A preliminary assessment of physical work exposures among electronic waste workers at Agbogbloshie, Accra Ghana

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ABSTRACT

Occupational exposure associated with unstructured, informal e-waste recycling has received very limited attention. This study aimed to quantify the occupational physical exposures among informal e-waste workers at the largest e-waste site in Africa.

A cross-sectional field survey of 163 male e-waste workers was conducted using a self-report occupational physical activity questionnaire, along with direct work observations, and pedometer estimates of walking activity for a subset of workers (n = 42).

Results indicated significant differences in self-reported 7-day work exposures among the three main e-waste job categories, namely, collectors (n = 70), dismantlers (n = 73) and burners (n = 20). Prolonged walking, sitting and standing on five or more days in the workweek was frequently reported by collectors (87%), dismantlers (82%) and burners (60%), respectively. Nearly 90% of collectors and burners and 60% of dismantlers reported lifting and carrying on five or more days in the workweek.

The exposure combinations identified suggest a risk for musculoskeletal disorders (MSDs). Findings call attention to the need for research examining potential associations between physical exposures and MSDs affecting e-waste workers in Agbogbloshie. The high exposure variability both between and within workers has implications for future exposure assessments conducted in unregulated, informal work settings.

1. Introduction

Electrical and electronic waste (e-waste) poses a new global health challenge (Bakhiyi et al., 2018; Perkins et al., 2014). Rapid technological advances and high demand for new electronic and electrical equipment has led to accelerated obsolescence and a shorter lifespan for modern-day electronic appliances, devices and gadgets (Shamim and Mursheda, 2015). Consequently, managing and recycling the sheer volume of discarded e-waste has created a global environmental and occupational health problem. Each year, large volumes of e-waste from Europe and North America get shipped to developing countries such as Ghana, Nigeria and South Africa (Maphosa and Maphosa, 2020; Oteng-Ababio, 2012). While a small fraction of these electronics get put to second-hand use, the majority (estimated over 80%) are either unusable or very close to their end-of-life and end up in dumpsites (Maphosa and Maphosa, 2020). Subsequently, sustainable management of these waste in a manner that is environmentally and occupationally safe has become a challenge (Adanu et al., 2020; Bakhiyi et al., 2018).

E-waste recycling activities in middle- and low-income countries is particularly challenging due to the lack of appropriate recycling infrastructure and policy (Maphosa and Maphosa, 2020). Safe work methods and equipment required for efficient extraction of re-usable and/or valuable constituents from old, discarded electronic appliances and devices are lacking (Zhang and Xu, 2016). The recycling process is almost exclusively manual, informal, unregulated and conducted by low-skilled workers, with little or no attention to occupational health and safety practices such as the use of personal protective equipment or properly designed workstations. Manual e-waste recycling is

labour-intensive and has become an emerging global health problem due to the health risks it presents (Perkins et al., 2014). Prior studies describe manual waste collection as requiring varying levels of manual material handling (MMH) combined with long periods of sitting and/or standing in non-neutral postures, and/or walking in unfavourable outdoor environmental conditions (Emmatty and Panicker, 2019; Kuijer et al., 2010). These forms of physical activities are likely to have adverse effects on the health of workers (Kwon et al., 2011), and more particularly when performed under harsh environmental conditions (Kong et al., 2018). Studies specific to informal e-waste recycling work at worksites in China (Chi et al., 2011), India (Wath et al., 2011), Brazil (Gutberlet and Baeder, 2008). and Nigeria (Ohajinwa et al., 2018) collectively suggest diverse socioeconomic realities and work conditions across locations, while highlighting the pervasive problem of informal e-waste recycling faced by many countries around the world.

1.1. Background on E-waste recycling at agbogbloshie, Ghana

Over the last 20 years, Agbogbloshie in Accra, Ghana, has become one of the largest dumping grounds for electronic waste in the world (Heacock et al., 2016), making it one of the most polluted places on earth (Bernhardt and Gysi, 2013; Oteng-Ababio, 2012). E-waste workers at this site are among the poorest and the most vulnerable members of the urban populations in Ghana (Akormedi et al., 2013; Amankwaa, 2013). The site is occupied mainly by migrants from the northern part of Ghana. Among them are farmers who have travelled to Southern Ghana including Agbogbloshie to look for alternate sources of income. The primary goal of e-waste recycling at Agbogbloshie is to recover valuable scrap metals such as copper, gold, iron and aluminium for sale (Acquah et al., 2019; Akormedi et al., 2013). The major processes consist of scavenging and collecting e-waste items, then manually dismantling irreparable and/or non-functional items, and finally open-air burning of insulated wires and other components that cannot be dismantled in order to extract valuable metals. Engaging in informal e-waste recycling at Agbogbloshie is known to adversely affect the health of workers due to high exposure to toxic chemicals (Basu et al., 2016; Feldt et al., 2014; Srigboh et al., 2016; Wittsiepe et al., 2015), elevated noise (Akormedi et al., 2013; Burns et al., 2016; Carlson and Krystin, 2016), and harsh environmental conditions (Akormedi et al., 2013; Burns et al., 2016; Yu et al., 2017).

Prior studies on the physical work conditions and work-related physical activity exposures of e-waste workers at Agbogbloshie have only provided qualitative interview-based descriptions (Acquah et al., 2019; Akormedi et al., 2013; Yu et al., 2017). These studies offer evocative summaries of the physical work conditions and various work-related illnesses and injuries. For example, a recent qualitative study by Acquah et al. (2019) reported both acute injuries (e.g., burns, lacerations) and chronic health issues such as musculoskeletal pains, coughs, and headaches across the three main categories of e-waste workers: collectors, dismantlers and burners. The adverse work-related health effects were compounded by the lack of use of personal protective equipment, low level of health risk awareness, and by evidence of psychosocial stressors associated with e-waste recycling. The latter includes psychological demands, poor social support, low income, and limited opportunities for other types of gainful employment (Acquah et al., 2019; Akormedi et al., 2013; Yu et al., 2017). However, reliable quantitative data on the nature of the physical exposures at the Agbogbloshie work site is lacking. Hence, we undertook an initial step to quantifying these physical work exposures in order to understand the magnitude of the risk of developing work-related musculoskeletal disorders (MSDs) towards the longer-term goal of developing appropriate ergonomic interventions adapted to the local context.

1.2. Occupational exposure assessment in informal work

Ergonomics studies on occupational physical exposures among low-

skilled workers who engage in non-structured, informal work such as waste collection and sorting is relatively scarce (Emmatty and Panicker, 2019; Todd, 2009). To date, most studies on occupational exposures to injury risk factors have largely focused on formal industrial settings such as manufacturing (Bao et al., 2015; Dickerson et al., 2018; Lavender et al., 1999; Marshall et al., 2000; Mossa et al., 2016; Silverstein et al., 1987), construction (Buchholz et al., 1996; Parida and Ray, 2012), agriculture (Kong et al., 2018) healthcare (Czuba et al., 2012; Janowitz et al., 2006; Punnett and Bergqvist, 1999; Robertson et al., 2012; Stucke and Menzel, 2007) or office work (Armstrong et al., 1994; Wærsted et al., 2010), to cite only a few. The main focus of these physical work exposure assessments include quantifying the magnitude of the exposure (e.g., intensity of force exertions, weight of loads carried, non-neutral postures), the repetitions involved, and the duration of the exposure (Andreas and Grooten, 2018; Chiasson et al., 2012; Li and Buckle, 1999; Takala et al., 2010). These physical exposures are predisposing factors to the development of work-related MSDs (Eatough et al., 2012; Kuorinka et al., 1995; Marras, 2008) and potentially interact with a range of other organisational, psychosocial and individual factors (Bongers et al., 2002; Kuorinka et al., 1995; Oakman et al., 2014; Bongers et al., 2002; Jaffar et al., 2011) to cause or aggravate MSDs.

