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UNIVERSITY OF GHANA, LEGON

EVALUATION OF ERGONOMIC RISK FACTORS AND WORK-RELATED MUSCULOSKELETAL DISORDERS ASSOCIATED WITH INFORMAL ELECTRONIC WASTE RECYCLING AT AGBOGBLOSHIE IN ACCRA, GHANA

BY

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DECLARATION

I, Augustine Appah Acquah hereby declare that this thesis is the result of my work, except for the areas where specific references have been cited and duly acknowledged. I affirm that the studies reported in this document were carried out by me under the supervision of my team of academic supervisors and has not been submitted, either in part or in whole, to any other institution for an award of a degree.

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DEDICATION

I dedicate this work to all the wonderful people in my life who have contributed to make my academic story a success. Most especially to my late father Mr. Joseph Kwasi Acquah for financing my education and helping me attain a first degree which has provided me with the foundation to pursue a higher degree. I also dedicate this work to all the teachers and academic mentors I have had throughout my schooling.

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LIST OF ABBREVIATIONS

ANOVA - Analysis of variance

CMDQ - Cornell Musculoskeletal Discomfort Questionnaire

EEE Electronic and Electrical Equipment

E-waste - Electronic waste

GPS - Global Positioning System

ILO - International Labour Organisation

IMF - International Monetary Fund

MMH - Manual Material Handling

MSDs - Musculoskeletal Disorders or Musculoskeletal Discomfort

OPA - Occupational Physical Activity

OPAQ - Occupational Physical Activity Questionnaire

OCRA - Occupational Repetitive Action

OWAS - Ovaco Working Posture Analysis System

PA - Physical Activity

PATH - Posture Activity Tools Handling

PPE - Personal Protective Equipment

QEC - Quick Exposure Checklist

REBA - Rapid Entire Body Assessment

RULA - Rapid Upper Limb Assessment

SAP - Structural Adjustment Program

SPSS - Statistical Package for the Social Sciences

VAS - Visual Analogue Scale

WHO - World Health Organisation

WRMSD - Work-related MSD

3DSSPP - 3-Dimensional Static Strength Prediction Programme

OPERATIONAL DEFINITION OF TERMS

Observations

Observation refers to the act of closely monitoring an activity being performed. The details of the activity being performed are then recorded on a data capturing sheet. The term observations was used to refer to the details of a work activity that was captured within each 60s observation period used in this thesis.

Real-time

Real-time refers to the actual time an activity or an event took place.

Coding of ergonomic risk factors

This is the process of transforming field observations into a set of meaningful, cohesive categories. The term in this thesis was used to refer to converting ergonomic risk factors observed on the field into ordinal numeric categories based on the frequency and intensity of the risk factor that was observed.

Manual Material Handling

Manual Material Handling refers to moving or handling work materials, tools or equipment by lifting, lowering, pushing, pulling, carrying and holding.

Transcription

Transcription is the act of providing a written account of spoken words. This approach is used in qualitative studies to convert audio recordings into text to facilitate thematic analysis of data.

ABSTRACT

Generation of electronic waste (e-waste) is a worldwide problem due to an ever-increasing global demand for new electronic appliances, and high turnover in replacing old and obsolete electrical and electronic appliances. Agbogbloshie, an informal e-waste processing site in Accra, Ghana is one of the largest of its kind in the world. The management and recycling of e-waste in an environmentally and occupationally safe and sustainable manner is a major challenge resulting in workers developing multiple health conditions. In addition, e-waste workers are also exposed to several physical risks due to the rudimentary methods of recycling which are known pathways to developing musculoskeletal disorders (MSDs). Notwithstanding, studies on adverse health effects of e-waste recycling have focused primarily on chemical exposures with little attention to physical exposures. Physical ergonomic exposures associated with informal e-waste recycling by low-wage, low-skilled workers are poorly understood. Further, current ergonomic assessment tools are intended for well-structured work environments. Ergonomic assessment tools to determine the physical exposures in unstructured and unregulated work settings such as e-waste recycling are lacking.

