Development of an observation-based tool for ergonomic exposure assessment in informal electronic waste recycling and other unregulated non-repetitive work

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Abstract: Most existing ergonomic assessment tools are intended for routine work. Time- and cost-efficient observational tools for ergonomic assessment of unregulated work are lacking. This paper presents the development of an observation-based tool designed to investigate ergonomic exposures among informal electronic waste workers that could be applied to other unregulated jobs/tasks. Real-time coding of observation is used to estimate the relative duration and intensity of exposure to key work postures, forceful exertions, movements, contact stress and vibration. Time spent in manual material handling activities such as carrying, lifting and pushing/pulling of working carts are also estimated. A preliminary study conducted with 6 e-waste workers showed that the tool can easily be used with minimal training and good inter-observer agreement (i.e., 89% to 100%) for most risk factors assessed. This new assessment tool provides effective and flexible options for quantifying ergonomic exposures among workers engaged in unregulated, highly variable work.

1. INTRODUCTION

Various tools for estimating ergonomic exposures exist, including observation methods (Chiasson et al., 2012; Herzog and Buchmeister, 2015), direct methods employing instrumentation (Winkel and Mathiassen, 1994) and self-reported questionnaires (Spielholz et al., 2001). These methods have been validated in industrial (Buchholz et al., 1996; Karhu et al., 1977) and office (Gambo, 2017) settings where tasks are predefined and constitute primarily a daily routine. Most current assessment methods are time-consuming (Chaffin et al., 2006; Takala et al., 2010), some are either expensive to implement, require intensive training of observers in order to effectively use them (Buchholz et al., 1996) or are just not conducive for use in unregulated work environments wherein the type and intensity of work performed, even by the same individual, are highly variable within and between days. For example, a previous study at an informal electronic waste (e-waste) recycling work-site at Agbogbloshie in Ghana, reported challenges with compliance to bioinstrumentation (Acquah et al., 2018). Characterising ergonomic exposures in low-resource, unstructured work settings such as e-waste recycling work in developing countries remains a challenge for ergonomics practitioners.

Specific to e-waste recycling processes at Agbogbloshie, the rudimentary work practices present a significant number of ergonomic hazards (Acquah et al., 2019b) and predispose workers to alarming rates of work-related musculoskeletal disorders (MSDs) (Acquah et al., 2019a). The latter study revealed a 90% overall prevalence of MSDs among e-waste workers, including the lower back (65%), knees (39.3%) and shoulders (37.4%). Quantifying suspected ergonomic risk factors related to unregulated work are important for examining associations between exposures and MSDs so as to design ergonomic interventions that address specific risk factors and work conditions in e-waste recycling. Our previous attempts to reliably quantify the physical work exposures of e-waste recycling workers at Agbogbloshie were hindered by the inability of existing observational tools to account for high variability in the type, duration, and intensity of e-waste recycling tasks performed by workers per shift and over time.

This study aimed to address a methodological gap by developing a low-cost observation-based ergonomic exposure assessment tool that enables easy quantification of the intensity and duration of physical exposures encountered in unregulated work settings such as informal e-waste work. As an initial step to assess inter-observer reliability (% agreement) and validity (i.e., ability to quantify differences in exposures between 2 high-risk worker categories), the developed tool was used on a limited scale to estimate exposures of e-waste dismantlers and burners.

2. METHODS

A methodology to characterize the key ergonomic exposures in e-waste recycling was developed based on concepts employed in other observational methods including RULA (McAtamney and Corlett, 1993), OWAS (Karhu et al., 1977), PATH (Buchholz et al., 1996), quick exposure checklist (QEC; Li and Buckle, 1998) and tools used to estimate ergonomic exposures in other work settings (Gilkey, 2002).

2.1 Tool Development

This study was approved by the College of Health Sciences Ethical Review Committee at the University of Ghana, Accra. Written informed consent was obtained from all participants.

