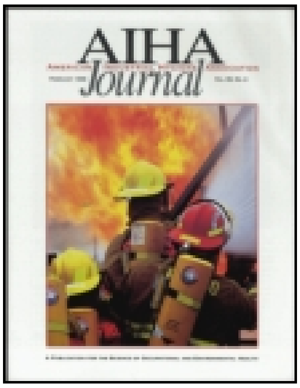

American Industrial Hygiene Association Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/aiha20

Development and Evaluation of an Observational Method for Assessing Repetition in Hand Tasks

Wendi A. Latko [a], Thomas J. Armstrong [a], James A. Foulke [a], Gary D. Herrin [a], Randall A. Rabourn [a] & Sheryl S. Ulin [a]

[a] The University of Michigan, Center for Ergonomics, Dept. of Industrial and Operations Engineering, 1205 Beal Avenue, Ann Arbor, MI, 48109-2117

Version of record first published: 18 Jun 2010.

To cite this article: Wendi A. Latko, Thomas J. Armstrong, James A. Foulke, Gary D. Herrin, Randall A. Rabourn & Sheryl S. Ulin (1997): Development and Evaluation of an Observational Method for Assessing Repetition in Hand Tasks, American Industrial Hygiene Association Journal, 58:4, 278-285

To link to this article: http://dx.doi.org/10.1080/15428119791012793

Development and Evaluation of an Observational Method for Assessing Repetition in Hand Tasks

AUTHORS
Wendi A. Latko
Thomas J. Armstrong
James A. Foulke
Gary D. Herrin
Randall A. Rabourn
Sheryl S. Ulin

The University of Michigan, Center for Ergonomics, Dept. of Industrial and Operations Engineering, 1205 Beal Avenue, Ann Arbor, MI 48109-2117

Several physical stressors, including repetitive, sustained, and forceful exertions, awkward postures, localized mechanical stress, highly dynamic movements, exposures to low temperatures, and vibration have been linked to increased risk of work-related musculoskeletal disorders. Repetitive exertions have been among the most widely studied of these stressors, but there is no single metric for assessing exposure to repetitive work. A new methodology enables repetitive hand activity to be rated based on observable characteristics of manual work. This method uses a series of 10-cm visual-analog scales with verbal anchors and benchmark examples. Ratings for repetition reflect both the dynamic aspect of hand movements and the amount of recovery or idle hand time. Trained job analysis experts rate the jobs individually and then agree on ratings. For a group of 33 jobs, repetition ratings using this system were compared to measurements of recovery time within the cycle, exertion counts, and cycle time. Amount of recovery time within the job cycle was found to be significantly correlated with the analysis ratings (r^2=0.58), as were the number of exertions per second (r^2=0.53). Cycle time was not related to the analyst ratings. Repeated analyses using the new method were performed 1½ to 2 years apart on the same jobs with the same group of raters. Ratings for repetition differed less than 1 point (on the 10-cm scale), on average, among the different sessions. These results indicate that the method is sensitive to exertion level and recovery time, and that the decision criteria and benchmark examples allow for a consistent application of these methods over a period of time. This method of rating repetition can be combined with similar scales for other physical stressors.

Keywords: cumulative trauma disorders, ergonomics, job analysis, repetition

Various physical stresses, including repetitive, sustained, and forceful exertions, awkward postures, localized mechanical stress, highly dynamic movements, exposure to low temperatures, and vibration have been linked to increased risk of work-related musculoskeletal disorders (WRMSD).[1–6] Specifically, several studies have implicated repetitive exertions as a significant contributor to workers' risk of developing these disorders (Table I).

There is widespread evidence to indicate that an exposure-response relationship exists between exposure to repetitive work and development of disorders[3] (Figure 1). Although it is clear that risk increases as exposure increases from very low levels to very high levels, less is known about the exact shape of the dose-response curve, i.e., the critical exposure levels at which a worker's risk significantly increases.

A major reason for this knowledge gap is the difficulty in quantifying the level of repetitiveness (i.e., exposure) in manual work. There is no single metric that has been used to assess repetition. Previous studies of repetitive work have examined repetitiveness in terms of repeated cycles or amount of hand activity (Table I). For example, some investigators have attempted to quantify repetition based on production standard data, e.g., cycle time or parts produced (see Table I). However, such methods are difficult to apply to certain tasks, especially those with long cycle times or complex operations. Also, a measure of cycle time alone does not account for how busy the hands are during the cycle. For example, a

Support for this project was provided by Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health grant # R01-OH02941 and gifts from private industry.

TABLE I. Selected Epidemiologic Studies that Showed a Relationship Between Repetitive Work and Upper Extremity Musculoskeletal Disorders

