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Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders – Part II: comparison of different methods of measuring force level and repetitiveness

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This paper focuses on comparisons between the different methods of assessing repetitive hand activities. Various methods were used to measure hand force and repetitiveness of hand activities on 733 subjects in the study described by Bao *et al.* (2006). Two definitions of repetitiveness were used in analysis of detailed time studies of repetitive hand activities and four parameters of the American Conference of Governmental Industrial Hygienists (ACGIH) hand activity level (HAL) and the Strain Index methods were estimated by ergonomists and used to quantify repetitiveness. Hand forces were measured or estimated using three different methods: 1) measured with a force gauge or mimicked on a force gauge (force matching); 2) estimated by ergonomists using rating scales; 3) self-reports by subjects. The jobs were also evaluated using the ACGIH HAL and Strain Index methods when different repetitiveness quantification methods were used. Results showed that different definitions of repetitive exertion might lead to measuring different physical exposure phenomena and produce very different results. There were poor correlations between the measures of repetitiveness estimated by the different methods. Correlations between force quantifications using different methods were also poor. This suggests that parameters measured by different methods might not be interchangeable. Both the ACGIH HAL and Strain Index methods identified more 'hazardous' jobs when repetitiveness was estimated by ergonomists than when it was calculated by detailed time studies of forceful hand exertions. The Strain Index method identified more 'hazardous' jobs than the ACGIH HAL method. Overall, the between-methods agreements were found to be moderate to substantial.

Keywords: Exposure quantification; Repetition; Inter-method comparison; Hand force; Job evaluation

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1. Introduction

Researchers from the Washington State Department of Labor and Industries conducted a large prospective epidemiological study on work-related upper extremity musculoskeletal disorders (UEMSDs). The overall objective of this study was to assess the incidence and persistence of UEMSDs as a function of an individual characteristics, physical load and psychosocial factors. Hand activities were quantified in two dimensions, force level and repetitiveness & hand activities. Each of the dimensions was measured in several different methods. Results of between-exposure group and within-exposure group variations have been presented and discussed in Bao *et al.* (2006). The present paper addresses issues related to comparisons between the different measurement methods.

Various definitions and measurement methods have been used by different researchers to quantify force levels and repetitiveness of hand activities. For instance, hand force has been measured by taking measures of object weights (Stetson *et al.* 1993), mimicked by workers using a hand dynamometer (Casey *et al.* 2002), observed by experienced ergonomists (Moore and Garg 1995), self-reported by workers or measured by electromyography on the forearm muscles (American Conference of Governmental Industrial Hygienists 2001). Repetitiveness of hand activities has been quantified by the measurement of frequency of hand and wrist movements or frequency of hand forceful exertions (Stetson *et al.* 1991). The measurements were sometimes obtained by time–motion studies completed by viewing recorded task performances, and sometimes estimated by experienced ergonomists on-site or from video records.

Several widely used repetitive hand activity exposure evaluation criteria, such as the American Conference of Governmental Industrial Hygienists (ACGIH) hand activity level (HAL) (American Conference of Governmental Industrial Hygienists 2001) and the Strain Index (SI) (Moore and Garg 1995), have suggested the use of different measurement methods to collect data for job evaluations and that data collected from the different measurement methods are interchangeable. For instance, the amplitude of force for the ACGIH HAL can be determined by worker ratings using visual analogue scales, such as the Borg (1982) scales, observer ratings using visual analogue scales, biomechanical calculations based on force requirements of job performance and the coefficient of friction between the object surface and skin, force gauges to measure force directly in certain cases, and forearm muscle activities quantified by electromyography (American Conference of Governmental Industrial Hygienists 1999). The SI method (Moore and Garg 1995) suggests estimating force level (intensity of exertion) using rating scales with verbal descriptors, measuring external force and normalizing the data based on maximal strength data and using the Borg (1982) Scale.

The level of hand activity in the ACGIH HAL method is related to exertion frequency and duty cycle. It could be estimated with ratings by a trained observer using a visual scale or determined based on detailed time studies that calculate frequency of exertion and duty cycle (Latko *et al.* 1997, American Conference of Governmental Industrial Hygienists 2001). In the SI method, repetitiveness is quantified through three components: duration of exertion (DE) – the average length an exertion is maintained; efforts per min (EM) – the frequency of exertion; and speed of work (SW) – the perceived pace of the task. DE and EM are obtained through time studies, by calculation from measurements of the duration of all exertions during an observation period and by counting the number of exertions that occur during the observation period respectively. These two measures correspond to the frequency and duty cycle of the level of hand activity in the ACGIH HAL method. The SW can be obtained by using rating scales with verbal descriptors or using pre-determined time-measurement systems such as MTM-1 (Moore and Garg 1995). Validity of such interchangeability has not been well studied.