A critical aspect of selecting a suitable method for physical exposure assessment is the structure or regularity of the job content. Structured work environments such as manufacturing assembly lines are more straightforward to characterize based on a limited amount of exposure data. In contrast, exposure assessment in non-repetitive manual work (i. e., where the intensity, repetitions, and duration of the tasks vary over time and between workers) is challenging because the assessments may need to be performed across multiple workers and over long durations in order to develop a representative profile of the exposure. Thus, assessment of physical work exposures in informal and unstructured work settings often require a preliminary job analysis (Acquah et al., 2019) and use of multiple measurement methods in order to understand their variability (Neitzel et al., 2013). Methods for quantifying physical work exposures include self-reported questionnaires, observational methods, direct measurements (Burdorf and van der Beek, 1999; Li and Buckle, 1999) and biomechanical analyses involving specific tools such as the NIOSH lifting guide or the University of Michigan's 3D Static Strength Prediction Program (Chaffin et al., 2006). Direct measurements and biomechanical analyses provide more accurate results; however, these methods tend to be expensive (Juul-Kristensen et al., 2001) and their application to non-repetitive work settings can be challenging (Chaffin et al., 2006). Compared to direct measurements, assessments relying on observational methods and self-reported questionnaires are more cost-effective and easier to implement in applied settings, and thus are still widely used despite their subjective nature and lower accuracy and precision (Takala et al., 2010).

1.3. Study aims

The primary aim of this study was to quantify the occupational physical activity (OPA) exposures of e-waste workers engaged in informal e-waste recycling at Agbogbloshie, and to compare these exposures among the three main e-waste job categories, namely, collectors, dismantlers and burners.

2. Methods

2.1. Study site and population

The Agbogbloshie e-waste site is about 0.5 km² (Laskaris et al., 2019). It is located close to the central business district of Accra (Oteng-Ababio, 2012) near the Agbogbloshie food market, and along the banks of the Korle lagoon and Odaw river (Davis et al., 2019). The workforce largely consists of itinerant workers who collect scrap metal and e-waste items, dismantle items to extract valuable constituents and

burn items that cannot be dismantled (Davis et al., 2019). The workers are almost exclusively males, primarily young adults and occasionally minors (<18 years old).

2.2. Study design

A cross-sectional study involving the use of a questionnaire, supplementary field observations, and pedometry measurements was conducted between August to October 2018. Direct field observations were conducted on random days throughout the study period in order to contextualize and supplement the data obtained from questionnaires and direct field measurements. E-waste workers were recruited for the study by word of mouth. They were recruited from different locations of the site in an attempt to obtain a diverse sample in terms of job category (i.e. collecting, dismantling and burning). Following a verbal description of the study objectives and methods, a self-selected sample of 163 male e-waste workers agreed to participate in the study. Written informed consent was obtained from all adult participants. For minors, written informed consent was obtained from the adult relatives they work with or their immediate adult work supervisors. These work supervisors typically served as guardians for the minors while they were at the e-waste site.

The study was approved by the College of Health Sciences Ethical Review Committee at the University of Ghana, Accra. Participants were compensated 30 Ghana Cedis (approximately 5.26 US dollars) after data collection was completed.

2.3. Assessment tools

2.3.1. Demographic questionnaire

A brief questionnaire was developed to obtain information about demographic characteristics (e.g., age, gender), primary job category, main work activities performed, and work history of participants (e.g. number of years and/or months having worked in e-waste recycling, average number of days and hours of work per week). A team of 5 researchers serving as interviewers fluent in English as well as Dagbani, which is the local dialect spoken by e-waste workers, administered the questionnaire and recorded participant responses on paper. In addition to the questionnaire, participants' weight, stature, and stride length were measured and used later to calibrate the pedometers used in the measurement of cumulative step counts. Stride length was computed using procedures recommended by the device manufacturer, namely, by measuring the total distance walked for 10 steps (i.e., measured from the heel of the foot taking the first step to the toe of the foot taking the last step) and dividing the distance by 10 (Omron, 2019).

2.3.2. Modified occupational physical activity questionnaire (OPAQ)

The OPAQ (Reis et al., 2005), which is a seven-item survey questionnaire, was used to collect information on the average time spent per week in work-related sitting or standing, walking, and in performing heavy labour activities such as lifting, carrying, pushing and pulling. For the purposes of this study, we collectively refer to lifting, carrying, pulling and pushing activities as MMH in place of the less common term 'heavy labour activities' used in the OPAQ. Modelled on questions from the OPAQ and Quick Exposure Checklist (QEC; Stanton et al., 2004), participants were also asked to indicate the maximum weight handled in the workweek during MMH on an ordinal scale as either light (5 kg or less), moderate (6–10 kg), heavy (11–20 kg), or very heavy (>20 kg). Participants were considered quite adept at estimating weight since they often weigh e-waste items to determine its financial value (i.e., price when buying or selling) as part of their typical workflow. A pilot study was conducted in December 2017 to determine the feasibility of using the OPAQ, specifically, to determine whether participants understood the questions and could respond appropriately to obtain the desired information. Based on the results and feedback from 15 e-waste workers, three modifications to the OPAQ were implemented. First, since workers

indicated that their estimation of the proportion of time spent sitting, standing and walking or performing MMH activities was not reliable (poor estimation of exact time), the questionnaire was modified to obtain a binary response (Yes/No) to whether each activity was performed for (1) at least 1 h continuously during the workday, and (2) a total of 4 h in a workday. Second, the frequencies of work-related standing and walking were assessed separately as opposed to the original OPAQ which assesses standing and walking together. Third, the assessment of MMH activities (labelled "heavy labour" in the original OPAQ), which form the core component of e-waste recycling, was assessed by asking participants to rate on an ordinal scale how often they performed lifting, carrying, and pushing and/or pulling activities within a workweek. The modified version of the OPAQ (Appendix-A) was administered to the participants, their verbal responses were documented on the paper questionnaire by the researcher, and subsequently coded into Stata V15 for analysis. When responding to the questionnaire, participants were instructed to use the full workweek prior to when the questionnaire was presented as the reference period (i.e., a 7-day period starting Monday morning).