2.1.1 Understanding the processes and activities

Initially, multiple field visits, walk-through observations and structured worker interviews were conducted from August 2018 through October 2018 in order to fully understand and appropriately document the processes involved in e-waste recycling. Three main e-waste recycling activities were previously identified and classified: i.e., collecting, dismantling and burning of e-waste (Acquah et al., 2019b). *Collecting* involved traveling to different neighbourhoods and nearby residential areas scavenging for end-of-life electronics. *Dismantling* involved breaking apart e-waste items to separate the different metal constituents. *Burning* involved open-air burning of insulated components (e.g., copper cables) to retrieve valuable metals for sale. Work methods for each job process were adequately described to capture the main components of the tasks involved and the work tools used.

2.1.2 Development of the coding guide and coding template

Following the initial phase described above, data coding criteria were developed. The focus of the tool being developed was to estimate the ergonomic risk factors e-waste workers were exposed to, the proportion of time each factor was present and the time spent in key manual material handling tasks. Thus, the tool was designed to assess posture, force, repetition, contact stress and vibration. In addition, manual material handling activities such as carrying, lifting, pushing/pulling a cart were also distinguished.

Postures were assessed for the neck, trunk, lower and upper limbs. To facilitate the pace of coding for each segment in real time while obtaining meaningful results in agreement with the relevant literature, segment postures were categorized on an ordinal scale with at most 2 or 3 levels as described below.

- *Neck:* Two postures were coded as either neutral (i.e. flexion or lateral bending < 30^0) or non-neutral (i.e. flexion or lateral bending > 30^0). The study opted for a simple binary classification based on findings by Buchholz et al. (1996) who demonstrated that adding more neck posture categories reduced inter-observer agreement for the PATH tool. Unlike OWAS which excludes the neck, this body segment was included since neck pain was among the top six MSDs reported by e-waste workers (Acquah et al., 2019a).

- *Trunk:* Three postures were distinguished and coded as neutral (<20º flexion), moderate (between 20º and 45º) or severe (>45º) forward flexion and/or lateral bending. The threshold criteria were adapted from prior studies [i.e., the PATH methodology by Buchholz et al., (1996), guidelines by NIOSH (2014)]. Lateral bending or twisting were combined with flexion postures since these postures were observed to often occur in conjunction. The addition of moderate and severe flexion to trunk postures (although absent in OWAS) was based on findings by Punnett et al. (1991) who reported increased risk of back disorders associated with severe vs. mild trunk flexion, twisting and lateral bending.

- *Upper limbs*: Three postures similar to those in PATH (Buchholz et al., 1996) and OWAS (Karhu et al., 1977) were distinguished and coded as hands/arms below waist height, below shoulder height but above waist height, and above shoulder height.

- *Lower limbs*: Three postures were categorised as walking, sitting or standing, which were simplifications of those used in in other methods (Buchholz et al., 1996; Karhu et al., 1977). Walking was coded as either ordinary walking or walking while pushing/pulling a cart as is usually the case for e-waste collectors. Standing was either neutral or standing with knees bent >45º. Sitting was coded in 3 subcategories; sitting with either hips and knees at about 90º, hips and knees greater than 90º or hips and knees less than 90º.

Other ergonomic risk factors assessed in addition to posture included force exertions and movement repetition using ordinal categories based on the QEC (Li and Buckle,2000). Force was subjectively graded as low (≤1kg), moderate (between 1kg to 4kg) or high (≥4kg). Repetition was coded as low (≤10x per min), medium (11-20x per min), and high (≥20x per min). The developed tool also assessed exposure to contact stress and vibration. These were coded on a binary scale as either visually present or absent.

Following initial piloting of the tool and in-depth consultations with experts in the field, the tool was modified to include common manual material handling activities performed during e-waste recycling, i.e., carrying, lifting, pushing/pulling of a cart or wheel-barrow. Lifting and carrying activities were coded as Light (≤5kg), Moderate (6 to 10kg), Heavy (11 to 20kg) and Very Heavy (≥20kg), akin to the QEC (Li and Buckle, 2000). In order to familiarize observers with estimates of the weight handled by workers, frequently handled items and work tools identified from field visits were weighed using a weighing scale prior to conducting structured observational assessments. With respect to pushing/pulling of wheelbarrow or cart, the focus of the coding was whether the wheelbarrow or cart was empty or loaded.