The authors of ACGIH HAL and the SI recognized that the different measurement methods have different levels of precision. The various specified measurement methods for collecting the different parameters allow practitioners and researchers to have a common framework for comparing results and identifying 'hazardous' jobs.

The present paper focuses on comparisons between the measures for each of the two parameters (force level and repetitiveness of hand activities) quantified by different methods. The specific aims of this paper are: (1) to compare two different definitions of repetitiveness for repetitive hand activities analysed by detailed time studies; (2) to study relationships between ergonomist's estimates of the HAL and the SI repetitiveness parameters and repetitiveness obtained from the detailed time studies; (3) to study relationships of force quantifications using three different methods: self-report of a worker; estimation of an ergonomist; and direct measurement with an instrument; (4) to compare job evaluation results using the different measurement methods based on the ACGIH HAL threshold limit values (TLV) and the SI methods.

2. Method

Exposure data from 733 subjects on force level and repetitiveness of hand activities were used in the analyses. Detailed background information on the subjects can be found in the companion paper (Bao *et al.* 2006). Exposure data used for the analyses included measurements of force level and repetitiveness of hand activities. Details regarding the data collection and analysis procedures can also be found in the companion paper. Following is a summary of the parameters used in the present analysis.

Force levels of lifting, push/pull, pinch gripping and power gripping were collected on-site in three different ways: direct measurement, subjective estimates by ergonomists, and self-reporting by the subjects. Measured lifting and push/pull forces were obtained by using force gauges. Measured pinch gripping and power gripping forces were acquired by having subjects replicate the forces used in task performance on a hand dynamometer (Bao and Silverstein 2005). The ergonomists estimated force levels using rating scales as recommended by the ACGIH method (American Conference of Governmental Industrial Hygienists 1999). The direct measurements and ergonomists' estimates were collected for all four force types. Subjects' self-reported forces were only applicable to pinch and power gripping and the Borg (1982) 10-point scales were used for this measurement. All forces were collected at task level and then computed to the job level using task distribution information (number of tasks in an individual's job and hours spent on the different tasks). The task distribution information was obtained through interviews of either supervisors or employees.

Two definitions of repetitive hand activity were investigated in the analysis: one based on forceful hand exertion and the other based on repetitive hand muscle activity (hereafter referred to as 'repetitive muscle activity').

The forceful hand exertion definition was similar to that defined by Stetson *et al.* (1991), where hand forceful exertion was taken to be a conspicuous application of force by the hand and included using the hand to hold, manipulate, trigger, push, pull or otherwise handle an object. A subjective determination, by ergonomists, of whether the forces should be considered as a conspicuous application of force was performed based on conceptually defined operational criteria: a lifting force or a pinch grip force ≥ 8.9 N, and a push/pull or power grip force ≥ 44.5 N.

The repetitive muscle activity included all hand muscle activities. In this definition all 'required' hand and forearm muscle efforts were considered as hand exertion activities, regardless of the force required. For example, moving a piece of paper from one location to another would count as a hand exertion activity. 'Required' efforts were defined as any action that was required by the job rather than the personal preference of the worker. A worker holding a piece of paper and talking to a co-worker would not be considered a hand exertion activity when the piece of paper had no relation to the communication.

A detailed time study was conducted for both forceful hand exertion and repetitive muscle activity analyses using the time-study program Multi-Video Task Analysis (Yen and Radwin 1995). Percentage time (%) or duty cycle and frequency of each type of forceful hand exertion were computed. The frequency of the forceful hand exertion was calculated by considering the occurrences of all the different forceful hand exertions. The activities were considered mutually exclusive, so that only one force was counted when multiple forces occurred at the same time. Both duty cycle and frequency of exertion were initially obtained at task level. Using task distribution information, both parameters were computed at the individual's job level by using a time-weighted averaging method.