2.3.3. Pedometer measurements

From the 163 participants, a random subset of 47 participants were provided a waist belt instrumented with a pedometer (Omron HJ-321) at the start of their workday and collected at the end of the workday for two consecutive workdays randomly selected in the study period. The average readings from both workdays were used in the analysis. Ten pedometers were acquired for the study; however, 5 pedometers were not returned by participants early in the study. Thus, data collection was limited to using 5 pedometers. This also caused a decrease in sample size from 47 down to 42 of 163 participants equipped with a pedometer on two consecutive workdays. Overall, pedometry data obtained from 9 collectors, 27 burners and 6 dismantlers were used in data analysis. The pedometers provided data about total steps count, aerobic step counts, average steps per minute, distance walked, and energy expenditure (kilocalories; kcal) over an entire workday. Aerobic steps were recorded whenever a minimum of 60 steps were taken within a 10-min period (Duchečková and Forejt, 2014). The Omron pedometer has been validated against other well-known physical activity monitors (Battenberg et al., 2017; Kendall et al., 2019) and has an accuracy greater than 90% for measuring step counts (Battenberg et al., 2017). This specific pedometer model has been used widely in other studies that monitored physical activity (Olzenak and Byrne, 2017; Owoeye et al., 2016; Sampaio et al., 2016; Yusoff et al., 2018).

2.4. Statistical analysis

All measures were analysed using the Stata V15 software package (StataCorp LLC, TX). Descriptive statistics were used to summarise demographic variables and the proportion of workers who performed different types of OPA. Separate one-way ANOVA tests were used to examine statistical differences in age, years on the job, days worked per week, and hours worked per day across the three primary job categories (i.e., collectors, dismantlers, and burners). Separate Chi-square (χ^2) tests were conducted to examine differences in the proportion of participants by primary job category that reported long durations of sitting, standing, and walking postures, frequent MMH activities of lifting, carrying, pushing and/or pulling, and maximum load handled, which were assessed on ordinal rating scales. Significant main effects of job category were further analysed using Chi-square pairwise tests with a Bonferroni adjustment for multiple comparisons ($p < 0.05$). Pedometer measurements (total and aerobic step counts, steps per minute, distance walked, and energy expenditure) were not normally distributed, and thus medians and interquartile ranges (IQR) were reported in order to reduce the influence of data outliers. Separate non-parametric Kruskal-Wallis tests were used to examine significant differences across the three e-waste job categories for each of the five pedometer measures.

Qualitative data obtained from direct observations were used to supplement and contextualize the quantitative results where possible.

3. Results

3.1. Participant demographics

The age of participants ranged from 11 years to 43 years. Of the 163 participants, 25 (15.3%) were minors while 6 (3.6%) did not know their age. The majority of participants (63.1%) were in the 18–29 years age range. Only 6 participants (3.8%) out of those knowing their age were older than 40 years. Work experience represented as the number of years worked in e-waste recycling ranged from 1 week to 25 years with an average ± standard deviation (SD) of 6.48 ± 5.44 years. Participants worked for at least 2 days in a week but the majority reported working at least 6 days (88%) or 7 days (54%) per week. The mean ± SD reported work duration per day was 9.95 ± 2.43 h and ranged from 2 h to 14 h depending on the availability of work and the type of e-waste recycling activity performed. Direct field observation data revealed an average ± SD work duration of 6.26 ± 2.63 h per day with a range of 2–12 h per day with intermittent breaks that varied considerably from 10 min to about 4 h such as when waiting for recycling products from other e-waste workers (i.e., from collectors to dismantlers, or from dismantlers to burners).

Based on the primary job performed, 70 (42.9%) of the participants were categorized as collectors, 73 (44.8%) as dismantlers, and 20 (12.3%) as burners. A few of these participants also reported performing tasks associated with a secondary job category. For instance, 9 collectors (5.5%) engaged in occasional dismantling of e-waste, 3 collectors (1.8%) and 2 dismantlers (1.2%) also reported performing burning-related tasks. Due to the small number of such cases, only the primary job category was used in the subsequent statistical data analysis.

Table 1 summarizes the age distribution, the number of years of experience in e-waste work, number of workdays per week and hours of work per day stratified by the three e-waste job categories. Collectors had the broadest age range (11–43 years). Notably, all the minors in the study were collectors. The average age differed significantly by job category ($p = 0.004$). The mean age was significantly higher for dismantlers (26.7 ± 6.6 years) compared to collectors (23.4 ± 6.2; $p = 0.007$) and burners (22.8 ± 3.9; $p = 0.055$). Years of work experience in e-waste recycling also differed significantly by the primary job

category ($p = 0.013$). Years of e-waste work experience was significantly higher among dismantlers (7.9 ± 5.4) compared to collectors (5.3 ± 5.7; $p = 0.014$) and burners (5.5 ± 3.2; $p = 0.176$). There was no significant difference in the average number of workdays per week ($p = 0.292$) or average hours worked per day ($p = 0.277$) among the three categories of e-waste workers (Table 1).

3.2. Occupational physical exposures of E-waste workers

3.2.1. Sitting, standing and walking

Direct field observations indicated that all of the participants performed their work while either sitting, standing or walking during the workday. The corresponding proportions are detailed after the following contextual description to contrast with what is usually assumed in regulated industrial work. Dismantlers were observed usually sitting on a very low stool or a dismantled appliance such as an old cathode ray tube television or microwave oven. Hence, sitting was more of a squatting posture such that the included angles at the knees and hips were less than 90°. Observations also revealed a diverse range of sitting durations between dismantlers. When not walking to search for and collect items, the collectors' mode of sitting varied widely. It involved sitting on their collection cart that corresponded to a sit-stand posture with the included angle at the hips and knees exceeding 90°. Collectors also occasionally sat on the ground or on a piece of log or rock along the route travelled in search of e-waste. A considerable amount of sitting was observed during workers idle time. Dismantlers and burners took rest breaks seated under a shed after they exhausted their stock of items to dismantle or burn and waited for supplies. Collectors were also observed sitting to rest at random intervals and for varying durations while in search of e-waste in nearby communities. For all workers, standing and walking were done on uneven surfaces. These surfaces were soft and muddy during rainy periods or hard and bumpy during the dry season. Walking performed by dismantlers was primarily for transporting insulated components, cables, and wires to the burners for the extraction of metal, e.g., gold, copper, aluminium. Due to toxic fumes generated during open-air burning this task was done at short distances away from the sites where dismantling and other ancillary tasks of weighing and selling of e-waste products were performed (Laskaris et al., 2019; Nti et al., 2020; Takyi et al., 2020). In addition to burning insulated copper wire for dismantlers at a fee, some burners also spent time in extreme torso flexion picking and gathering leftover pieces of metal scrap littered across the burning sites for sale. This was observed more commonly among entry-level burners.

Table 2 summarizes the proportion of collectors, dismantlers and burners who reported engaging in sitting, standing or walking for 1 h or more continuously in a workday, and separately for a total of 4 h or more in the workday during the previous workweek. Sitting continuously for ≥1 h in a workday was reported mostly by dismantlers (91.8%) while standing continuously for ≥ 1 h during a workday was reported mostly by burners (95%). Chi-square test of proportions indicated no statistically significant differences in the proportion of participants across the three job categories who reported sitting ($p = 0.119$) or standing ($p = 0.070$) continuously for ≥ 1 h in a workday. However, the proportion of participants who reported ≥1 h of continuous walking differed significantly ($p = 0.018$) across job categories. Post hoc comparisons revealed that the proportion of participants reporting continuous walking ≥1 h in a workday was significantly higher for collectors (92.9%) compared to dismantlers (78.1%; $p = 0.038$) but not significantly different from burners (75.0%).