Study	Study Design	Population	Health Outcome	Factor(s) Considered as Measure of Repetition
Kuorinka and Koskinen[7] (1979)	cross-sectional	workers in manual jobs in scissors manufacturing	tension-neck and muscle-tendon syndrome	number of pieces handled per year
Luopajarvi et al.[8] (1979)	cross-sectional	assembly line packers and shop assistants	tenosynovitis	number of repetitive exertions
Cannon et al.[9] (1981)	case-control	workers in aircraft engine manufacturing	carpal tunnel syndrome	observation of repetitive motion tasks of the wrists
Punnett et al.[10] (1985)	cross-sectional	garment workers and hospital employees	persistent shoulder, wrist, and hand pain	observation of repetitive upper extremity exertions
Silverstein et al.[11] (1986)	cross-sectional	workers from six industrial sites	hand/wrist cumulative trauma disorders (specific diagnoses and nonspecific symptoms)	cycle time <30 sec or 50% of cycle in same fundamental movements
Armstrong et al.[12] (1987)	cross-sectional	workers from seven work sites in six industries	hand and wrist tendinitis	cycle time <30 sec or 50% of cycle in same fundamental movements
Wieslander et al.[13] (1988)	case-control	surgical carpal tunnel syndrome patients, other surgical cases, and general population	carpal tunnel syndrome	presence of repetitive wrist movements identified by worker and occupational hygienist
Barnhart et al.[14] (1991)	cross-sectional	workers at a ski assembly plant	carpal tunnel syndrome	observed repeated and/or sustained activities involving wrist motion and/or pinch grip
Kurppa et al.[15] (1991)	cross-sectional	workers in a meat-processing factory	tenosynovitis, peritendinitis, and epicondylitis	observed work "strenuous to the muscle-tendon structures of the upper limbs"
Chiang et al.[16] (1993)	cross-sectional	fish-processing workers	shoulder girdle pain, epicondylitis, and carpal tunnel syndrome	cycle time <30 sec or 50% of cycle in same fundamental movements
Schoenmarklin et al.[17] (1994)	cross-sectional	workers in 20 jobs in 8 industrial plants	"hand/wrist CTDs" as reported on OSHA 200 logs	velocity and acceleration of wrist movements
English et al.[18] (1995)	case-control	patients attending three orthopedic clinics	various soft-tissue diseases of the upper limb	frequency and duration of various upper extremity motions
Schierhout et al.[19] (1995)	cross-sectional	workers in 46 jobs in 11 factories	self-reported regional musculoskeletal pain	cycle time

30-second cycle time used by some investigators[11,12,16] would not be suitable for certain jobs, such as those involving computer keyboard use or some assembly operations in which the worker performs a brief exertion and is idle for the rest of the cycle. In situations such as these, production standard-based methods may inaccurately estimate the true activity level of the hands. Other methods consider hand activity more directly, by defining repetition according to number of hand exertions per cycle or unit time,[7,8] the velocity and acceleration of motions,[17] or the duration of micropauses.[20] Potential difficulties with these methods include difficulty in defining and identifying "exertions," complications arising from exertion length, and the technical requirements of instrumentation. Other investigators have relied on observation or worker reports to classify the repetitiveness of jobs,[9,10,13,14,18,19] but these studies provide few details of the specific criteria used in making the classifications.

In general, existing methods for exposure assessment fall into one of the following categories (see Table I): (1) production standard data; (2) observational methods, including checklists; and (3) instrumentation. The system described in this article is observational, in which repetition or hand activity is characterized using a visual-analog scale ranging from the lowest to the highest amount imaginable. The rating system consists of a 10-cm visual-analog scale that ranges from 0, which corresponds to no hand activity, to 10, the most possible hand activity. Rating scales such as these are common subjective assessment techniques often used to elicit workers' perception of job attributes.[21] The system includes decision rules and benchmark examples to aid in determining the magnitude of the stress. This article will focus on the rating scale for repetition/hand activity, although similar scales can be developed for the other stressors such as force, contact stress, and awkward postures.

The verbal anchors and decision criteria that form the foundation of the rating scale have been developed through extensive observation of a large number of jobs. These anchors and criteria are intended to provide benchmarks against which the raters can

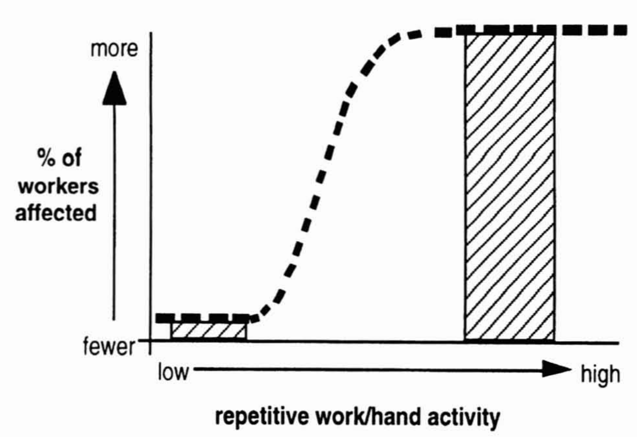

FIGURE 1. Proposed exposure-response curve for work-related upper extremity musculoskeletal disorders. Studies[2,4] have shown higher risk at higher exposure levels. The exact shape of the curve is not known.

compare the job being observed, promoting consistency in ratings between analysts and jobs. The methods employed in these ratings are similar to those used to determine performance ratings in work measurement[22] and in scoring many competitive sporting events at both the recreational and professional level, notably diving,[23] figure skating,[24] and gymnastics.[25] In all these cases the outcome of interest is not an easily quantifiable entity. The ratings are based on professional judgment, applied by highly trained individuals, and aided by a set of well-defined decision criteria.

System Development

The development and initial application of this system consisted of three subtasks: (1) proposal of initial scale based on factors considered in previous studies (see Table I), (2) preliminary job selection/classification, and (3) ratings/rating system application and enhancement (Figure 2). In the preliminary job selection and classification stage, a team of two or more researchers conducted a plant walk-through, during which available jobs were observed. The goal of this job selection was to obtain examples of jobs encompassing the full range of the possible repetition rates. Jobs were selected based on an initial subjective assessment of repetition/hand activity. Representative workers, equipment, and job cycles were identified, and the selected jobs were videotaped and documented. Written documentation included production standards, job tasks, workstation layout and nominal dimensions, and materials, tools, and equipment. The job information was then taken back to the university lab where it was further analyzed.