Repetitiveness of hand activity was also subjectively estimated by ergonomists using rating scales with verbal anchors during the site visits. Parameters collected included HAL (American Conference of Governmental Industrial Hygienists 2001) and three parameters from the SI (Moore and Garg 1995): DE (% of cycle, EM and SW). All subjective estimates were made at the task level and then, based on the task distribution information of the jobs, time-weighted to obtain corresponding parameters at the individual's job level.

Using the data obtained by the different measurement methods, the jobs were evaluated by modified ACGIH HAL TLV (American Conference of Governmental Industrial Hygienists 2001) and modified SI (Moore and Garg 1995). All evaluations were conducted at the individual's job level using the time-weighted average approach. To simplify the comparison, only evaluation results using ergonomist's estimated forces are presented in this paper. When different types of forces occurred at the same time, the highest force was used for the job evaluation.

To facilitate the comparisons between the different methods, data were grouped based on six different exposure categories. The exposure categorization was subjectively determined by an ergonomist through observations of hand force (low and high) and repetition (low, medium and high) at the work sites. No detailed measurements were used for the exposure categorization. Further details regarding the job exposure categorization can be found in the companion paper (Bao *et al.* 2006).

2.1. *Statistical analysis*

Descriptive statistics were calculated for the frequency and duty cycle of both forceful hand exertion and repetitive muscle activity in order to compare their distributions across the different exposure categories. One-way ANOVA was used to test differences between the frequencies and duty cycles of repetitiveness measures of the different exposure categories. Duncan's multiple-range test was used for the post-hoc comparisons between the different exposure categories.

Correlation analyses between frequency and duty cycle of forceful hand exertion and between frequency and duty cycle of repetitive muscle activity were performed for the right and left hand respectively. Spearman rank-order correlation coefficients were computed.

Correlation analyses were also performed between frequencies of forceful hand exertion and repetitive muscle activity analyses, and between duty cycles of the two analyses. Correlation analyses between the frequencies of the two detailed analyses and the ergonomist's estimates (HAL, EM and SW) were also performed.

Comparisons between the three force amplitude quantification methods were also performed using the Spearman rank-order correlation coefficients.

Agreement analyses were performed between the ACGIH HAL evaluations using the ergonomist's estimated parameters and the calculated parameters of the detailed forceful hand exertion analysis. Similar analyses were also made for the jobs evaluated using the SI method. Comparison between job evaluations using the ACGIH HAL method and the SI method was also performed. Percentage of agreement and weighted kappa statistics were calculated. The weights are given by the formula: $1 - |i - j|/2$, where i and j are the indices of the rows and columns of the different methods.

All statistical analyses were performed using the SAS program (version 9; SAS Institute, Cary, NC, USA) except the agreement analysis using kappa statistics, which was performed using the STATA program (version 8.2; Stata Corp, College Station, TX, USA).

3. Results

3.1. *Comparisons between the two different repetitiveness definitions*

Figure 1(a) shows the frequencies of the two different repetitive hand activity definitions, and figure 1(b) shows the duty cycles of the two definitions. Only right hand data are shown in the figures. Similar patterns were obtained for the left hand.

Higher frequencies of both forceful hand exertion and repetitive muscle activity were found to be associated with the higher repetition exposure categories ($p < 0.05$, figure 1(a)). Higher frequencies of forceful hand exertion were also related to the high force job exposure category ($p < 0.05$; figure 1(a)). However, this relationship was not statistically significant for the repetitive muscle activity analysis ($p > 0.05$; figure 1(a)). Higher duty cycles of forceful hand exertion were related to higher repetition exposure categories ($p < 0.05$; figure 1(b)) and to the high force job exposure category ($p < 0.05$; figure 1(b)). However, no such patterns were found between duty cycles of repetitive muscle activity and the exposure categories ($p > 0.05$; figure 1(b)).

A high frequency of forceful hand exertions appears to be correlated with higher duty cycles (Spearman rank-order correlation coefficients = 0.84 and 0.91 for right and left hand, respectively). No such relationship was found between the frequency and duty cycle of the repetitive muscle activity analysis (Spearman rank-order correlation coefficients = −0.27 and −0.01 for right and left hand, respectively).