The proportion of participants that spent ≥4 h per workday sitting, standing and walking differed significantly by job category ($p < 0.001$) for each of the three postures (Table 2). The proportion of participants that reported sitting for ≥4 h was significantly higher for both dismantlers (82.2%) and burners (65.0%) compared to collectors (30.0%; $p < 0.001$ and $p = 0.013$, respectively). The difference in proportions between dismantlers and burners was not statistically significant

Table 1
Participant primary job category and demographic characteristics.

Variable	Job Category (n)	Range	Mean ± SD	ANOVA results
Age in years	Collectors (69)	11–43	23.4 ± 6.2	$F = 5.77$, $p = 0.004$ *
	Dismantlers (70)	18–42	26.7 ± 6.6	
	Burners (18)	18–30	22.8 ± 3.9	
Years of work at e-waste site	Collectors (70)	0.02 (1wk) - 22	5.3 ± 5.7	$F = 4.45$, $p = 0.013$ *
	Dismantlers (73)	1–25	7.9 ± 5.4	
	Burners (20)	1–13	5.5 ± 3.2	
No. of workdays per week	Collectors (70)	4–7	6.3 ± 0.7	$F = 1.24$, $p = 0.292$
	Dismantlers (73)	2–7	6.1 ± 1.0	
	Burners (20)	2–7	6.0 ± 1.1	
No. of working hours per day	Collectors (70)	6–14	10.3 ± 1.8	$F = 1.30$, $p = 0.277$
	Dismantlers (71)	4–14	9.8 ± 2.9	
	Burners (20)	2–12	9.4 ± 2.7	

* indicates significance at $p < 0.05$.

Table 2
Proportion of e-waste workers stratified by job category engaged in work-related sitting, standing and walking activities.

Variable	Job Category (n)	Proportion of participants		Chi-square statistic and p-value
		Yes (%)	No (%)	
Sitting continuously for ≥ 1 h during a workday	Collectors (70)	56 (80.0%)	14 (20.0%)	$\chi^2 = 4.487$, $p = 0.106$, Fisher's exact $p = 0.119$
	Dismantlers (73)	67 (91.8%)	6 (8.2%)	
	Burners (20)	18 (90.0%)	2 (10.0%)	
Standing continuously for ≥ 1 h during a workday	Collectors (70)	53 (75.7%)	17 (24.3%)	$\chi^2 = 4.881$, $p = 0.087$, Fisher's exact $p = 0.070$
	Dismantlers (73)	52 (71.2%)	21 (28.8%)	
	Burners (20)	19 (95.0%)	1 (5.0%)	
Walking continuously for ≥ 1 h during a workday	Collectors (70)	65 (92.9%)	5 (7.1%)	$\chi^2 = 7.211$, $p = 0.027$, Fisher's exact $p = 0.018*$
	Dismantlers (73)	57 (78.1%)	16 (21.9%)	
	Burners (20)	15 (75.0%)	5 (25.0%)	
Sitting for a total of ≥ 4 h during a day's work	Collectors (70)	21 (30.0%)	49 (70.0%)	$\chi^2 = 40.376$, $p = 0.001$, Fisher's exact $p = 0.001*$
	Dismantlers (73)	60 (82.2%)	13 (17.8%)	
	Burners (20)	13 (65.0%)	7 (35.0%)	
Standing for a total of ≥ 4 h during a day's work	Collectors (70)	13 (18.6%)	57 (81.4%)	$\chi^2 = 19.384$, $p = 0.001$, Fisher's exact $p = 0.001*$
	Dismantlers (73)	36 (49.3%)	37 (50.7%)	
	Burners (20)	12 (60.0%)	8 (40.0%)	
Walking for a total of ≥ 4 h during a day's work	Collectors (70)	62 (88.6%)	8 (11.4%)	$\chi^2 = 19.961$, $p = 0.001$, Fisher's exact $p = 0.001*$
	Dismantlers (73)	40 (54.8%)	33 (45.2%)	
	Burners (20)	13 (65.0%)	7 (35.0%)	

* indicates significant main effects at $p < 0.05$.

($p = 0.204$). The proportion of participants that reported standing for ≥ 4 h was also significantly higher among dismantlers (49.3%) and burners (60.0%) compared to collectors (18.6%; $p < 0.001$ and $p = 0.001$, respectively). In contrast, walking for a $> = 4$ h was reported at a higher proportion by collectors (88.5%) compared to both dismantlers (54.8%; $p < 0.001$) and burners (65%; $p = 0.038$). Differences in proportions between dismantlers and burners for both prolonged standing and walking were not statistically significant ($p > 0.05$).

3.2.2. Manual material handling activities

Manual material handling activities identified by direct observations included lifting and carrying of loads as well as pushing and pulling hand-drawn carts used for transporting e-waste. Descriptions of observations are followed by quantitative results. The frequency and magnitude of the load handled differed between tasks and job categories. Loads handled by collectors included the force to tow or move the hand-drawn collection cart, which is a function of the design of the cart used, the load on the cart, and the terrain (Jung et al., 2005). The weight of the cart and the items collected varied from day to day as a function of items identified for recycling. Collectors also lifted and carried items when loading and unloading the cart. All 25 (15.3%) minors in the study self-identified as collectors. These minors were observed walking behind their supervisors, typically an older or senior worker, pushing the hand-drawn cart from the rear as the senior worker pulled the cart from the front. It is typical for younger entry-level workers arriving at the

e-waste site to assist other workers until they gained some experience and accumulated enough capital prior to working independently. Loads handled by dismantlers mainly consisted of the weight of items being dismantled and occasionally the weight of the wheelbarrow used to convey items such as insulated metal components and wires to the burning site for metal recovery. Manual dismantling also involved repetitive forceful exertions in non-neutral postures using tools such as hammers, chisel and screwdrivers. The load handled by burners was mainly from the weight of components (e.g., insulated cables, wires) being burnt. Lifting and carrying among burners involved using a long metal rod to lift and flip wires/cables during burning. This was usually done with the trunk in slight flexion. Occasionally, burners would lift, carry and lower items from a wheelbarrow onto the ground for burning and this involved moderate to severe forward flexion of the trunk for short intervals.

Table 3 summarizes the proportion of participants by job category based on their self-reported frequency of performing the three different MMH activities, namely, lifting, carrying, and pushing-pulling in the previous workweek. Chi-square test of proportions indicated statistically significant differences across job categories for each of the three MMH activities ($p < 0.001$). In term of lifting activities, a high proportion of collectors (91.2%) and burners (94.1%) reported performing lifts on ≥ 5 days in a week compared to dismantlers (65.8%), with the difference between collectors and dismantlers being statistically significant ($p = 0.001$). In contrast, the proportion of dismantlers that reported lifting activities 3–4 times a week (24.7%) was significantly higher than collectors (4.4%; $p = 0.001$). Carrying activities on ≥ 5 days per week were performed mostly by collectors (91.2%) compared to burners (82.4%) and dismantlers (62.5%), with the difference between collectors and dismantlers being statistically significant ($p < 0.001$). However, the proportion of participants that reported carrying on 3–4 days a weeks was significantly higher among dismantlers (22.5%) compared to collectors (2.9%; $p = 0.001$). Pushing and/or pulling of a hand-drawn cart on ≥ 5 days per week was significantly more frequent among collectors (68.2%) compared to dismantlers (26.4%; $p < 0.001$) and burners (26.3%; $p = 0.003$). The proportion of burners that reported infrequent or no pushing/pulling activities (63.2%) was significantly higher than the proportion of collectors (28.8%; $p = 0.018$).