The ratings/rating system enhancement was conducted at the university by a team of four to six faculty and staff who were experienced in ergonomic analysis in general, and this technique in particular. The videotaped jobs and documentation were presented to the team members, who independently rated the jobs for repetition/hand activity using the 10-cm scale and written guidelines (decision criteria and benchmark examples). Raters selected and rated the busiest hand during the cycle. When all team members had completed their individual ratings, the ratings were discussed with the goal of reaching consensus. Consensus was defined as: (1) a difference of no more than 1 point on the 10-point scale between the lowest score the highest score, and (2) the bases of all differences had been addressed. If the individual ratings for any stressor initially met consensus, no further discussion was necessary for that stressor. If consensus was not initially met, the outlying raters were given the opportunity to briefly explain the rationale for their ratings. In some cases the discrepancies were due to observational differences: one rater simply noticed something that no one else did, or an individual overlooked something that everyone else saw. In these cases the affected rater(s) adjusted their ratings accordingly and consensus was achieved (Figure 2).

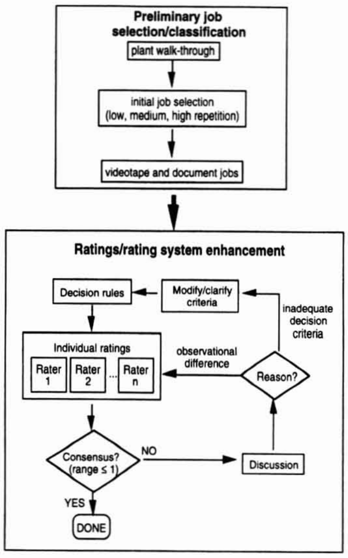

FIGURE 2. Flow chart illustrating the steps involved in job selection and system development and application

Occasionally, jobs were encountered for which the team was not able to quickly reach consensus. These cases signaled an inadequacy in the decision criteria. In these situations the team members discussed the repetitive activity observed relative to the existing criteria and proposed modifications to clarify the decision criteria. In some cases the rating guidelines were then updated to include these enhancements (Figure 2).

Sometimes jobs were composed of two or more different tasks, e.g., building up subassemblies and installing subassemblies, or the workers rotated between multiple jobs on a production line or in a work cell. In most of these cases the raters mentally integrated the two tasks and produced a single rating; however, each task could be rated separately and a time-weighted average (TWA) calculated.

This rating system for repetition has evolved from the assessment of over 185 jobs. These jobs encompass a wide variety of industries, including furniture manufacturing, automotive components, appliance manufacturing, and paper products, and include both traditional, short-cycle assembly jobs as well as long cycle-time jobs with more task variability. The decision criteria and benchmark examples draw from this diverse group of jobs, providing a comprehensive set of guidelines that can be generalized to a wide variety of manufacturing jobs. Videotaped examples of the various rating levels have been assembled from these jobs and are maintained in a library; they are used for calibration and training purposes. Table II lists representative jobs from the full range of the rating scale.

The result of this iterative process is illustrated in Figure 3. The final observational rating method addresses repetition from the standpoint of hand activity rather than repeated work elements. This rating scheme draws from the studies cited in Table I and integrates, either directly or indirectly, several of the factors considered in those studies into a single scale. The factors directly considered in the repetition/hand activity rating include (Figure 3) (1) duration and frequency of observed rest

TABLE II. Representative Jobs from the Full Range of the Rating Scale

Job[A]	Industry	Rating[B]
Inspector; visual observation of passing parts; no handling	appliance mfg	1
Unload plastic drum lids from molding machine; long pauses between cycles	fiber drum mfg	1
Load/operate press to form head liners; wait for machine to cycle	auto components	1
Loading automatic fabric wrapping machine; wait for machine to cycle	auto components	2
Load/operate trim machine for head liners; wait for machine to cycle	auto components	2
1-min transfer task; 6-sec cycle	laboratory	2.5
Stacking large drums; wait for next drum	fiber drum mfg	2.5
Connecting ground wire on dryer; attach 1 clip and drive 2 bolts	appliance mfg	3.5
Glass inspection, manipulating glass and visually inspecting for defects	glass/mirror mfg	4
Visor silkscreen (load, activate, unload)	auto components	4
Feeding drum cover through glue machine and loading onto forming machine	fiber drum mfg	4.5
Hanging back panels of dryers on racks (2 jobs)	appliance mfg	4.5
Panel upholstery (office cubicle panels)	office furniture mfg	5
Overhead console upholstery; load fabric and frame into press; smooth fabric by hand	auto components	5
1-min transfer task; 3-sec cycle	laboratory	5
Securing fan on dryer; position housing; drive 3 bolts and position fan	appliance mfg	6
Wiring heater box on dryer; position wire harness and insert 4 connectors	appliance mfg	6
Securing upper back panel on dryer; position back panel and drive 3 bolts	appliance mfg	6
Securing back of console on dryer; insert 4 connectors	appliance mfg	6.5
Securing top panel on dryer; drive 3 bolts	appliance mfg	6.5
Mirror cutting; load etching machine and separate cut mirrors	glass/mirror mfg	6.5
Spray painting racks of visors and armrests	auto components	7
Assembling lid for armrest/center storage unit	auto components	7
Sewing armrest covers (2 jobs)	auto components	7.5
Assembling cupholder	auto components	7.5
Office chair upholstery; cover seats and backs	office furniture mfg	8
Press loading; small parts	fiber drum mfg	8
1-min transfer task; 1.5-sec cycle	laboratory	8
Handle assembly; riveting (2 jobs)	fiber drum mfg	9

[A]Thirty-three jobs included in this study
[B]Ratings are on a 10-point scale, and are expressed as the average of 5 raters, rounded to the nearest 0.5 point. In all cases, the range in ratings between the five raters was less than or equal to 1 point.

pauses (i.e., the amount of recovery time within the task), and (2) the speed of hand movements (i.e., how fast the fingers and wrist move).