To facilitate easy recording of observed data in the absence of hand-held tablets or computerised devices, a pen and paper-based coding template was designed. Ordinal categories associated with each of the risk factors assessed were assigned numerical codes and written in cells juxtaposed to these risk factors. The columns in the template corresponded to the observation duration/time and the rows corresponded to the ergonomic risk factor being assessed. Each cell corresponded to 60 seconds of observation. To enhance speed in data coding, when no changes were observed between two epochs, the preceding cell was left blank until a change in the risk factor being assessed was observed at which point the new value was written in the cell corresponding to that time interval.

2.2 Observer Training

Two research assistants (RAs) were trained for two weeks. The first week of the training focused on familiarizing the RAs with the processes and work methods involved in e-waste recycling by watching assigned videos of workers performing e-waste recycling and interpreting the various exposure codes using a coding guide. Next, the RAs were instructed on use of the newly developed tool to code observations from the videos. During this time, they were allowed to pause the video when necessary to facilitate the capture/identification of required details. They were also encouraged to discuss any instances of confusion or ambiguity with the coding process among themselves. The second week of training was conducted in the field and focused on coding from direct observations in real time. During the direct field observations, the observers worked concurrently so that inter-observer agreement could be established.

2.2.1 Inter-observer agreement

Inter-observer agreement was determined by comparing coded data for 6 workers including 3 dismantlers and 3 burners. Each worker was observed while performing their primary dismantling or burning task by two observers simultaneously for 10 minutes. As a preliminary study, the 10min duration was considered adequate for capturing limited exposure to a range of risk factors. Inter-observer agreement using the kappa statistic (Stata v.15) was compared for the neck, trunk, upper and lower limb postures as well as force, repetition, contact stress and vibration.

2.3 Piloting of the tool

The developed tool was piloted on the same 6 workers whose data were used for assessing inter-observer agreement. Each worker was observed for a full work-day and the proportion of time exposed to different ergonomic risk factors computed.

2.3.1 Procedure for data collection

Workers were approached during the field visits and were presented the purpose of the study. At the time of the visit 6 workers consented to participate in the study and were observed for one entire work shift. E-waste workers have variable work schedules and work durations which is usually dependent on availability of raw materials to work with (Acquah et al., 2019b). The observers also wore a video camera (GoPro Inc.) to obtain a backup of the observed data thus ensuring the opportunity to review and/or verify missing data later if necessary.

2.3.2 Data processing

The observation data coded on the paper templates by each observer were entered into MS Excel spreadsheets. Conventional methods were used to count the frequency of noted observations. The proportion of time spent in various postures, activities and exposure duration to risk factors were computed in Excel, and analysed in Stata v.15.

3. RESULTS

3.1 Demographics

Mean ± standard deviation age, weight and height of participants were 22.8 ± 2.3 years, 69.5 ± 9.0 kg and 168.3 ± 5.7 cm, respectively. Differences in age (p = 0.440), weight (p = 0.148) and height (p = 0.072) between dismantlers and burners were not statistically significant.

3.2 Inter-observer agreement

Data coded by the two observers for neck posture (dismantlers), upper limbs (burners), lower limbs (burners and dismantlers) as well as repetition and contact stress (dismantlers) were in perfect agreement. Table 1 summarizes the percent agreement and kappa statistic for other areas. Pooled data showed 89.17% to 100% agreement for all risk factors observed.

Table 1: Inter-observer agreement for two trained observers using 10-minute observations each of 6 workers (i.e., 3 burners and 3 dismantlers).