Table 4 summarizes the number and proportion of participants stratified by their self-reported level of maximum weight handled during the prior workweek coded on an ordinal scale from light (≤ 5 kg) to very heavy (>20 kg). Over 86% of all study participants reported handling an object weighing heavier than 20 kg (i.e., labelled 'Very heavy'). Results from the Chi-square test of proportions indicated a statistically significant difference among job categories in the level of maximum weight handled ($p = 0.011$). The proportion of participants that reported handling weights heavier than 20 kg was significantly higher for collectors (95.6%) compared to dismantlers (81.9%, $p = 0.034$) and burners (68.4%, $p = 0.002$). The proportion of participants that reported handling moderate weights between 6 and 10 kg was significantly higher for burners (15.8%) compared to collectors (1.5%, $p = 0.025$). None of the other paired comparisons within weight category were statistically significant.

3.2.3. Pedometer measurements

Table 5 summarizes the median and IQR values for regular steps, aerobic steps, steps per minute, distance covered and energy expenditure (kcal) among the subset of collectors, dismantlers and burners. Kruskal-Wallis tests indicated no statistically significant differences across the three job categories for any of the five pedometer measures ($p > 0.05$). The small sample sizes for collectors (n = 9) and burners (n = 6) may have contributed to reduced statistical power in detecting any differences. The median number of regular and aerobic steps were slightly higher for collectors than burners and dismantlers (Table 5), while the median aerobic step count was lowest (zero) for dismantlers. The median distance walked by participants in each category was 5.4 km

Table 3
Self-reported frequency of manual material handling activities related to e-waste work performed by participants and stratified by job category within a workweek.

Activity type	Job Category (n)	None or rarely	1–2 days per week	3–4 days per week	≥5 days per week	Chi-square statistic & p-value
Lifting	Collectors (68)	1 (1.5%)	2 (2.9%)	3 (4.4%)	62 (91.2%)	$\chi^2 = 20.524$, $p = 0.002$, Fisher's exact $p = 0.001$*
	Dismantlers (73)	0 (0.0%)	7 (9.6%)	18 (24.7%)	48 (65.8%)	
	Burners (17)	0 (0.0%)	1 (5.9%)	0 (0.0%)	16 (94.1%)	
Carrying	Collectors (68)	0 (0.0%)	4 (5.9%)	2 (2.9%)	62 (91.2%)	$\chi^2 = 26.656$, $p < 0.001$, Fisher's exact $p < 0.001$*
	Dismantlers (72)	2 (2.8%)	9 (12.5%)	16 (22.2%)	45 (62.5%)	
	Burners (17)	2 (11.8%)	1 (5.9%)	0 (0.0%)	14 (82.4%)	
Pushing and/or Pulling	Collectors (66)	19 (28.8%)	0 (0.0%)	2 (3.0%)	45 (68.2%)	$\chi^2 = 37.053$, $p < 0.001$, Fisher's exact $p < 0.001$*
	Dismantlers (72)	32 (44.4%)	15 (20.8%)	6 (8.3%)	19 (26.4%)	
	Burners (19)	12 (63.2%)	1 (5.3%)	1 (5.3%)	5 (26.3%)	

* indicates significant main effects at $p < 0.05$.

Table 4
Number and proportion of participants reporting different categories of maximum weight handled within a workweek, stratified by job category.

Job Category (n)	Maximum weight handled, n (%)				Chi-square statistic & p-value
	Light (< 5 kg)	Moderate (6–10 kg)	Heavy (10–20 kg)	Very heavy (> 20 kg)	
Collectors (68)	0 (0.0%)	1 (1.5%)	2 (2.9%)	65 (95.6%)	$\chi^2 = 15.686$, $p = 0.016$, Fisher's exact $p = 0.011$*
Dismantlers (72)	2 (2.8%)	5 (6.9%)	6 (8.3%)	59 (81.9%)	
Burners (19)	2 (10.5%)	3 (15.8%)	1 (5.3%)	13 (68.4%)	

* indicates significant main effects at $p < 0.05$.

for collectors, 4.9 km for burners and 3.2 km for dismantlers, respectively. The median calorie expenditure from walking was marginally higher for burners (190 kcal) compared to collectors (170 kcal) and dismantlers (122 kcal), however the small sample sizes for collectors and burners make their respective median estimates relatively unstable.

4. Discussion

This study quantified the OPA exposures of e-waste workers at Agbogbloshie with an emphasis on differences among the three main categories of workers, namely, collectors, dismantlers, and burners. Notably, the results indicated that the type and level of self-reported exposures vary substantially between and within worker categories. Despite its preliminary and cross-sectional nature, this study is only one of few conducted at Agbogbloshie, Ghana that focuses on the physical demands of informal e-waste recycling. Prior exposure studies were mostly descriptive accounts (Acquah et al., 2019; Akormedi et al., 2013; Yu et al., 2017), which although insightful, failed to provide meaningful quantitative information about the source and magnitude of physical activity exposures. The latter is necessary to enable comparisons with other work settings and/or other informal e-waste recycling sites in developing countries, to estimate the potential for developing MSDs, and to guide the design and implementation of tailored ergonomics interventions (e.g., engineering controls, health and safety policy, worker training). More broadly, the study adds to the growing knowledge-base documenting exposure of e-waste workers at Agbogbloshie to various occupational hazards such as toxic chemicals, air pollutants, and noise (Akormedi et al., 2013; Basu et al., 2016; Srigboh et al., 2016; Wittsiepe et al., 2015; Yu et al., 2017).

Our results corroborate qualitative findings by Akormedi et al. (2013) and Yu et al. (2017) about e-waste worker characteristics, the challenging work environment, and the physically strenuous work conditions prevailing at Agbogbloshie. We discuss the ergonomics implications of these findings.

4.1. E-waste workers

Participants in this study were mostly collectors (43%) and dismantlers (45%), while burners comprised only 12% of the study sample. The latter may have reduced statistical power in pair-wise comparisons of proportions involving burners for some of the exposure variables, e.g., between collectors and burners for continuous walking ≥1 h. Differences in job content and financial prospects may explain the smaller number of burners at Agbogbloshie and in our study sample. Akormedi et al. (2013) reported that burners earned substantially less income per day compared to collectors and dismantlers (i.e., USD 16 compared to USD 26 and USD 52 respectively, on a good day). The reliance on dismantlers to provide items for burning and the high exposure to smoke

Table 5
Pedometer measurements obtained from a sub-set of study participants (n = 42) averaged over 2 workdays and stratified by job category.