The aim of this thesis, therefore, was to quantify the ergonomic risk factors and work-related MSDs associated with informal e-waste recycling at Agbogbloshie. Clearly defined specific objectives led to studies that allowed for the development of an observation-based exposure assessment tool adapted to unregulated and unstructured work in an informal sector.

The studies were conducted at the e-waste site in Agbogbloshie, Accra Ghana. A reference population was recruited from Madina Zongo in Accra for comparison of work-related musculoskeletal disorders with e-waste workers. Participants in this thesis were conveniently

sampled due to the informal and unstructured nature of the study sites. Direct field observations and in-depth interviews of eight e-waste workers were first conducted to better understand the processes and challenges associated with e-waste recycling. The obtained data were manually transcribed and coded into themes for analysis. Subsequently, a cross-sectional survey of 163 male e-waste workers complemented with direct field observations and pedometers was used to quantify workers' occupational physical activities over a work week. The Occupational Physical Activity Questionnaire was modified by the researcher for this purpose. The Cornell Musculoskeletal Discomfort Questionnaire was used to estimate the self-reported prevalence of MSDs in 11 specific body regions of 176 e-waste workers and 41 non-e-waste workers from the reference population. To quantify exposure to physical risk factors, an observation-based tool that satisfies ease-of-use criteria and adapted for unstructured work in developing countries was designed. This new tool was used in real-time to quantify intensity and duration of e-waste workers' exposure to ergonomic risk factors. The job categories, sample size, and the respective number of observations were determined based on preliminary observations. Thus, 6 dismantlers, 6 burners, and 11collectors were observed for 8, 6, and 3 days, respectively.

Qualitative and observational data were analysed using thematic analysis while quantitative data were analysed using descriptive and inferential statistics. Chi-squared tests for categorical variables and ANOVA for continuous variables were used to test for statistical differences among e-waste worker categories, namely, collectors, dismantlers and burners. Multiple regression was used to examine relationships between physical exposure variables and MSDs.

Results addressing the specific objectives of this thesis were as follows: Thematic analysis showed that, e-waste recycling at Agbogbloshie, from collection and transport to sorting to dismantling to

open air burning are done manually using crude methods that require the use of rudimentary tools and physical strength. Assessment of occupational physical activity revealed that, all three categories of e-waste workers performed frequent strenuous occupational activities which differed significantly by primary job category. In addition, a high prevalence of MSDs was reported among e-waste workers (89.2%) compared to the reference population (70.7), which was claimed to interfered with their ability to work. Lower back pain was predominant regardless of job category. The newly developed ergonomic assessment tool showed good inter-observer agreement (i.e., 89% to 100%) for most risk factors assessed. Results from using this tool indicated that, durations of severe trunk flexion were significantly higher for dismantlers and burners (98.3 ± 24.6 and 188.7 ± 25.4 minutes respectively) compared to collectors; while high forces were exerted over longer periods by collectors and dismantlers (228.3 ± 20.1 and 177.3 ± 20.4 minutes respectively). Highly repetitive movements (> 20 / min) were significantly higher for dismantlers and burners (186.9 ± 20.9 and 178.8 ± 22.5 minutes respectively) than collectors. Although contact stress was present in all jobs, vibration was predominant among dismantlers.

In conclusion, e-waste workers at Agbogbloshie are exposed to prolonged durations and high intensities of multiple ergonomic risk factors that predisposes workers to MSDs. The thesis identifies the ergonomics risk factors that need to be prioritised in the development of locally adapted ergonomic interventions for the efficient recycling of e-waste and the reduction of health and safety risks posed by unregulated and unstructured work in developing countries. The observational tool developed demonstrates promise in addressing the need for ergonomic tools tailored to informal and unregulated manual work settings, but needs refining to improve the measurement effort and precision in the assessment of risk factors and MSDs.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter presents a general background that provides the contextual basis of this thesis and highlights the need to conduct this research. The potential ergonomic risk factors associated with informal e-waste recycling is captured in the problem statement alongside the need to investigate these risk factors. Furthermore, a justification for the relevance of this study and the need to develop an ergonomic assessment tool tailored to unregulated and unstructured work environments such as e-waste recycling is presented. In addition, the chapter provides a conceptual framework for this thesis as well as the general and specific objectives of the thesis.

