Inter-rater reliability of video-based ergonomic job analysis for maintenance work in mineral processing and coal preparation plants

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A large proportion of fatal and non-fatal injuries in mineral processing and coal preparation plants can be attributed to maintenance and repair work. Maintenance work in the mining industry has received little attention due to the challenges associated with collecting and evaluating information on exposures to risk factors and possibly due to the adverse working conditions. The goal of this study was to develop a reliable method to systematically quantify exposures to environmental attributes and physical task demands for maintenance work in mineral processing and coal preparation plants. Hierarchical task analysis was carried out for commonly observed and reported maintenance tasks. A detailed taxonomy of environmental features and physical task demands thought to contribute to injury was created. Two raters independently coded 41 videos using the Multimedia Video Task Analysis™ software to measure the percentage of task time that workers were exposed to each of the variables defined in the taxonomy. For most exposure variables, the mean differences in exposures coded between raters were low and the correlations of exposure durations were high. For variables in which the mean differences in exposure were considered to be too high, modifications to the approach were made to improve measurement reliability. This study provides some evidence to suggest that video based ergonomic job analysis is a viable tool for characterizing the environmental and physical demands of maintenance work in mineral processing and coal preparation plants.

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INTRODUCTION

In mineral processing and coal preparation plants (hereafter referred to as mills and prep plants), machine maintenance and repair work account for an average of over 700 injuries each year (Pollard et al., 2012). In an analysis of Finnish industrial maintenance injuries, Lind (2008) found that 48% of the 33 fatalities studied occurred during preventive maintenance tasks. Most fatal and non-fatal traumatic injuries were due to falls, being caught between objects, and incursions with machinery parts. Additionally, maintenance work has been found to entail other risk factors such as frequent awkward postures, forceful exertions, manual materials handling, and working in hot noisy environments (Chervak & Drury, 1996). There is a critical need to understand the environmental and physical task demands of maintenance work in mills and prep plants to identify important work-related risk factors for worker injury and illness.

Evaluation of ergonomic risk factors in industrial maintenance work has not received much attention, with one exception being the aviation industry (Chervak, et al., 1996). One reason for the lack of attention given to maintenance is because it is challenging to evaluate (Pollard, et al., 2012). Not only is the work non-routine, but there are machine and electrical hazards, poor lighting, high noise levels, dust, and poor walking surfaces that present challenges to workers and evaluators.

Direct measurement of work-related risk factors in facilities such as mills and prep plants can pose serious challenges. Electrogoniometers, torsiometers, and pressure measuring systems are difficult to use in these environments as maintenance workers are often very active, mobile, and work in tight spaces. Wires often get caught in equipment, wireless reception in mills and prep plants is spotty, and sensors either shift or fall off. Video-based analysis is ideal in situations where researchers do not have easy regular access to work sites. The use of video recordings allows the environmental and physical work demands of jobs to be collected as safely as possible by minimizing worker and observer distraction during work. Also, the videos can be analyzed later to systematically characterize occupational exposures.

The objective of this study was to develop a comprehensive, reliable, and practical methodology to quantify information about environmental and physical demands during maintenance work in mills and prep plants. Ultimately, the results will help inform workplace redesign and safety intervention efforts.

METHODS

Task familiarization and hierarchical task analysis

Due to the non-routinized nature of maintenance work in the mills and prep plants studied and the lack of literature on systematic evaluation of the maintenance tasks, the first step was to develop a task description for commonly observed maintenance tasks (Moir et al., 2003; Paquet et al., 1999). Maintenance records were obtained, for one calendar year, from one prep plant and one sandstone mill to identify the most commonly performed maintenance tasks. These included: greasing conveyors, replacing conveyor rollers, splicing conveyor belts, screen (sizing and de-watering) maintenance/replacement, replacing pipe, and replacing bearings. Researchers visited multiple sites, observed and video recorded the commonly performed maintenance tasks, and interviewed workers about their maintenance tasks.