Comparisons between the frequency and duty cycle of forceful hand exertion and repetitive muscle activity analyses showed that repetitive muscle activity had significantly higher values than those for forceful hand exertion (figure 1(a, b), $p < 0.05$). Correlation analyses showed that frequencies from the two different hand activity analyses appeared to be only slightly correlated (Spearman rank-order correlation coefficients = 0.20 and 0.36 for the right and left hand, respectively). No such correlation was found for the duty cycles between the two different analyses (Spearman rank-order correlation coefficients = 0.16 and 0.05 for the right and left hand, respectively).

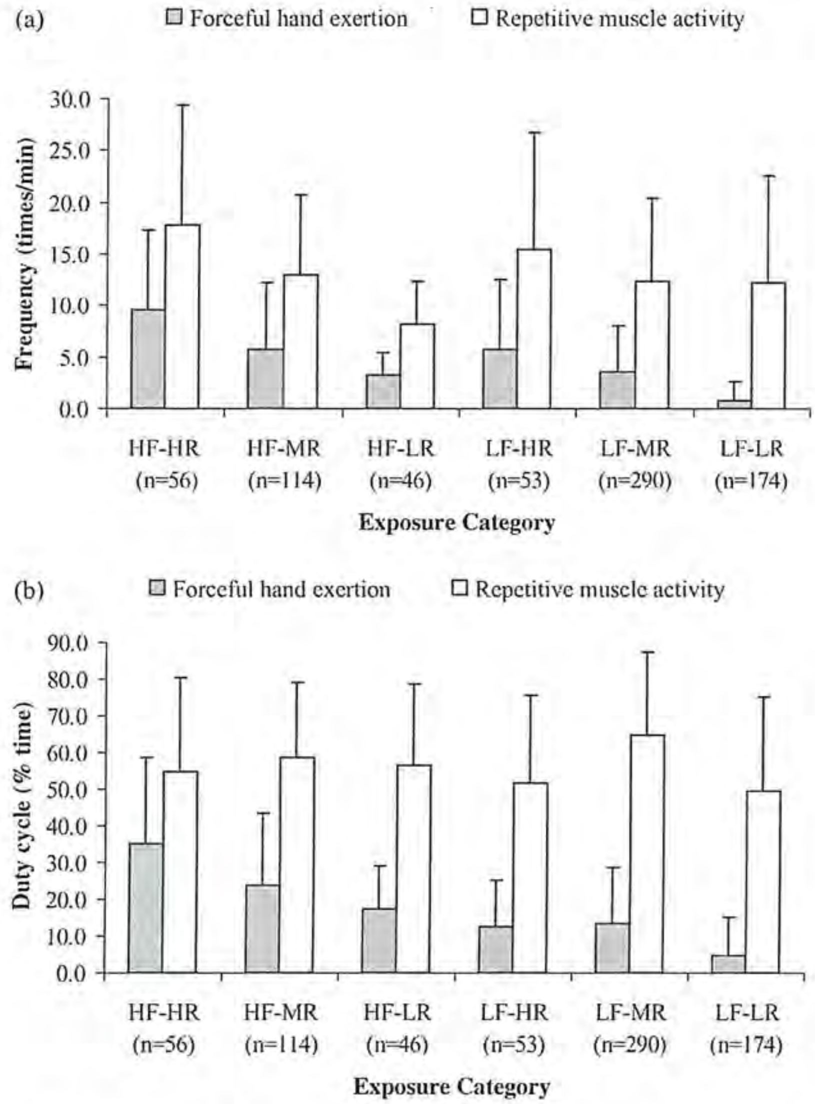

Figure 1. Comparisons by job exposure category between the two definitions used to quantify repetitive hand activities (right hand data only). a) Frequency in times/min; b) duty cycle in % time. HF = high force; HR = high repetition; MR = medium repetition; LR = low repetition; LF = low force.

3.2. *Comparisons between different repetition estimates*

The ergonomist's estimated measures (HAL and the three SI parameters) appear to have distribution patterns similar to the frequencies of forceful hand exertions and repetitive muscle activity; that is, higher values for high repetition exposure categories and high force exposure categories.

The correlation coefficients between frequency of forceful hand exertion, frequency of repetitive muscle activity, HAL, EM and SW are presented in table 1. The ergonomist's estimated parameters were only somewhat correlated with the frequencies obtained from the detailed time study results based on the two different repetitive hand activity definitions. Correlations between the ergonomist's estimated parameters (HAL, EM and SW) were relatively stronger than those between the ergonomist's estimates and the frequencies obtained from detailed time studies.