As the repetition rating increases, the duration and frequency of rest pauses decreases until a rating of 10 is achieved, where rest pauses are virtually nonexistent. Higher levels of repetition are also characterized by faster movements of the hands. This definition of repetition does not consider cycle time; a very long-cycle job could have a high repetition rating if the hands are in constant, rapid motion with no recovery time. Similarly, short-cycle time jobs may be rated low on the scale if the worker's hands are idle most of the cycle. Within this framework, ratings are discounted if there is a wide variety of different hand motions in the task.

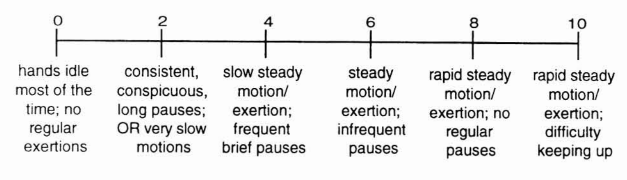

FIGURE 3. Visual-analog scale for rating repetition/hand activity, with verbal anchors

EVALUATION

The evaluation entailed examining (1) how well the method assessed those factors it was designed to assess, and (2) test-retest results.[26] Because there is no single, recognized definition of repetition, the ratings were compared with characteristics of repetitive work that have been identified by previous researchers (Table I). The three methods chosen for comparison are common observational metrics: hand exertions per second, amount of recovery time, and cycle time.

A subset of 33 jobs (Table II) was randomly selected for this further analysis from those which previously had been rated by the team. This subset represented five different industries and one laboratory simulation. The team repetition ratings on the jobs ranged from 1 to 9 on the 10-point scale, with an approximately uniform distribution over that range. A researcher, blinded to the team ratings, performed the hand exertion analysis, recovery time analysis, and cycle time calculation on each of the 33 jobs. The same jobs were rated again by the team $1\frac{1}{2}$–2 years after the initial ratings to assess the consistency of repetition/hand activity ratings by the same raters over time. All ratings and data collection were performed from the same segments of videotape.

Hand Exertions

Methods

The hand exertion analysis consisted of counting the number of exertions by the most active hand during several cycles of the job and averaging over the cycles. An exertion was defined as a conspicuous application of force by the hand, and included using the hand to hold, manipulate, trigger, push, pull, or otherwise handle an object.[27] For each task at least five cycles were observed and the exertion counts averaged. The exertion values were divided by cycle time (yielding exertions per second) to facilitate comparative analysis.

Results

The results of this analysis are presented in Figure 4. The agreement (r^2) between the team ratings of repetition and the number of exertions per second was 0.53 ($p<0.0001$).

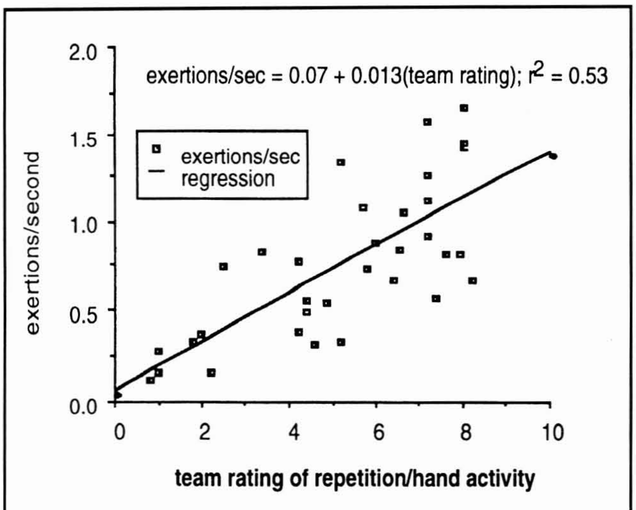

FIGURE 4. Relationship between team ratings of repetition/hand activity and number of exertions per second in 33 jobs

Recovery Time

Methods

Recovery or rest time was operationally defined as periods when the hand was not holding, manipulating, triggering, pushing, pulling, or otherwise handling an object, and included times when the hand was completely idle, resting upon an object for voluntary support, moving freely, or reaching for an object. At least five cycles of the each task (Table II) were observed and the recorded recovery time values averaged. These values were then divided by cycle time to obtain the percent of recovery time within the cycle. Figure 5 illustrates typical work/recovery profiles over time for three levels of repetition/hand activity.