Each of the maintenance tasks was divided into job tasks and activities in a manner similar to that used for construction work (Moir et al., 2003). A job task was defined as a collection of activities with a specific aim such as greasing conveyors. Activities were defined as sub-tasks to meet the specific aim, e.g. walking to greasing point along conveyor, attaching grease gun to nozzle, greasing conveyor, etc. This allowed researchers to analyze information about exposures for specific job tasks.

Exposure taxonomy for job analysis

An exposure taxonomy was developed to systematically characterize the environmental and physical demands for the maintenance tasks. A list of the initial exposure variables and exposure categories that were selected is provided in Table 1. A detailed justification for the included variables is provided below.

Floor surface and surface condition. When investigating the Mine Safety and Health Administration (MSHA) injury database for mills and prep plants between 2004 and 2008, researchers found a substantial number of sprain and strain injuries. Of these injuries, slipping and falling when walking/running represented about 14%, and slipping and falling when getting on or off equipment represented 10% (Heberger & Pollard, 2011). Site visits also identified hazards in the work environment that may contribute to slip and fall accidents at plants. Water is often used in mills and prep plants as a means of dust suppression and commonly ends up on travel ways. Further, the usage of conveyors contributes to rock and ore spillage found on many walking surfaces. Therefore, in addition to floor surface material and condition of the floor surface, the presence of debris was also categorized.

Gross posture. Field observations indicated that there was a large variation in gross body posture. Maintenance workers were often kneeling, crouching, or walking, which would predispose them to differing types of injuries.

Trunk flexion, lateral bending, and twisting. The prevalence of back injuries is high in many industries including mining mills and prep plants (Mine Safety and Health Administration, 2009). In addition, back flexion, trunk twisting, and lateral bending greater than 20° have been associated with back disorders (Punnett et al., 1991). A trunk flexion variable was coded whereby a hip to shoulder angle greater than 20° from the vertical was used as a surrogate measure for back flexion. Lateral bending and/or twisting of the trunk greater than 20° were also coded.

Hand position above shoulder. Repetitive work above the shoulders has been shown to increase the risk of MSDs at the shoulder (National Institute for Occupational Safety and Health, 1997; Nussbaum et al., 2001). In addition, 13% of the reported injuries at mills and prep plants affected the shoulder (Mine Safety and Health Administration, 2009). To track these exposures, instances in which a worker had one or both of their hands at or above shoulder level were coded. It should be noted that shoulder flexion and/or abduction angles were not considered; instead the location of the hand was taken relative to the shoulder, independent of the orientation of the torso, in order to simplify and improve the reliability of the shoulder posture analysis.

Tools used and weight of item. MSHA injury data also revealed that handling supplies or materials during loading/unloading or during machine maintenance and repair accounted for 24% and 13% of all reported injuries, respectively (Heberger, et al., 2011). One challenge with observational analysis is the difficulty in coding forceful exertions. Therefore, similar to other observational methods such as PATH (Buchholz et al., 1996), the weight of the item held in the hand was used as a surrogate measure. During video collection, the items handled by workers were weighed and measured so that the frequency and duration of the weights handled over time could be quantified.

Table 1. Initial set of exposure variables and exposure categories identified for evaluating the environmental and physical demands of maintenance work in mills and prep plants

Variable	Initial categories selected
Floor surface	Flat surface, Outdoor ground, Inclined surface, Stairs, Ladder, Other
Surface condition	Dry, Wet, Muddy, Ice
Standing/walking on debris	Yes, No
Gross posture	Walking, Standing, Sitting, Squatting, Crawling, Both knee kneeling, One knee kneeling, Laying down, Other
Trunk flexion	Yes, No
Trunk lateral bending and/or twisting	Yes, No
Hands at or above shoulder	Neither, 1 hand, 2 hands
Tools used	Note specific tool
Weight of item	<10 lb, 10-25 lb, >25 lb
Holding item	Left hand, right hand, both hands

The initial exposure variables and exposure categories were coded using Multimedia Video Task Analysis™ (MVTA) software by two observers based on four (4) sample videos of mill and prep plant maintenance tasks. Difficulties associated with coding each of the variables were identified, refinements to the definition of some of the variables and categories were made, and variable categories were expanded to be more comprehensive and specific. Table 2 lists the exposure variables and categories used for the job analysis.