1.1 Background

Electronic waste (e-waste) is a broad term which encompasses all end-of-life electronic and electrical equipment (EEE). E-waste in recent times has contributed substantially to the global waste stream (Zaman & Swapan, 2016). Accumulation of waste is a global concern resulting from overconsumption. Hence, waste management and recycling have received increased interest globally (Chatterjee & Kumar, 2009; Guerrero et al., 2013; Wilson et al., 2006). More specifically, high demand for new EEE has resulted in high turnover and shorter lifespan for modern day appliances and gadgets (Shamim & Mursheda, 2015). The increase in obsolescence has resulted in huge quantities of discarded electrical and electronic appliances – termed as e-waste - being produced annually. In 2015 41.8 million tons of e-waste was produced globally (Breivik et al., 2014). A substantial portion of these end-of-life and discarded EEE make their way across the

Atlantic into developing countries, such as Ghana, Nigeria, Chile, Brazil and India (Bakhiyi et al., 2018). In 2009, over 215,000 tons of e-waste was imported into Ghana (Amoyaw-Osei et al., 2011). Each year, large volumes of e-waste from Europe and North America are dumped legally and illegally into developing countries such as Ghana ending up in landfills (Oteng-Ababio, 2012). Consequently, sustainable management and recycling of discarded electronic waste (e-waste) in a manner that is environmentally and occupationally safe has become a global challenge (Bakhiyi et al., 2018). In developing countries, this challenge is heightened by the lack of appropriate recycling infrastructure, and legislation concerning e-waste, as well as the absence of efficient methods and equipment required for extraction of re-usable and/or valuable constituents from e-waste in a manner that reduces occupational health risk (Guerrero et al., 2013; Osibanjo & Nnorom, 2007; Zhang & Xu, 2016).

E-waste recycling sites are primarily located in south east Asia and Africa (Loeffelbein, 2018). Among them, Agbogbloshie in Accra, Ghana, is one of the world's largest, and a potential source of environmental pollution with associated health impacts. Agbogbloshie has served as a major e-waste hub for decades (Davis et al., 2019; Heacock et al., 2016), and is estimated that well over 171,000 tons of e-waste is processed annually (Prakash et al., 2010). Thus, over the last 20 years, Agbogbloshie has become one of the most polluted places on earth (Oteng-Ababio, 2012). Hence, this recycling site presents enormous health risks to e-waste workers and nearby populations as a result of exposure to air-borne pollutants, including complex mixtures, particulate matter (PM), excessive noise levels, and physical agents associated with poor work methods.

In Agbogbloshie, where recycling of e-waste is done informally and often unregulated, workers engage in inappropriate and unsafe recycling practices including open air dismantling, leaching,

scouring and open air burning, especially of electrical cables to recover valuable metals and re-usable parts (Akormedi et al., 2013; Amankwaa, 2013; Yu et al., 2017). Additionally, informal e-waste recycling is labour intensive with use of rudimentary tools, and therefore often characterized by manual lifting of metal scraps, long bouts of sitting and standing in non-neutral postures, or walking in unfavourable outdoor environmental conditions (Emmatty & Panicker, 2019; Kuijer et al., 2010). These forms of physical activities have been cited to adversely affect the health of workers and often the cause of acute injuries and cumulative trauma disorders (Kong et al., 2018).