Variable	**Burners (n = 30 minutes)**		**Dismantlers (n = 30 minutes)**		**Pooled (n = 60 minutes)**	
Posture	Kappa	% agreement	Kappa	% agreement	Kappa	% agreement
• Neck	0.760	93.33%	**	**	0.782	96.67%
• Trunk	0.687	86.67%	0.257	91.67%	0.695	89.17%
• Upper limbs	**	**	0.000	96.67%	0.000	98.33%
• Lower limbs	**	**	**	**	1.000	100%
Force	0.754	95.00	0.636	86.67%	0.878	94.17%
Repetition	0.610	85%	**	**	0.667	92.50%
Contact stress	0.851	93.33%	**	**	0.925	96.67%
Vibration	0.000	96.67%	0.651	96.67%	0.933	96.67%

**Perfect agreement. All coded values were the same for both observers.

3.3 Preliminary data (exposure profile for 6 workers)

The total observation times were 721 minutes for the 3 burners and 382 minutes for the 3 dismantlers. The proportion of work time corresponding to various ergonomic exposures differed between burners and dismantlers. Burners spent 65.2% of their work time in neutral standing (standing with knees straight) and 32.3% sitting with their hips and knees angles less than 90º. Dismantlers spent 85.1% of their work time sitting (with their hips and knees less than 90º) and 13.9% in neutral standing. Figure 1 depicts the proportion of working time spent by burners and dismantlers in different neck, trunk and upper limb postures. Burners and dismantlers spent the majority of their work time (81.3% and 99.2% respectively) in non-neutral neck postures. They mostly worked with their arms/hands below waist level (99.7% for burners and 99.0% for dismantlers). Whereas dismantlers worked with their trunk in moderate flexion (79.8% of working time), burners worked most of the time with their trunks severely flexed (76.4% of work time).

Figure 2 summarizes the proportion of time burners and dismantlers were exposed to various intensities of force and repetition. Burners were exposed to low force exertions for 96.5% of their work time, while dismantlers were exposed to high force exertion 66.8% of their work time. However, burners and dismantlers spent most of their work time (73.5% and 84.8%, respectively) in high repetition tasks (i.e. > 20 movements/min).

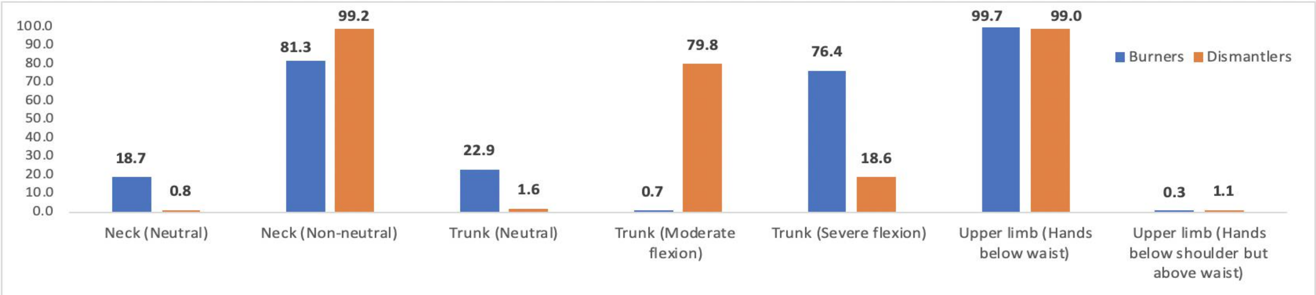

Figure 1: Proportion of time (%) spent by burners (n = 3) and dismantlers (n = 3) in different work postures