3.3. *Comparisons of different force measurement approaches*

Table 2 shows the correlations between the forces quantified by the three different methods. Some correlation was found between measured forces and the ergonomist's force level estimates for lifting and push/pull forces. Correlations between the measured forces, the ergonomist's force level estimates and the subject's self-reported force levels of the pinch grip and power grip forces were lower than those for lifting and push/pull forces.

3.4. *Job evaluations using the American Conference of Governmental Industrial Hygienists hand activity level and Strain Index methods*

Table 3 shows the comparison of the evaluation results using the ACGIH HAL criteria when two different methods were used to quantify the HAL. Three risk levels are used in

Table 1. Spearman rank-order correlation coefficients (for right hand) between frequency of forceful hand exertion (Freq1), frequency of repetitive muscle activity (Freq2), hand activity level (HAL), efforts per min (EM) and speed of work (SW).

	Freq1	Freq2	HAL	EM	SW
Freq1	1.00	0.20	0.32	0.12	0.33
Freq2		1.00	0.22	0.24	0.28
HAL			1.00	0.61	0.62
EM				1.00	0.46
SW					1.00

$p < 0.0001$ for all comparisons, n = 733.

Table 2. Spearman rank-order correlation coefficients between directly measured forces, ergonomist's estimated force levels and subject's self-reported force levels (Borg 10-point scale rating of perceived exertion (RPE)).

Lifting (n = 877)	Directly measured	Estimated		Push/pull (n = 210)	Directly measured	Estimated	
Directly measured	1.00	0.75		Directly measured	1.00	0.61	
Estimated		1.00		Estimated		1.00	
Pinch Grip (n = 402)	**Directly measured**	**Estimated**	**Self-report RPE**	**Power Grip (n = 322)**	**Directly measured**	**Estimated**	**Self-report RPE**
Directly measured	1.00	0.40	0.36	Directly measured	1.0	0.30	0.36
Estimated		1.00	0.44	Estimated		1.0	0.44
RPE			1.00	RPE			1.00

$p < 0.0001$ for all comparisons, n = number of measurements.

the ACGIH HAL method (from low to high): Safe (minimal risk, with workers working below this level generally considered safe); Action limit (increased risk, general controls recommended); and TLV (high risk level, when negative health effect may develop). The results show that more jobs were characterized as above the TLV when the HAL was estimated by ergonomists (144 jobs or 20.6%) than from the time study results of forceful hand exertions (62 jobs or 8.9%). The agreement between using these two methods was 88.9% with a weighted kappa statistic of 0.65.

It should be noted that, due to the fact that the ACGIH HAL method did not provide complete data for the HAL conversion based on exertion frequency and duty cycle (at low exertion frequency and high duty cycle or high exertion frequency and low duty cycle), the evaluation results were categorized as missing data in those situations (affecting 35 jobs of the 733 jobs or 4.8%, for right hand only).

Similar results were found when using the SI method to evaluate the jobs (table 4). More jobs were classified as hazardous when the EM and DE parameters were estimated by ergonomists (Method 1: 277 jobs or 37.8%) compared to those calculated from time studies of forceful hand exertions (Method 2: 115 jobs or 15.7%). The agreement between the results using these two methods to calculate the SI was 73.0% with a weighted kappa statistic of 0.54.

Table 5 shows the comparison between job evaluation results using the ACGIH HAL and the SI methods. The 'hazardous' risk level in the SI method is equivalent to the 'above the TLV' risk level in the ACGIH HAL method. Ergonomist's estimated HAL and DE (exertion duty cycle) and EM (frequency of exertion) were used in the calculations. The SI identified more hazardous jobs (277 jobs or 37.8%) than the ACGIH

Table 3. Distribution of American Conference of Governmental Industrial Hygienists (2001) hand activity level job evaluations using repetitiveness information from ergonomist's estimates (method 1) and detailed time study results (method 2), showing number of jobs and % of total in each category.*

		Method 2		
		Safe	Action Limit	TLV
Method 1	Safe	472 (67.6%)	1 (0.1%)	0 (0.0%)
	Action Limit	64 (9.2%)	16 (2.3%)	1 (0.1%)
	TLV	20 (2.9%)	63 (9.0%)	61 (8.7%)

*Right hand data only, n = 698. TLV = threshold limit value.