Variable	Job Category	Median	Lower Quartile	Upper Quartile	Kruskal-Wallis test
Total Step Count	Collectors (9)	9482	5282	10812	$\chi^2 = 3.688$, $p = 0.158$
	Dismantlers (27)	5556	3504	8412	
	Burners (6)	8964	5042	9870	
Aerobic Step Count	Collectors (9)	1531	0	2756	$\chi^2 = 3.526$, $p = 0.172$
	Dismantlers (27)	0	0	1520	
	Burners (6)	607	0	1883	
Steps per minute	Collectors (9)	91.3	0	102.1	$\chi^2 = 2.859$, $p = 0.240$
	Dismantlers (27)	0	0	97	
	Burners (6)	47.1	0	101.2	
Distance (km)	Collectors (9)	5.4	3.0	5.9	$\chi^2 = 4.049$, $p = 0.132$
	Dismantlers (27)	3.2	2.0	4.6	
	Burners (6)	4.9	3.0	5.4	
Energy expenditure (kcal)	Collectors (9)	170	95	296	$\chi^2 = 3.334$, $p = 0.189$
	Dismantlers (27)	122	71	182	
	Burners (6)	190	107	207	

and toxic fumes from open air burning made this task less appealing to workers (Acquah et al., 2019; Akormedi et al., 2013). Workers at this site did not have assigned roles or designations. On few occasions, participants reported performing e-waste recycling activities other than their primary job. For example, a dismantler who did not have enough items to dismantle may temporarily assume the role of collector and walk/travel into the community in search of more e-waste items to dismantle. Likewise, a burner who did not have items to burn may assume a dismantling role by helping other dismantlers to disassemble their items for a small fee or in exchange for some of the extracted metal (e.g., copper wires). Since such secondary activities were infrequent and with limited impact on exposure estimates in the present context, these were not distinguished or differentiated in the present study. However, the potential for fluid roles wherein worker change their main activities (and hence related exposures) on their own over time may have implications for prospective longitudinal studies.

Our study also confirmed prior reports that e-waste recycling at Agbogbloshie is performed mainly by men (Akormedi et al., 2013). The absence of women has been attributed to the high physical demands of manual e-waste recycling and a preference for less strenuous supportive roles such as vending food and water to workers (Ahlvin, 2012). The worker population at this site was also relatively young (mean age of 24.8 years) and included 25 minors (15.3%). All minors in the study sample were collectors and assisted older workers in scavenging and gathering e-waste items. The substantial proportion of minors working at the site is particularly concerning since Ghana is a signatory to multiple international instruments that prohibit child labour (UNICEF, 2019). Our finding suggests broader concerns about poorly enforced legislation and policies prohibiting child labour. UNICEF-Ghana estimates that about 21% of children in Ghana aged between 5 and 17 years were involved in child labour and 14% were engaged in hazardous forms of labour (UNICEF, 2019). However, the problem of child labour is not unique to Agbogbloshie but plagues waste picking/collecting in many developing countries around the world (ILO, 2004).

The experience level of workers recruited for this study varied from as little as 7 days to as high as 22 years. Experience in e-waste recycling work for the study cohort was least among collectors (5.3 ± 5.7 years) and highest among dismantlers (7.9 ± 5.4 years). Prior studies suggest that low-skilled migrants from northern Ghana seeking a means of livelihood were often drawn to e-waste recycling at Agbogbloshie and often start out as collectors (Akormedi et al., 2013). These collectors overtime progress to more technical and lucrative roles of e-waste recycling such as dismantling. Collecting of e-waste requires extensive walking (e.g., over 75% of collectors performed over 10,000 steps daily) with a low prospect of obtaining e-waste items on any day, as observed in this study.

E-waste recycling was performed every day of the week. Most participants worked six days per week and rested either on Fridays or Sundays. Akormedi et al. (2013) suggested that rest days may correspond to workers religious affiliation with Muslims more likely to take Fridays off while Christians took Sundays off. Furthermore, e-waste workers reported to spend between 2 and 14 h a day performing various recycling tasks, with a computed average of about 9 h per day. This finding corroborates prior reports of a typical 10–12 h of work per day among workers at Agbogbloshie (Akormedi et al. (2013). Variability in the number of hours and work distribution can be explained by our observations. We noticed that the workday duration depended on the recycling task being performed and the availability of work to be done. For example, a dismantler who had few items to dismantle, could complete the task in about 2 h and would be idle for the rest of the day until a new batch of items were available for dismantling from the collectors. On the other hand, collectors would spend longer time wandering in search of e-waste. Burners were also engaged in less active work times as burning of a pile of copper wires took under 20 min and required occasional manipulation during burning despite continuous standing and stepping/walking. Some burners kept busy by gathering

potentially valuable metal scrap and remnants littered about the burning sites. Overall, the lack of temporal structure and definitive roles presents methodological challenges when comparing exposures across time or between work sites and work domains (e.g., manufacturing, office work).

4.2. Occupational physical exposures

Participants' exposures to sitting, standing, walking and MMH activities differed substantially by the primary job category. Particularly concerning were the high proportion of workers that reported exposure durations ≥ 4 h in the workday (e.g., prolonged sitting, standing, walking) and frequent exposure to lifting and carrying on ≥ 5 days per week. The health implications of these specific combinations of exposures and job category are discussed in relation to prior research. However, we advise caution for direct comparisons with activity questionnaires from other work settings since most studies base their exposures on an 8-h workday and/or a 5-day workweek (e.g. Reis et al., 2005).

4.2.1. Sitting

Prolonged sitting was most frequent among dismantlers (Table 2), who assumed largely deviated postures from sitting on a low stool or non-functional appliance, with excessive forward flexion and twisting of the trunk while performing their task. Prolonged sitting (Hoogendoorn et al., 1999), and in non-neutral postures (Roffey et al., 2010) have been associated with chronic low back pain. Biomechanical studies have also shown possible adverse effects on spinal structures from sustained non-neutral trunk postures (Chaffin et al., 2006). Sitting for long periods at work changes the activation patterns of a number of weight-bearing muscles, which in the long term affects the curvature of the back resulting in back pain (Beach et al., 2005; Callaghan and McGill, 2001). Prolonged sitting is also associated with lower bone mineral density due to a limited physical stress (see Chaffin et al., 2006) and osteoporosis (Kolbe-Alexander et al., 2004). Thus, prolonged sitting among e-waste dismantlers could increase their risk of work-related low back pain and disorders, as suggested by the high prevalence of low back disorders among informal waste collection and processing workers (Emmatty and Panicker, 2019; Ohajinwa et al., 2018).

4.2.2. Standing

Standing at work may be advantageous to the worker in that it provides a large degree of freedom and ensures a wide range of mobility in the lower limb thereby increasing efficiency and productivity (Halim and Rahman Omar, 2011). That notwithstanding, prolonged standing may also lead to muscle fatigue and discomfort (Garcia et al, 2015, 2016, 2018, 2020), chronic venous insufficiency and other occupational injuries (Garcia et al, 2015, 2016, 2018, 2020; Lafond et al., 2009; Madeleine et al., 1997; Tomei et al., 1999). E-waste recycling activities such as burning involve a considerable amount of standing (see Table 2) and significant associations between prolonged standing and work-related low back, lower leg and shoulder MSDs have been pointed out (Chandrasakaran et al., 2003; Musa et al., 2000). Prolonged standing transfers the load of the upper body to the lower parts resulting in low back pain (Halim and Rahman Omar, 2011) and pain in the feet (Messing and Kilbom, 2001). Furthermore, standing during burning of e-waste is compounded with forward flexion and twisting of the trunk pose further harm to the low back. Bending and twisting of the spine during work is associated with low back pain (Chaffin et al., 2006; Marras, 2008; Marras et al., 1998; Wai et al., 2010a).