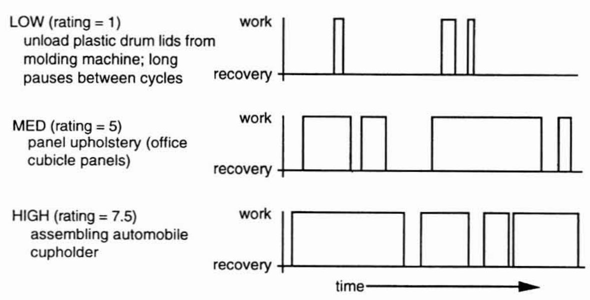

FIGURE 5. Typical work/recovery profiles for jobs at various levels of the rating scale

Results

The results of this analysis are presented in Figure 6. The agreement (r^2) between the team ratings of repetition and the percent of cycle spent in recovery was 0.58 ($p<0.0001$). Jobs in the low repetition range (rating = 0–3) averaged 64% (±16%) recovery time during the cycle. Medium repetition jobs (rating = 4–6) averaged 26% (±22%) recovery time, and high repetition jobs (rating = 7–10) averaged 12% (±12%) recovery time.

Cycle Time

Methods

All 33 jobs included in this study had regular cycles, with a consistent sequence of steps being repeated throughout the work task. A cycle was defined as the time period during which the worker handled or performed operations on one unit of product. A minimum of five cycles of each job was observed, and average cycle time was calculated. These cycle times were compared with the team ratings of repetition.

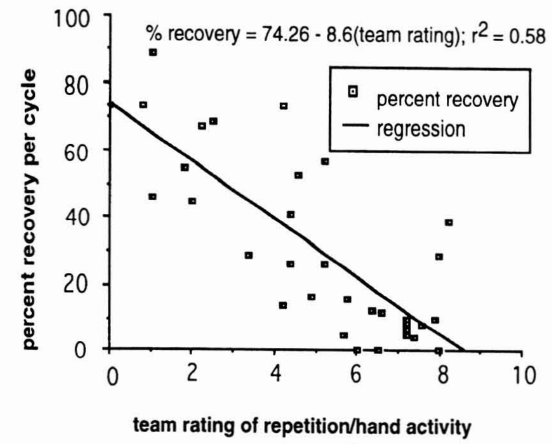

FIGURE 6. Relationship between team ratings of repetition/hand activity and percent recovery time within the task cycle for 33 jobs

Results

Cycle times for the 33 jobs in this study ranged from 1.2 sec to 214 sec. Figure 7 illustrates the cycle time and team rating of each of the 33 jobs; there was no statistically significant relationship between cycle time and team rating. For example, the job rated lowest by the team (rating = 1) was an inspection task with a cycle time of only 8 seconds. The job with the longest cycle time (214 sec) was an upholstery job that the team rated 8 on the 10-point scale. Because a cycle time of 30 sec has been used as a cutoff point for repetitive and nonrepetitive work,[11,12,16] a t-test was performed to determine if there was a significant difference in the team ratings of jobs with cycle times less than 30 seconds compared with those with cycle times longer than 30 seconds. The jobs (n=11) with cycle times greater than 30 seconds had a mean team rating of 5.1 (±2.25), while the jobs (n=22) with cycle times less than 30 seconds had a mean rating of 5.3 (±2.3). This difference

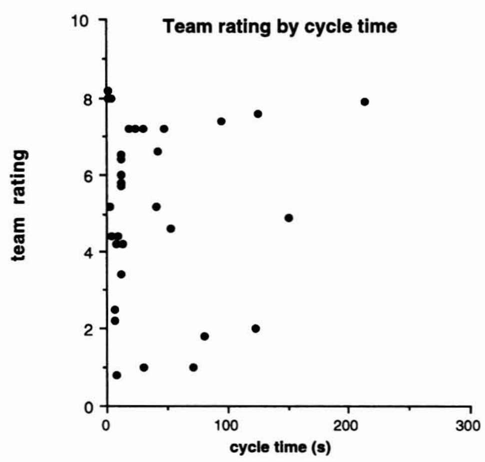

FIGURE 7. Plot of cycle time and team rating of repetition/hand activity for 33 jobs. There was no significant relationship.

was not statistically significant (p>0.85).

Test/Retest

Methods

The same 33 jobs were analyzed by the same team on two separate occasions to determine the consistency with which a given group was able to apply the decision criteria. Time between the two analyses ranged from 79–118 weeks. The team analyzed several other jobs in the interim, lowering the probability that any team members would have remembered the exact rating they had given the jobs originally. The 33 jobs were presented to the team in a random order. The rating procedure on both occasions followed that described in the System Development section.

Results

The results of this evaluation are reported graphically in Figure 8. The two sets of ratings exhibited a good correlation ($r^2 = 0.88$). For the 33 jobs, 66% of the ratings differed by 1 unit or less between the two sessions. A paired t-test indicated a significant difference between the ratings for the two sessions ($p<0.05$), with the ratings from the second session being approximately 0.6 units higher than the first session. Although this difference was statistically significant, it was well within the 1 unit range defined as consensus.

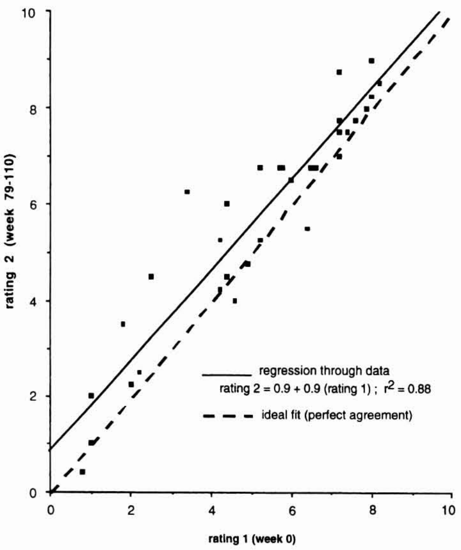

FIGURE 8. Average team ratings of repetition on two different occasions for 33 jobs ($r^2 = 0.88$)