Assessment of inter-rater reliability

Two observers familiar with the taxonomy independently evaluated 41 video recordings of mill and prep plant maintenance tasks. The recordings represented a diverse set of the aforementioned maintenance tasks performed by several workers at varying sites. The average length of each video was 3.5 min (SD = 2.8 min), representing a total observation time of 2.37 hours. One of the raters (rater A) had domain-specific knowledge and collected some of the videos on-site. The other rater (rater B) had no field experience and was only shown the videos along with a briefing of the work tasks. However, both observers helped develop the taxonomy and trained together, as described earlier, to help ensure that the exposure definitions were applied similarly.

All variables and categories in the taxonomy were coded only if they were clearly visible. Postural angles were estimated or measured using a swing arm protractor at the discretion of each rater.

For each video, percent time spent in each variable category was calculated based on total observable time and then weighted based on the length of the video. The normalized difference was calculated as a comparison metric since total observable time for the exposure categories varied. The normalized difference between raters in percentage of working time (PWT) exposed was calculated as:

$$Norm.Diff. = \frac{|PWT_{Rater\ A} - PWT_{Rater\ B}|}{\left(\frac{PWT_{Rater\ A} + PWT_{Rater\ B}}{2}\right)} * 100$$

To evaluate the inter-rater reliability, Pearson's correlation coefficients of the exposure ratings between raters were calculated.

RESULTS

Between 83% and 95% of each video was clearly visible and could be used for coding. Table 2 summarizes the percent time spent in each category as rated by the two raters, normalized differences in time between raters, Pearson's correlation coefficients for each exposure category, and acceptability of the inter-rater agreement based on the normalized difference in time and the Pearson's correlation coefficients. If a category was rated less than 5% of total working time by both raters, then it was considered to be too rare to measure. If the normalized difference was greater than 10%, it was considered unacceptable. The results suggest that the raters, despite their differences in domain knowledge, could code most of the exposure categories reliably.

Floor surface and surface condition categories were coded very reliably, with absolute differences between raters under 5% of working time with highly correlated paired measurements. It should be noted that the large normalized difference in time for categories of "ladder" and "other" are because these categories were observed very rarely (i.e. even a one-second difference in percent time resulted in large normalized differences in exposure). Although coding of the surface condition was reliable, presence of debris on the floor or obstacles in the path of travel were not coded reliably.

Most of the gross postures were coded reliably. Standing and kneeling were among the posture variables coded most consistently. The reliability for coding trunk postures (particularly trunk rotation and lateral bending) was low. To illustrate some of the results summarized in Table 2 as differences between the two raters, Figure 1 shows the correlations for the percent time spent on a horizontal paved floor surface and Figure 2 shows the correlations for percent time spent with trunk flexion greater than 20° for the two raters. Although overall associations were high (Figure 1: r = 0.93; Figure 2: r = 0.94), there were some misclassifications, as in one case where rater A coded time on a horizontal paved surface as 100% and rater B coded it as 0% (Figure 1). Similarly, Figure 2 indicates that, although overall correlations are high, rater A consistently overestimates, or rater B consistently underestimates the time spent with trunk flexion greater than 20°. These differences in coding could be corrected with additional training.

Table 2. Exposure variables and exposure categories used for analysis, overall percent time spent in category as rated by rater A and B, normalized difference in time between raters, Pearson's correlation coefficient and acceptability of inter-rater agreement for each category (✓: Acceptable; ×: Unacceptable; ?: Too rare to decide)