Reducing the time spent in standing could help decrease the risk of adverse health effect. For example, the use of cable strippers to extract copper from insulated wires instead of burning could reduce work-related standing in addition to alleviating some of the health risks to burners from smoke inhalation and environmental contamination from open-air burning. However, such interventions had limited success at

Agbogbloshie (Adanu et al., 2020; Little, 2016) for sociocultural reasons that fall outside the scope of the present study.

4.2.3. Walking

Prolonged walking (i.e., walking for hours without taking a break) increases energy expenditure (Patton et al., 1991) and induces fatigue (Morrison et al., 2016; Pinto Pereira and Gonçalves, 2011; Walsh et al., 2018; Yoshino et al., 2004) which may increase the risk of physical discomfort, pain and MSDs. The associated risks may be exacerbated by walking over uneven, unpaved terrain, in a harsh outdoor environment including hot and humid climate, and/or with poor air quality due to toxic fumes from open burning and sewage (Akormedi et al., 2013; Yu et al., 2017). Prolonged walking was most prominent for collectors (88.5%). Numerous studies have reported an association between prolonged walking and low back pain (Garcia et al., 2016; Roffey et al., 2010). Thus, e-waste of the trunk while performing their long hours of walking such as when collecting e-waste is likely to pose serious health risks to workers. Walking for prolonged periods subjects the spine to prolonged biomechanical loading with detrimental effects on spinal structures (Callaghan and McGill, 2001). Furthermore, collectors often walk these long distances while pulling a hand-drawn cart which exerts additional compressive and shear stresses on the spine and the shoulder as predicted by biomechanical analyses (see Chaffin et al., 2006 for review). Appropriate measures to reduce the adverse effects of these health risks are necessary.

Pedometry generally provides more accurate and reliable estimates of physical activity exposures than self-report questionnaires (Sitthipornvorakul et al., 2014; Takala et al., 2010). However, direct measurements are challenging in non-repetitive work settings such as the unregulated, informal e-waste recycling work investigated in this study. Furthermore, statistical comparisons between self-reported walking and pedometer measurements were not considered meaningful here since the former assessed the perceived frequency of continuous walking during the workweek preceding the administration of the questionnaire, while the pedometers measured the effective walking on 2 consecutive but randomly selected workdays of the study. The high day-to-day variability in physical activity exposure discussed above further diminishes the validity of direct comparisons between the pedometry and self-reported data. For instance, some workers were observed performing secondary e-waste recycling tasks that differ from their primary job during periods of low work volume.

Non-parametric statistical analysis indicated no significant differences between pedometer measurements of the three e-waste job categories. Thus, these data need to be interpreted with caution. However, trends in self-report-based walking and pedometer measurements among job categories provide useful insights that might have implications for future research at Agbogbloshie. Median pedometer steps and distances walked were higher for collectors than burners and dismantlers. Aerobic steps count and cadence (steps/min) were also slightly higher for collectors than burners and dismantlers (see Table 5). These trends were compatible with the self-reported questionnaire data and were not surprising considering that collectors travelled long distances between the e-waste scrapyard and adjacent communities. In contrast, the pedometer-based total step counts for dismantlers and burners were higher than expected based on trends in the observations and self-reported data. Compared to burners, the aerobic step counts for dismantlers and burners were also low suggesting multiple short bouts of walking. About 50% of dismantlers recorded no aerobic steps likely due to the predominance of sitting or standing in place to perform their task. On a few occasions, when dismantlers had few parts to work with, they were observed walking to neighbouring communities in search of e-waste instead of waiting for collectors to return with e-waste items. Similarly, burners were observed switching to dismantling tasks for short durations to earn some income while waiting for new items to burn. This may explain the relatively high pedometer readings on some days which increased the median step counts (i.e., 5360 steps for

dismantlers and 8964 steps for burners) among these otherwise more sedentary groups. It is also possible that the many short bouts of walking caused burners and dismantlers to underreport their frequency of continuous walking and thus not adequately captured by the questionnaire. While these initial study findings may not be decisive, it does provide evidence that frequent exposure to prolonged sitting, standing and walking is present at levels that should raise concern. Further systematic study is needed to quantify the variability in these exposures both between and within workers over time.

4.2.4. Manual material handling activities

E-waste recycling at Agbogbloshie involved different types and intensities of MMH activities. However, the present study only quantified the self-reported frequency of performing MMH activities in a workweek. The frequency of MMH activities differed both between and within job categories. Lifting and carrying were notably more frequent for burners and collectors than dismantlers, with 80–90% of burners and collectors performing these activities on ≥ 5 days per week. Although the frequency of lifting and carrying was lower for dismantlers than collectors or burners, they reported a high intensity of load handling suggesting interactions between hand load frequency, intensity, and possibly duration across job categories. Understandably, pulling and pushing activities was more prevalent among collectors by definition of their job. However, not all collectors operated carts and instead walked with a cloth sack to carry e-waste items. The 68% of collectors that reported performing pushing and/or pulling on 5 or more days in the preceding workweek was in sharp contrast to the nearly 29% of collectors who reported no pushing and/or pulling in the week. This reinforces the high variability in work exposures among collectors, with much of this variability potentially related to the choice of MMH equipment and from success or failure in locating items for recycling on a given day.

MMH activities may be a source of work-related MSD among e-waste workers. Although not exactly e-waste recycling, manual collection and handling of solid waste performed in informal settings is associated with a high prevalence of shoulder and low back MSDs (Abou-Elwafa et al., 2012; Kuijer et al., 2010; Mehrdad et al., 2008). Additionally, there is strong evidence in the ergonomics literature that identifies MMH including lifting, carrying, pushing and pulling as a leading cause of work-related shoulder and low back disorders (Hoogendoorn et al., 1999; Hoozemans et al., 2002; Roffey et al., 2010; Wai et al., 2010b). Hoozemans et al. (2002) have also reported a dose-response relationship between pushing and/or pulling and shoulder complaints among industry workers. Although some of these physical activities may not be strenuous when considered on their own, their repetition and combination with extreme postures contribute to the development of MSDs, as widely acknowledged in previous studies (Chaffin et al., 2006; Fan et al., 2014; Latko et al., 1999). Collectively these studies suggest that the extent of MMH activities performed could predispose e-waste workers at Agbogbloshie to developing work-related MSDs; thus, calling for additional research to examine associations between specific physical work exposures and MSDs in this worker population.

4.3. Study limitations

The unregulated nature of e-waste recycling at Agbogbloshie made it difficult to employ sampling strategies used in regular industrial work. However, attempts were made to sample participants at different locations within the e-waste site and on different days to obtain a representative sample. This study had a modest sample size but was comparable to other survey studies conducted at Agbogbloshie (n ∼ 142 to 180; Adanu et al., 2020; Laskari et al., 2019). Another limitation was that the accuracy of the self-reported data relies on the ability of participants to recall the duration and frequency of their typical exposures to the different work activities. This is particularly challenging in unregulated unstructured work, wherein the exposures vary considerably

among workers, and for the same worker within days and between days. For example, some participants did not have a response to questions about MMH activities, which reduced the effective sample size in Tables 3 and 4

Bias in workers responses to the questions could also stem from self-perceptions about their work activity exposures as well as low literacy, nuances in local dialects, and differences in comprehension and interpretation of the questionnaire. To minimize this effect, the present study employed professional research staff who were familiar with English and the local language as to conduct the field interviews. The format of the self-report questionnaire responses, whether continuous, ordinal or categorical, was also important to consider because of the low literacy and language diversity. During the pilot phase of the study, participants found it difficult to accurately estimate their proportion of time spent performing the different OPAs. Thus, a categorical scheme was employed in the modified OPAQ. For example, the time spent in sitting, standing and walking was presented in two ways: (1) 1-h of continuous activity, and (2) a total of 4 h of activity during the workday (Appendix A). As an initial step, this format to the questionnaire helped reduce participant's wavering or indecision about the responses and shorter response times. Although this format made it relatively easy for workers to provide information on their OPA exposures, a more reliable direct form of quantification of these OPA levels could be explored in future studies.