Table 4. Distribution of the Strain Index job evaluations using repetitiveness information from ergonomist's estimates (method 1) and detailed time study results (method 2), showing number of jobs and % of total in each category.*

		Method 2		
		Safe	Action	Hazardous
Method 1	Safe	231 (31.5%)	6 (0.8%)	0 (0.0%)
	Action	169 (23.1%)	45 (6.1%)	5 (0.7%)
	Hazardous	77 (10.5%)	90 (12.3%)	110 (15.0%)

*Right hand data only, n = 733.

Table 5. Job evaluations using the American Conference of Governmental Industrial Hygienists (ACGIH) hand activity level (HAL) (American Conference of Governmental Industrial Hygienists 2001) and the Strain Index methods, showing number of jobs and % of total in each category.*

		Strain Index parameter method		
		Safe	Action	Hazardous†
ACGIH HAL method	Safe	230 (31.4%)	185 (25.2%)	69 (9.4%)
	Action	5 (0.7%)	19 (2.6%)	66 (9.0%)
	TLV	2 (0.3%)	15 (2.0%)	142 (19.4%)

*Right hand data only, n = 733. The ergonomist's estimated repetitiveness was used in the calculations.
†The 'hazardous' risk level in the Strain Index method is equivalent to the 'above the threshold limit value (TLV)' risk level in the ACGIH HAL method.

HAL method (159 or 21.7%). The agreement was 74.1% with a weighted kappa statistic of 0.45.

When the HAL, DE and EM were determined from the time studies of the forceful hand exertion analysis, the relationship between the job evaluation results using the two methods remained similar; that is, the SI identified more hazardous jobs (96 or 13.8%) compared to the ACGIH HAL method (62 or 8.9%). The agreement was 87.3% with a weighted kappa statistic of 0.57.

4. Discussion

4.1. *Comparison of the two different definitions of repetitiveness*

Using the two different definitions, measures of repetitiveness in terms of exertion frequency and duty cycle varied significantly. The first difference was that the frequency and duty cycle were much higher when the repetitive muscle activity definition was used compared to when the forceful hand exertion definition was used (figure 1(a, b)). This was to be expected since the repetitive muscle activity analysis counted more activities with forces that were lower than the operationally defined levels, which would not be counted when using the forceful hand exertion definition. The correlation between the frequencies of forceful hand exertions and repetitive muscle activities was only slight. There were almost no correlations between duty cycle analysis results based on the two different repetitiveness definitions. These results suggest that the two repetitiveness definitions may be very different and may have measured different physiological phenomena. Therefore, when repetitiveness is to be quantified, very specific definitions should be provided as to what is actually being measured.

The next question related to the different repetitiveness definitions is 'which definition should one use?' It is hoped to answer that question when the results from the present analyses are used in modelling the variables, which are the best predictors of specific musculoskeletal disorders.

High frequency–high repetition exposure category jobs were characterized by higher exertion frequencies and longer durations (higher duty cycle) in the forceful hand exertion analysis when compared to low frequency–low repetition exposure category jobs (figure 1(a, b)). For low force jobs, although time spent on forceful hand exertion was short (reflected by lower duty cycles in the forceful hand exertion analysis, figure 1(b)), the hand might still be actively in use (for example, holding a light part). This hypothesis may be supported by the relatively long duty cycles for repetitive muscle activity in low force exposure categories (figure 1(b)), along with the lack of significant correlation between the frequency and duty cycle for repetitive muscle activity analysis.

4.2. *Comparisons of the different repetition estimates*

Measures of repetitiveness obtained from detailed time studies of the two explicitly defined repetitive hand activities (i.e. forceful hand exertion and repetitive muscle activity) have only weak correlation with the ergonomist's estimated parameters (table 1). The weak correlation may suggest that, when the ergonomists made subjective estimates of repetitiveness, more abstract (or less specific) information about the task was used. The higher correlation values between the different ergonomist's estimated parameters can be explained by the use of similar abstract definitions when making subjective estimates.