DISCUSSION

Hand Exertion and Recovery Time Analysis

Both the hand exertion count (Figure 4) and the percent of recovery time within the cycle (Figure 6) were significantly correlated with the team ratings of repetition/hand activity ($r^2 = 0.53$ and 0.58, respectively). It is expected that there would be some relationship between the measures of exertion frequency and recovery time and the repetition/hand activity ratings. A perfect relationship would not be predicted, because the team rating for repetition/hand activity is an integrated score, which takes into account the speed of hand movements as well as the amount of recovery time within the cycle. The exertion counts and number or pieces handled, as used by Kuorinka[7] and Luopajarvi[8] (Table I) give an indirect indication of speed, in that a worker can accomplish more exertions per unit time if those exertions are rapid; however, the exertion counts do not directly assess movement speed. Also, the exertion counts do not account for the length of the exertions or the amount of recovery time within the cycle, both of which are factors that are considered by analysts using the rating method. The raters consider the trade-off between recovery time and movement speed. For example, one worker may move quickly to load a machine, then wait while it cycles, while another may perform an assembly operation at a steady speed throughout the task, with few pauses. In such a case both workers could receive similar ratings on the repetition/hand activity scale because of the interrelationship between movement speed and recovery time.

Cycle Time

No significant relationship was observed between the team ratings and cycle time (Figure 7). This is an important finding, because several epidemiologic studies have used production standard-based metrics to assess exposure to repetitive exertions (Table I). It is possible to find high repetition, short-cycle jobs, and low repetition, long-cycle jobs (see Figure 7). This appears to be the case for the cited studies. This does not, however, mean cycle time can be used to characterize repetition in all settings. Although the criteria applied in these previous studies may have been appropriate for those particular groups of jobs, the findings of this study suggest that applying such criteria to a random group of jobs, which were not selected with these criteria in mind, may not be appropriate.

Part of the reason for this poor agreement may be because the rating system takes into account the trade-off between speed of movements and the amount of recovery time, rather than considering cycle time directly. Based on the rating system, for a given task, the repetition level will increase as the cycle time decreases because movements will have to be faster or recovery time will be shorter if the same amount of work must be accomplished in a shorter time. However, merely calculating cycle time does not account for the different physiological requirements in different tasks. Similarly, counting the number of pieces handled does not consider what the worker does while handling each piece.

Some investigators have attempted to address this issue by adding additional constraints to the cycle time criterion. For example, Silverstein et al.[11] and Armstrong et al.[12] identified "fundamental cycles" within the work cycles as a sequence of steps that were repeated within the cycle. "High repetitive" jobs were defined as having a cycle time less than 30 seconds or performing the same type of fundamental cycles more than 50% of the cycle time, while "low repetitive" jobs had a cycle time greater than 30 seconds and less than 50% of the cycle time involving the same type of fundamental cycles. These criteria have been used in several subsequent studies by other researchers. While increasing the sensitivity of the cycle time metric, these additional conditions require more detailed analysis and analyst training. Although this definition of repetitiveness can be used to categorize certain jobs for epidemiologic purposes, there are some limitations to its use. One is the difficulty in expanding it beyond a dichotomous characterization. Because the exposure is defined both in terms of cycle time and fundamental cycles, it is unclear how similar criteria could be developed to divide exposures into three or more levels. For example, three conditions of a laboratory simulation were included in this study: a 1-m transfer at 1.5-sec, 3-sec, and 6-sec intervals (see Table II). Each transfer took approximately 1.2 second, allowing 20, 60, and 80% recovery time, respectively. By the Silverstein/Armstrong[11,12] criteria, all of these conditions would be classified as high repetitive. Extending this example, the same transfer task performed once every 29 seconds would also be categorized as high repetitive, and the worker would be able to rest nearly 28 sec of every cycle. Clearly the 1.5-sec, 3-sec, 6-sec, and 29-sec cycles differ in their exposure to repetitive exertions, but the existing metric does not allow differentiation between them.

Other investigators have provided fewer details of the criteria by which they judged work to be repetitive or nonrepetitive. Criteria such as occupations requiring "repetitive motion tasks involving the wrists,"[9] observation of repetitive upper extremity exertions,[10] observed "repeated and/or sustained activities" involving wrist motion or pinch grip,[14] and observed tasks "strenuous to the muscle-tendon structures of the upper limbs"[15] have been used to describe these exposure assessments. Although observation can be a powerful tool in assessing repetition, and these classification methods may have been adequate for the particular study for which they were employed, the descriptions provided by the investigators do not provide a framework that can be used to relate the results of their studies to other jobs and types of work.

There is evidence to indicate that both movement speed and recovery time are important parameters related to risk of WRMSDs. Schoenmarklin et al.[17] found both acceleration and velocity of the wrist to be associated with Occupational Safety and Health Administration reportable disorders associated with repetitive motion among their study population, with the highest predictive power exerted by acceleration in wrist flexion/extension (OR = 5.03). Bystrom et al.[28] suggest load and work/rest ratio acceptability limits for continuous and intermittent isometric contractions, based on a number of physiological indicators of localized muscle fatigue. In a laboratory study of cadaver hands, Goldstein et al.[29] found that cumulative tendon strain was related to the load placed on the tendon, and increased as the ratio of tendon loading time/nonloading time increased. These findings suggest that both the contraction intensity and the exertion/recovery patterns are significant in predicting physiological signs of muscle fatigue and tendon strain. This suggests that consideration of recovery time is important in determining the physiological burden of work from the standpoint of repetition. We suspect that there is a high correlation among velocity, acceleration, and muscle force for work tasks. There is a need for further laboratory and field studies combining electromyography and goniometers to clarify this relationship.