This study was also limited by its inability to continuously observe workers that were instrumented with pedometers in order to document the activities they performed which could help explain the trends in pedometer measurements. There could be a small possibility of some participants with pedometers being involved in additional activities other than their primary job. However, our observations of other workers suggested this was infrequent and as such was not considered in our statistical data analysis.

4.4. Methodological implications

From a methodological perspective, the current study draws attention to the need for new, validated methods to measure physical work exposures among workers engaged in informal e-waste recycling. Due to the challenges of studying informal work settings, in this study we opted for a multi-method approach, namely, direct observations, self-report questionnaires, and pedometry. The modified version of the OPAQ was appropriate in capturing information about some of the most common physical activity exposures among e-waste workers in a short period of time. However certain quantitative exposure data were missed. First, information about the frequency of force exertions associated with using hand tools (e.g., hammers, chisels, screwdrivers), which is typical among dismantlers, was not assessed in the OPAQ. Second, information about whole-body postures (e.g., standing, seated, squat, stooped) associated with MMH activities such as lifting, pushing and/or pulling, and magnitude of hand force exertions during tool use was not obtained. Additional research is needed to quantify the relationships between the MMH activities performed (type, magnitude or intensity, duration, and frequency) and the postures used during those activities specific to work methods in low-resource informal settings.

Direct instrumentation-based methods have advantages in terms of accuracy and reliability (Chaffin et al., 2006; Neitzel et al., 2013), however, the variable nature of informal e-waste recycling at Agbogbloshie presented some challenges. Pedometers were time and cost-prohibitive to use and as such not all participants in the study were instrumented with pedometers. Unfortunately, the pedometers were also perceived by participants as valuable and inexplicably would go missing during data collection. Five pedometers were not returned in the early stage of the study, which further limited data collection from more workers. These realities and trade-offs in field research can limit the ability to fully capture the variability in exposures between workers and within workers over time. Simple pocket pedometers were used for this study due to their low cost. Future studies could consider using GPS-enabled activity monitors (i.e., as a way to potentially track the devices and minimize the risk of loss or theft) and could measure additional physiological data (e.g., heart rate) to provide better information about the physical workload experienced. However, regardless of choice of direct instrumentation, this approach would not capture the sociotechnical and environmental interactions and economic constraints on workers that influence their choice of job category, work methods and equipment used, and consequently their work-related exposures.

To understand these realities facing low-skilled, low-income workers in an unregulated, informal work setting, qualitative direct observations in this study proved just as valuable as the quantitative questionnaire data. As such, development of a direct observation technique to systematically sample work content and quantify physical work exposures among e-waste workers may be most ideal. Direct observation and quantification of workers physical exposures have proven successful in other non-repetitive work settings such as construction (e.g., the Posture Activity and Tools Handled (PATH) work-sampling based approach by Buchholz et al. (1996)) and could provide a template for similar approaches suited to unregulated, informal e-waste recycling. More broadly, our study findings provide important lessons and motivation for future research to examine physical activity exposures and associated work-related injury prevalence in the informal e-waste recycling sector.

5. Conclusion

This study contributes to the limited literature on work-related activity exposures and work conditions of e-waste workers at the largest e-waste dumpsite in sub-Saharan Africa. While prior studies at Agbogbloshie emphasized exposures to toxic chemicals, poor air quality, and noise, this initial study draws unique attention to the physical work exposures associated with informal e-waste recycling. E-waste recycling involves varying levels of sitting, standing, walking and a range of MMH activities that collectively may be detrimental to the musculoskeletal health of the worker. Self-reported work exposures examined in this study differed substantially between the three primary e-waste job categories. Long hours of sitting were common among dismantlers while burners and collectors were more likely to be engaged in prolonged standing and walking respectively. All job categories had a high proportion of workers performing manual material handling activities on five or more days in the week. Dismantlers and burners engaged in frequent lifting and carrying tasks while pushing and/or pulling were most frequent among collectors. Frequent exposure to these physically demanding activities may compound the musculoskeletal health effects of prolonged sitting, standing and walking.

Achieving proper balance between sitting, standing, walking and performing MMH activities in informal e-waste work may help reduce its potential negative health effects. However, the development of appropriate and context adapted ergonomics interventions relies on accurate and reliable quantitative information about work exposures and associated work-related injuries. Our study highlights the need for further occupational safety and ergonomics research in the informal e-waste recycling sector. Specifically, more objective and reliable assessment methods that can account for the between and within worker variability in exposures inherent to informal e-waste work are required. Future studies also need to consider the local economic realities and social context encountered in an unregulated, low resource and multi-ethnic work environment.

CRediT authorship contribution statement

Augustine A. Acquah: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Resources. **Clive D'Souza:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Validation. **Bernard J. Martin:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Validation. **John Arko-Mensah:** Conceptualization, Investigation, Writing - review & editing, Supervision. **Paul K. Botwe:** Writing - review & editing, Supervision. **Prudence Tettey:** Writing - review & editing, Supervision. **Duah Dwomoh:** Formal analysis, Writing - review & editing. **Afua Amoabeng Nti:** Investigation, Writing - review & editing. **Lawrencia Kwarteng:** Investigation, Writing - review & editing. **Sylvia Takyi:** Investigation, Writing - review & editing. **Isabella A. Quakyi:** Conceptualization, Writing - review & editing, Supervision. **Thomas G. Robins:** Writing - review & editing, Resources, Supervision, Funding acquisition. **Julius N. Fobil:** Conceptualization, Investigation, Resources, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2021.103096.

AppendixA: Modified version of the OPAQ used for data collection

Q1. In the last workweek, did you do the following during your work schedule?
* Sitting activities.

	Yes	No
Prolonged sitting (4 h or more per day)	☐	☐
Sitting continuously for 1 h or more	☐	☐

* Standing activities.

	Yes	No
Prolonged standing (4 h or more per day)	☐	☐
Standing continuously for 1 h or more	☐	☐

* Walking.

	Yes	No
Prolonged walking (4 h or more per day)	☐	☐
Walking for 1 h or more	☐	☐

* Manual material handling activities.
Q2. In the last *work* week, how often did you do the following during your work schedule?

	Never or rarely	1–2 days last week	3–4 days last week	5 or more days last week
Lifting items	☐	☐	☐	☐
Carrying load	☐	☐	☐	☐
Pushing or pulling a cart or truck	☐	☐	☐	☐

Q3. If you *did* any of the above, what is the maximum weight you usually handle while performing these tasks?

☐ Light (5 kg or less)	☐ Moderate (6–10 kg)	☐ Heavy (11–20 kg)	☐ Very heavy (>20 kg)

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