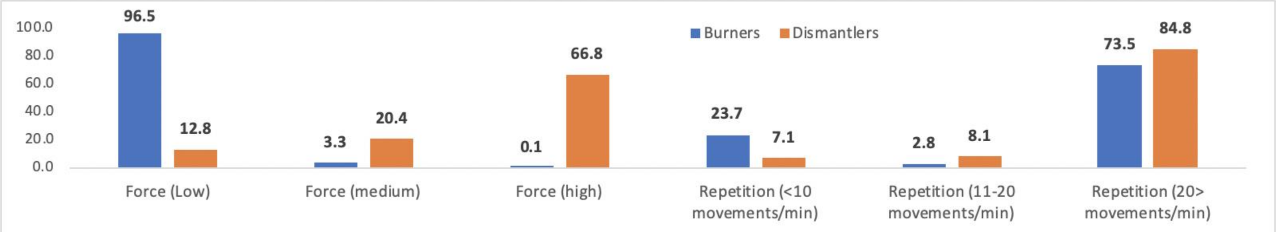

Figure 2: Proportion of time (%) exposed to different intensity levels of force and repetition for burners (n = 3) and dismantlers (n = 3).

Duration of exposure to contact stress were higher among dismantlers than burners (87.2% vs. 5.6% of the work time, respectively). Furthermore, exposure duration to hand vibrations was higher among dismantlers than burners (i.e., 77.8% vs. 2.9% of the work time, respectively).

4. DISCUSSION

An observation-based method was developed to quantify for the first time and in real time ergonomic exposures among unregulated type of work such as e-waste recycling in a developing country. Preliminary assessments of inter-observer agreement and real-time data coding suggests that our tool provides the necessary information to quantify the key physical exposures. Compared to other checklist-based tools (Laitinen et al., 1999; Neitzel et al., 2013; Seixas et al., 1998), our tool provides the opportunity to quantify intensity and duration of exposure to ergonomic hazards in real time.

Inter-observer agreement was high for upper and lower limb postures. This was mainly because lower limb postures walking, sitting and standing were easy to identify and their corresponding exposure levels were easy to distinguish. Burners mostly worked in a standing posture and occasionally would sit in between burning activities or while they waited for dismantlers to bring them items to burn. Among burners, standing with severe trunk flexion (76.4% of work time) was observed when not actively burning as they spent a substantial amount of time picking up pieces of metal that had fallen to the ground during the burning of e-waste. Upper limb activities for both burners and dismantlers were often performed with the arms below the waist height, which was relatively straightforward for the observers to identify. However, visual coding of trunk postures in real-time every 60 seconds, particularly discriminating between neutral and slight trunk flexion, was more challenging and susceptible to misclassification resulting in moderate agreement (McHugh, 2012) between observers (i.e., 89.17% agreement, kappa = 0.69).

Other common coding errors related to presence/absence of contact stress and vibration, especially for burners. These risk factors were easily identifiable among dismantlers since their task were performed with high force intensity (66.8% of the work time) using hammers and chisels while burners predominantly exerted low forces most of the time (96.5%). Repetition was difficult to estimate since the observers had little time to count in quick succession the number of hand movements while also discerning other risk factors within the 60s-time interval. Thus, during the training period observers had to get familiar with visual approaches to quickly and easily estimate these counts. As such, some disparities occurred between observers resulting in moderate agreement (kappa = 0.667, with 92.5% agreement). Finally, judging moderate and severe force was also a challenge for observers.

5. CONCLUSIONS

The newly developed tool was effective in capturing information in real time the relative duration and intensity of key risk factors. The method adequately estimates time spent in postures, exerting forceful and repetitive movements as well as indicating whether contact stress and vibration were absent or present. The tool is relatively easy to use compared to other established observation-based tools that are time consuming to evaluate one risk factor at a time and require a prolonged training period to achieve high inter-observer reliability.

The developed tool is amenable to unregulated work environments since the “low tech” pen and paper approach can be used in low-resource settings where funds to purchase portable computing devices and direct measurement instrumentation may be limited. While advantageous in low-resource settings, the pen and paper approach made the transfer of coding into spreadsheets tedious and time-consuming. Future studies could explore using the tool on portable (hand-held) computing devices. Although the simplification into a few categories (1-3 maximum) allows real-time coding, the tool cannot be used without some training. More comprehensive assessments of intra- and inter-observer reliability, and a study examining associations between physical exposures and MSD prevalence is underway.

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