Variable	Categories coded	% time by rater		Norm. Diff.	r	✓/×/?
		A	B			
Floor surface	Horizontal surface	32.0	31.2	2.5	0.93	✓
	Machinery /Equipment	16.8	13.9	18.9	0.88	×
	Horizontal screen	10.2	10.2	0.0	1.00	✓
	Horizontal grating	8.4	7.8	5.8	0.70	✓
	Stairs	7.9	8.2	3.8	0.99	✓
	Inclined grating	7.3	6.9	5.7	0.86	✓
	Unpaved surface	7.1	7.8	8.9	0.78	✓
	Wood plank	6.7	6.8	2.0	0.92	✓
	Ladder	0.5	0.4	30.4	0.88	?
	Inclined surface	0.1	0.0	-	-	?
	Other	2.5	3.0	19.4	0.53	?
Surface condition	Dry	76.1	79.1	4.0	0.87	✓
	Wet	23.7	20.9	13.0	0.76	✓
Debris / obstacle present		23.6	29.7	23.1	0.74	×

Variable	Categories coded	% time by rater		Norm. Diff.	r	✓/×/?
		A	B			
Gross posture	Standing	61.9	64.6	4.3	1.00	✓
	Both knee kneel	11.3	11.7	4.0	0.99	✓
	Walking (flat)	7.0	5.3	27.2	0.65	×
	One knee kneel	5.1	5.0	1.1	1.00	✓
	Crouch	3.2	3.8	14.9	0.98	?
	Squatting	3.2	2.3	34.6	0.53	?
	Walk up	2.7	2.1	27.4	0.64	?
	Laying down	2.7	2.3	15.8	1.00	?
	Walk down	2.2	2.2	0.7	1.00	?
	Sitting	0.6	0.6	0.6	1.00	?
	Crawling	0.1	0.1	16.2	0.21	?
Hand at or above shoulder	Right	22.6	22.6	0.1	0.80	✓
	Left	20.1	21.3	6.0	0.84	✓
Trunk	Flexion	62.0	54.2	13.4	0.94	×
	Lateral bending and / or twisting	48.3	24.1	66.7	0.62	×

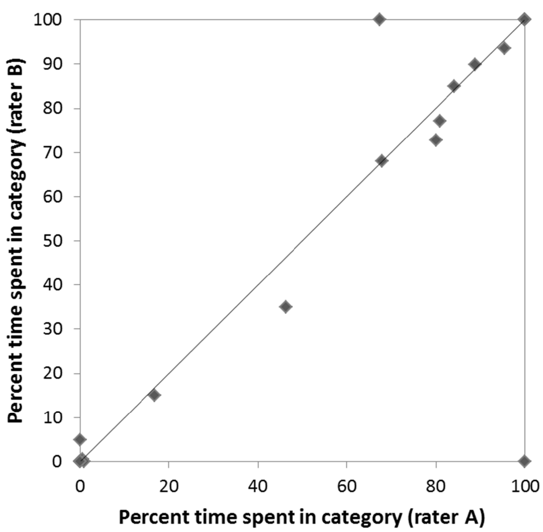

Figure 1. Example of correlation between rater A and rater B for percent time spent on a horizontal paved floor surface (diagonal line indicates perfect correlation)

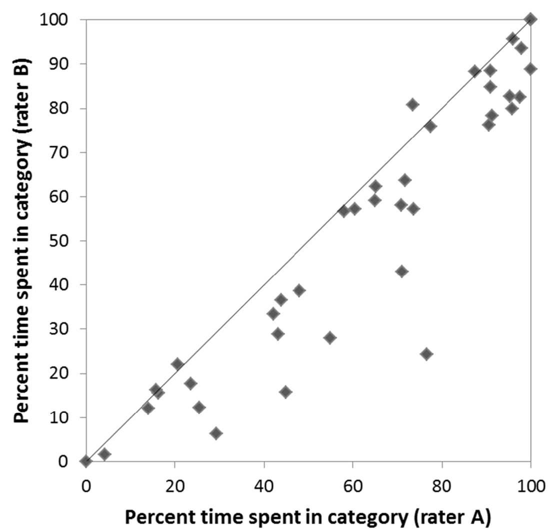

Figure 2. Example of correlation between rater A and rater B for percent time spent with trunk flexion greater than 20° (diagonal line indicates perfect correlation)