This observational system has some advantages over traditional methods for rating repetition in manual work. By relying on decision rules and verbal anchors, it considers the dynamic nature of the hand motion, rather than just the number of motions or the amount of idle time. Distinct advantages of this method are:

- application time is relatively short (repetition/hand activity can be rated in less than 5 minutes)
- no instrumentation is required
- team members can be trained to rate repetition/hand activity in approximately 1 hour
- the system can be applied by a team using videotape and written job documentation, or by a single investigator on site during a walk-through survey (although spot checks by a group of raters are recommended).

As similar scales are included for the other physical stressors (force, contact stress, and posture stress), it is predicted that training raters can be accomplished in approximately 1 day, while a thorough analysis of a job, evaluating all of the stressors, will be possible in between 30 and 60 minutes.

There is a need for a consistent method of exposure assessment that can be applied by different people. The ultimate goal of epidemiologic research is to provide guidelines for safe exposure limits, to minimize workers' risk of WRMSDs while maximizing productivity. For this goal to be reached, it is necessary to use exposure assessment techniques that are applicable in a wide variety of job settings and that will eventually allow the generalization from these studies to the working world in general. The method described in this article is one such possible technique.

CONCLUSIONS/FUTURE WORK

This work indicates that the proposed rating system is sensitive to the parameters of movement frequency and recovery time in hand intensive tasks. The method can easily be applied, requiring no instrumentation and a minimum amount of training. Experienced raters are able to consistently apply this method at points in time.

The decision criteria will continue to be enhanced with the addition of benchmark examples from different types of work, e.g., office, assembly, meat processing, etc. This repetition scale can be used in combination with similar scales for the other physical stressors associated with risk of WRMSDs (e.g., force, localized contact stress, and posture stress) to provide a comprehensive exposure assessment.

With regard to this method, there are several application and validity issues that need further study.

Inter- and Intrarater Reliability

It is important to evaluate the consistency with which this, or any, method can be applied by various analysts. Future studies are planned that compare the ratings of the same group of jobs by several groups of analysts, thus assessing the intergroup reliability. Studies are also planned that will examine the difference in individual versus group ratings, to determine the amount of consistency that can be obtained without the benefit of the consensus procedure. It is predicted that the method can be satisfactorily applied by individuals, although with some increase in the variability in the ratings.

Training/Analyst Experience

Experts were chosen as a starting point for evaluation because they represent a best case situation. Consistent expert ratings justify future studies of nonexperts. Because it is recognized that it is not always possible or feasible to have raters of the same level of expertise as those in this study, an important future consideration is the level of background knowledge necessary to adequately apply the decision criteria. The authors foresee a tool such as this being useful to a wide variety of users, including employee-based plant ergonomic teams. Trials with users of this type of background are planned. It is necessary to determine the amount of method-specific training that is required for analysts (both expert and nonexpert) to be able to effectively apply this technique. In addition, an evaluation of the "learning curve" by examining the length of time to rate and achieve consensus and the amount of variability in initial ratings, is planned.

Comparison with Instrumental Methods

Although there is no singular measure that all investigators have agreed on for assessing "repetition" (see Table I), instrumentation such as electromyography and electrogoniometry can provide information on patterns of muscle activity and movement. Studies comparing data from this instrumentation with ratings of the same tasks will be conducted to examine the relationships.

Evaluation of Similar Scales for Other Physical Stressors

While repetition is an important factor in the development of WRMSDs, several other factors, including forceful exertions, localized mechanical stresses, and awkward postures are also important. Similar observational scales can be used to assess exposure to these other stressors, giving a comprehensive system for exposure assessment. As these other scales are completed, reliability and validity analyses similar to those discussed above will be necessary.

Establishment of Exposure-Response Relationship

One of the original goals in the development of this method was the establishment of an exposure assessment tool to be used in epidemiologic research. As previously stated, the ultimate goal in epidemiologic research is to provide guidelines for safe exposure limits, to minimize workers' risk of WRMSDs while maintaining necessary levels of production. To more fully determine these relationships, more epidemiologic studies are needed that quantitatively compare workers' exposure with their health status.

ACKNOWLEDGMENTS

The authors wish to thank Alisa Bono for her assistance with data collection and analysis.

REFERENCES

1. **Viikari-Juntura, E.:** The role of physical stressors in the development of hand/wrist and elbow disorders. In *Repetitive Motion Disorders of the Upper Extremity.* S.L. Gordon, S.J. Blair, and L.J. Fine, eds. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1995. pp. 7–30.

2. **Andersson, G.B.:** Epidemiology of occupational neck and shoulder disorders. In *Repetitive Motion Disorders of the Upper Extremity.* S.L. Gordon, S.J. Blair, and L.J. Fine, eds. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1995. pp. 31–42.

3. **Armstrong, T.J., P. Buckle, L.J. Fine, M. Hagberg, et al.:** A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scand. J. Work, Environ. Health 19:*73–84 (1993).

4. **Hagberg, M. and L. Forcier (eds.):** *Work-related Musculoskeletal Disorders (WMSDs): A Reference Book for Prevention.* Bristol, PA: Taylor and Francis, Inc., 1995. pp. 139–212.

