus, the ability of any of these techniques to adequately characterize physical exposure from multi-task jobs is uncertain, and given each technique's shortcomings and the sometimes very poor between-technique exposure classification agreement (Table 5), we suspect that none of them adequately quantify physical exposure to workers performing multi-task jobs.

From a job design perspective, practitioners tend to design work at the task level alone, perhaps due to a lack of robust multi-task job physical exposure quantification techniques. This study suggests that those task level risk assessments might mislead the analyst regarding the true risk posed to workers with multi-task jobs. Accurately characterizing job physical exposure for workers with multi-task jobs remains an important problem to be addressed. Further studies of the effects of multi-task exposures are needed so that a more sophisticated and reliable technique to quantify risk from job physical exposure can be developed.

Limitations

Raw data for this study were collected independently over many years at three different research sites and then merged for these analyses. Some original analysts were no longer available at the time data were merged and thus we were unable to quantify inter-rater reliability between study sites. However, all three sites used very similar and rigorous protocols to collect and analyze their raw data. Further, both the SI and TLV for HAL have shown good inter-rater reliability, particularly when used by trained analysts, as was the case for these studies.[9,33] Nevertheless, it is possible that inter-rater differences may have caused exposure misclassifications, and these may account for some of the observed differences between the SI and the TLV for HAL.

Exertions below a force rating of 1 on the Borg CR–10 scale were not included when calculating SI scores. Had these low-intensity exertions been included, both the frequency of exertion and percent duration of exertion SI multipliers would have increased for certain tasks. These multiplier increases would have resulted in relatively higher SI scores and changed some exposure classifications, perhaps resulting in greater disagreement between the two models. Recently, developed algorithms to quantify HAL from quantified frequency and duty cycle[34] might also systematically change exposure classifications. However, quantifying HAL from time-study would also require more assessment time and resources, perhaps reducing the model's utility in industry as a surveillance tool. For task-level score calculations, we assumed that all tasks were performed for 8-hours per day regardless of their true duration. This assumption had no effect on TLV for HAL scores as hours per day of exposure is not a part of the model. However, including hours per day would increase variation in SI scores and thus could alter between model disagreement as well.

Further studies of the SI and TLV for HAL are needed to understand the effects of the above model classification decisions and to provide guidance for consistent application of these models in practice. In Part II,[35] we compare how well the SI and TLV for HAL, and the three multi-task exposure techniques (TWA, Typical, and Peak) predict prevalence of CTS among workers with and without job rotation. This comparison provides further insight into the utility of these widely-used models and techniques.

Conclusions

At the task level, the SI and TLV for HAL differed in exposure classification for 51.5% of tasks. This disagreement creates uncertainty for job design, job analysis, risk assessments, and developing intervention strategies. Similarly, large disagreement was observed between commonly used techniques (TWA, Typical, Peak) to quantify job physical exposure for workers performing multi-task jobs. None of these techniques appear to be satisfactory, especially in the context of job design and/or intervention. In particular, the TWA technique appears to systematically underestimate job physical exposure as compared to the Typical and Peak techniques. However, both the Typical and Peak techniques ignore exposures from all but one task performed during a work shift. An approach that integrates exposures from all tasks performed by a worker performing a multi-task job is needed for both research and industry use.

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