The analyses of repetitive muscle activity were conducted by trained laboratory technicians, whereas the analyses of forceful hand exertion were performed by experienced ergonomists. The ergonomists also estimated the HAL and SI parameters. One might expect that the low correlations between the various repetitiveness measures (table 1) may be partially due to the differences between the analysts. However, this assumption could not be supported by the results obtained (table 1). It was found that the correlations were weak (Spearman rank-order correlation coefficients = 0.20 to 0.28, table 1) between the laboratory technician's result on frequency of repetitive muscle activity and the ergonomist's results on frequency of forceful hand exertion and estimated parameters on HAL, EM and SW. However, the analyses showed that the correlations between the results that were all analysed by ergonomists were not better (Spearman rank-order correlation coefficients = 0.12 to 0.33; table 1). This may suggest that the low correlations between the measures obtained by the different methods are more closely related to their definitions than to the different groups of analysts.

4.3. *Comparison of the different force quantification approaches*

The correlation values between the ergonomist's estimates and direct measurements of weight lifted and pushing/pulling force were relatively high compared to the correlations between the different methods used for the pinch and power hand grip forces (table 2). This may be because the ergonomists gained some hints when performing the force ratings from the physical characteristics of the objects to be lifted and pushed or pulled, and/or from the worker's facial expressions and work postures when performing these activities.

The correlation values between the measured forces, the ergonomist's estimates and the worker's self-reports for pinch and power grip forces were weak. The difficulty in quantifying hand grip force has been recognized by many researchers. The force matching method used in this study has been shown to be feasible and reliable when several subjects are used (Bao and Silverstein 2005, R. Wells, personal communication). However, large individual variation can exist. Spielholz *et al.* (2001) found that direct measurement using electromyography appears to be the best available method for quantification of grip force. However, it may not be practical to apply electromyography in a large-scale epidemiological study with numerous subjects. The relationships between the worker's self-reported, the ergonomist's estimated and the directly measured hand force requires further exploration.

The low correlations between the different measurement methods suggest that the force quantification methods used in some of the widely used job evaluation methods may not be interchangeable.

4.4. *Comparison of job evaluations using the American Conference of Governmental Industrial Hygienists hand activity level and Strain Index methods*

As seen previously, when the repetitiveness parameters were obtained with different methods, different aspects of repetitive hand activities may actually be measured. This is reflected in the job evaluation results. The results showed that when the HAL, EM (exertion frequency) and DE (duty cycle) were estimated by ergonomists, more jobs were considered as hazardous compared to when they were computed from the detailed time studies of forceful hand exertions. One possible explanation may be that the ergonomists considered other hand/wrist movements in addition to the defined forceful hand exertions (high force applications) when estimating the repetitiveness of a task. However, frequency and duty cycle of forceful hand exertion were based on very specifically defined forces and detailed time studies. These analyses were not influenced by other force applications that were not defined.

In spite of the differences in the job evaluations, the overall agreements were moderate (for the SI job evaluations) to substantial (for the ACGIH HAL job evaluations), if the categorization criteria based on the kappa statistics suggested by Landis and Kock (1977) were used. Agreement between methods was higher when jobs were considered safe or hazardous (tables 3 and 4).

The American Conference of Governmental Industrial Hygienists (2001) suggested a conversion table for the HAL, based on exertion frequency and duty cycle, has missing values when exertion frequency is low and duty cycle is high, and when frequency is high and duty cycle is low. This is probably because no data were available when the conversion table was developed. With the current exposure dataset, together with the health outcomes, it should be possible to expand this table in the near future.

The SI method appears to have identified more hazardous jobs compared to the ACGIH HAL method (table 5). In table 5 it can be seen that (similar to the results shown in tables 3 and 4) frequencies are greater in the cells of 'safe vs. safe' and 'hazardous vs. TLV' compared to the other cells. The moderate agreement (87.3% with a weighted kappa statistic of 0.57) might be due to the high number of obviously safe or hazardous jobs among the subjects.

5. Conclusions

When the different definitions of repetitive exertion are used, different physical exposure phenomena may be measured and produce very different results. Correlations between the values of repetitiveness estimated by the different methods were poor and may be influenced by other factors.

Correlations between force quantifications using different methods were also poor. This may suggest that parameters measured by the different exposure quantification methods are not interchangeable.

Both the ACGIH HAL and SI methods identified more hazardous jobs when repetitiveness was estimated by ergonomists compared to when it was calculated by detailed time studies of forceful hand exertions. The SI method identified more hazard jobs than the ACGIH HAL method. Overall, the between methods agreement was moderate to substantial.

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