5. **Stock, S.R.:** Workplace ergonomic factors and the development of musculoskeletal disorders of the neck and upper limb: a meta analysis. *Am. J. Ind. Med. 19:*87–107 (1991).

6. **National Institute for Occupational Safety and Health (NIOSH):** *A National Strategy for Occupational Musculoskeletal Injuries: Implementation and Research Needs* (DHHS/NIOSH pub. no. 93-101). Washington, DC: Government Printing Office, 1992. pp. 6–7.

7. **Kuorinka, I. and P. Koskinen:** Occupational rheumatic diseases and upper limb strain in manual jobs in a light mechanical industry. *Scand. J. Work, Environ. Health. 5(suppl. 3):*39–47 (1979).

8. **Luopajarvi, T., I. Kuorinka, M. Virolainen, and M. Holmberg:** Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. *Scand. J. Work, Environ. Health. 5(suppl. 3):*48–55 (1979).

9. **Cannon, L.J., E.J. Bernacki, and S.D. Walter:** Personal and occupational factors associated with carpal tunnel syndrome. *J. Occup. Med. 23(4):*255–258 (1981).

10. **Punnett, L., J.M. Robins, D.H. Wegman, and W.M. Keyserling:** Soft tissue disorders in the upper limbs of female garment workers. *Scand. J. Work, Environ. Health. 11:*417–425 (1985).

11. **Silverstein, B.A., L.J. Fine, and T.J. Armstrong:** Hand wrist cumulative trauma disorders in industry. *Br. J. Ind. Med. 43:*779–784 (1986).

12. **Armstrong, T.J., L.J. Fine, S.A. Goldstein, Y.R. Lifshitz, et al.:** Ergonomics considerations in hand and wrist tendinitis. *J. Hand Surg. 12a(5, part 2):*830–837 (1987).

13. **Wieslander, G., D. Norback, C.J. Gothe, and L. Juhlin:** Carpal tunnel syndrome (CTS) and exposure to vibration, repetitive wrist movements, and heavy manual work: a case-referent study. *Br. J. Ind. Med. 46:*43–47 (1989).

14. **Barnhart, S., P.A. Demers, M. Miller, W.T. Longstreth, et al.:** Carpal tunnel syndrome among ski manufacturing workers. *Scand. J. Work, Environ. Health 17:*46–52 (1991).

15. **Kurppa, K., E. Viikari-Juntura, E. Kuosma, M. Huuskonen, et al.:** Incidence of tenosynovitis or peritendinitis and epicondylitis in a meat-processing factory. *Scand. J. Work, Environ. Health. 17:*32–37 (1991).

16. **Chiang, J., Y. Ko, S. Chen, H. Yu, et al.:** Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. *Scand. J. Work, Environ. Health. 19:*126–131 (1993).

17. **Schoenmarklin, R.W., W.S. Marras, and S.E. Leurgans:** Industrial wrist motions and incidence of hand/wrist cumulative trauma disorders. *Ergonomics 37(9):*1449–1459 (1994).

18. **English, C.J., W.M. Maclaren, C. Court-Brown, S.P.F. Hughes, et al.:** Relations between upper limb soft tissue disorders and repetitive movements at work. *Am. J. Ind. Med. 27:*75–90 (1995).

19. **Schierhout, G.H., J.E. Meyers, and R.S. Bridger:** Work related musculoskeletal disorders and ergonomic stressors in the South African workforce. *Occup. Environ. Med. 52:*46–50 (1995).

20. **Henning, R.A., S.L. Sauter, G. Salvendy, and E.F. Krieg:** Microbreak length, performance, and stress in a data entry task. *Ergonomics 32:*855–864 (1989).

21. **Sinclair, M.A.:** Subjective assessment. In *Evaluation of Human Work: A Practical Ergonomics Methodology.* J.R. Wilson and E.N. Corlett, eds. London: Taylor and Francis Ltd., 1990. pp. 58–88.

22. **Niebel, B.W.:** *Motion and Time Study,* 8th ed. Homewood, IL: Irwin, 1988. pp.375–405.

23. **Leas, D.E. (ed.):** *1993 & 1994 Official Rules of Diving and Code of Regulations.* Indianapolis, IN: United States Diving, Inc., 1993. pp. 115–120.

24. **United States Figure Skating Association (USFSA):** *1995–1996 USFSA Media Guide.* Colorado Springs, CO: USFSA, 1995. pp. 13–14.

25. **Loken, N.C. and R.J. Willoughby:** *The Complete Book of Gymnastics.* Englewood Cliffs, NJ: Prentice Hall, Inc., 1971. pp. 309–313.

26. **Kelsey, J.L., W.D. Thompson, and A.S. Evans:** *Methods in Observational Epidemiology.* New York: Oxford University Press, 1986. pp. 285–309.

27. **Stetson, D.S., W.M. Keyserling, B.A. Silverstein, and J.A. Leonard:** Observational analysis of the hand and wrist: a pilot study. *Appl. Occup. Environ. Hyg. 6(11):*927–937 (1991).

28. **Bystrom, S. and C. Fransson-Hall:** Acceptability of intermittent handgrip contractions based on physiological response. *Hum. Factors 36(1):*158–171 (1994).

29. **Goldstein, S.A., T.J. Armstrong, D.B. Chaffin, and L.S. Matthews:** Analysis of cumulative strain in tendons and tendon sheaths. *J. Biomech. 20:*1–6 (1987).