DISCUSSION

Exposure duration classification was consistent for most variables. However, there were some notable discrepancies between raters that could be in part explained by differences in domain knowledge about the work and differences in video-based job analysis experience. For example, post-hoc evaluation of the differences between raters indicated that rater A, who had collected some of the videos, was more accurate at estimating variables such as floor surface and surface condition as these conditions were often not clearly visible in the video frame. This accounted for most of the large discrepancies between raters, as seen in Figure 1. If appropriate video is unavailable, having individuals who are familiar with the task code safety and ergonomic risk factors is advisable, especially for the work environment variables. Additionally, these variables may be recorded along with the weights of items and be supplied to the personnel coding the videos. Likewise, rater B had considerably more experience than rater A in postural analysis, potentially resulting in the systematic discrepancy in coding trunk flexion (Figure 2). Additional ergonomics job analysis training could help reduce discrepancies related to experience.

Coding trunk lateral bending and/or rotation posed the greatest challenge to raters, with low correlation coefficients and high disagreement between raters. This was attributed to the angle at which the single video was collected, which did not provide adequate information to accurately estimate the rotation of the torso in relation to the hips. Hence, it is not advisable to measure the percent time with trunk lateral bending and twisting utilizing only one camera angle. This measure might be better estimated with two or more camera angles recording simultaneously or via on-site evaluations. Similar challenges were faced when coding trunk flexion; however, estimates were still considered reasonably reliable between raters.

It should be noted that this type of job analysis is quite time consuming. For our analysis, one minute of video took approximately 25-30 minutes to analyze. The high analysis time was associated with the large number of variables and exposure categories adopted for this study. After the initial set of variables was created they were expanded to be more comprehensive (ref. Table 1 and Table 2); however, there needs to be a balance between the comprehensiveness of the evaluation and the required coding time. We have therefore further refined and reduced the job analysis exposure variables and exposure categories (Table 3). We anticipate that this will reduce the coding time to approximately 10-12 minutes for each minute of video.

Poor video quality, varying video angles, and shaky video also exacerbated coding challenges and increased analysis time. Researchers who shadowed workers to collect video often did so in dimly lit conditions and on narrow walkways high above the ground with poor viewing angles due to limited space. There are significant challenges associated with not only on-site exposure assessments but also collecting video to analyze. Hands-free, high-resolution cameras with either low-light settings or with attached lighting would be beneficial for safe video capture that is appropriate for subsequent analysis.

From the initial evaluations of videos, some critical risk factor exposures are already visible. The percent time spent performing work on wet surfaces (22%) and working on or around debris (27%) was high. In addition, for 15% of the time the floor surface was the machinery/equipment itself. Workers also performed work kneeling 16% of the time and had back flexion angles of greater than 20° for 58% of the time. However, this data should be viewed with caution, as videos used may over-represent working time.

Table 3. Recommended exposure variables and exposure categories for evaluating the environmental and physical demands of maintenance work in mills and prep plants

Variables	Recommended categories
Floor surface	Paved, Unpaved, Horizontal grating, Inclined grating, Scaffolding, Stairs, Ladder, Machinery/Equipment, Other
Surface condition	Dry, Wet, Other
Standing on debris or obstacle	Yes, No
Gross posture	Walking, Standing, Kneeling, Squat/sit/crouch/crawl, Lying down, Other
Trunk flexion	Yes, No
Trunk lateral bending and/or twisting	Yes, No (or delete)
Hands at or above shoulder	Neither, 1 hand, 2 hands
Touching or holding item	One hand <10 lb, One hand > 10 lb, Two hands <10 lb, Two hands > 10 lb, Nothing

CONCLUSIONS

The objective of this study was to develop a methodology to quantify ergonomic and safety risk factors for maintenance work in mills and prep plants. A detailed taxonomy of environmental factors and postural risk factors was developed and the inter-rater reliability of the taxonomy was evaluated using a video-based job analysis technique. Although there was a high level of agreement between raters, there were discrepancies between raters for some exposure categories and the required coding time was quite high. Based on these results, the authors made refinements by reducing/combining similar categories for variables that should allow a comprehensive but practical job analysis of the environmental and physical demands of maintenance work in mills and prep plants.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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