A number of ergonomics studies have examined the relationship between occupational exposures and risks associated with various work conditions primarily in formal, structured and regulated industrial settings such as manufacturing (Mossa et al., 2016), construction (Parida & Ray, 2012), healthcare (Czuba et al., 2012), and agriculture (Kong et al., 2018). However, informal work activities such as e-waste recycling, which is mostly characterized by use of physical force and associated with awkward postures have received relatively less attention in ergonomic studies. With regards to e-waste recycling, research focus has been on the growing environmental and health hazards associated with recycling activities. This includes studies investigating the adverse effect of e-waste environment on the respiratory health of workers (Nti et al., 2020), human exposure to heavy metals (Feldt et al., 2014; Srigboh et al., 2016; Wittsiepe et al., 2015), as well as other potentially harmful environmental effects of e-waste recycling (Asante et al., 2011; Caravanos et al., 2013; Oteng-Ababio et al., 2014) including stress, noise and occupational injuries (Adusei et al., 2020; Burns et al., 2019; Burns et al., 2016). Physical or ergonomic hazards associated with e-waste recycling may contribute to the development of work-related musculoskeletal disorders (MSDs) and occupational injuries (Burns et al., 2019).

Work-related MSDs are critical occupational injuries that occur as a result of long-term exposure to ergonomic risk factors including non-neutral (awkward) postures, highly repetitive movements, forceful exertions, contact stress and vibration coupled with limited periods of rest and recovery (CDC, 2019; Chaffin et al., 2006; Ebersole & Armstrong, 2006; Iqbal & Alghadir, 2017). Musculoskeletal disorders are the most common work-related health problem among working populations in all parts of the world (Podniece & Taylor, 2008; Public Health Agency of Canada, 2014). Musculoskeletal disorders place an enormous economic burden on employers, employees and the health system (Hashemi et al., 1998; Sultan-Taïeb et al., 2017). The exposure of e-waste workers at Agbogbloshie to ergonomic risk factors has not been systematically studied. Assessment of physical and ergonomic predisposing factors to work-related MSDs may help plan possible interventions to reduce its adverse effects. Furthermore, unstructured and unregulated jobs such as e-waste recycling are highly variable in tasks performed between workers and within days and as such may require specifically designed assessment methods that considers this high variability.

1.2 Problem Statement

E-waste is a known global burden that presents with numerous health challenges resulting from improper management of end-of-life electrical and electronic appliances and automobile parts (Bakhiyi et al., 2018; Chatterjee & Kumar, 2009; Guerrero et al., 2013; Wilson et al., 2006). Despite its adverse effect, e-waste importation and recycling is on the rise in several developing countries, including Ghana. E-waste recycling in low-income countries are carried out in an unregulated, informal setting by low-skilled, low-wage workers, with very little or no adherence to occupational health and safety practices. Manual e-waste recycling is labour-intensive and

consequently has become an emerging global health problem (Perkins et al., 2014). Engaging in informal e-waste recycling work 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), noise (Akormedi et al., 2013; Burns et al., 2019; Burns et al., 2016; Carlson & Krystin, 2016), and harsh environmental conditions (Akormedi et al., 2013; Burns et al., 2016; Yu et al., 2017). Informal e-waste workers are at a higher risk of work-related accidents and are more likely to have physical injuries and disabilities compared to the general population (Adusei et al., 2020; Akormedi et al., 2013; Burns et al., 2019; Fischer et al., 2020).

E-waste workers in Agbogbloshie work under poor environmental conditions using rudimentary methods and basic working tools while not having access to personal protective equipment (Adusei et al., 2020; Akormedi et al., 2013; Yu et al., 2017). The increasing environmental and health challenges of e-waste recycling at Agbogbloshie can be attributed to the lack of environmentally sound disposal options for end-of-life electronics in Ghana. In addition, the appropriate legislative framework to regulate the importation of e-waste into the country (Amoyaw-Osei et al., 2011) does not exist. The problem is further compounded by poor e-waste recycling practises, harsh and risky working environments due to a fragile informal e-waste recycling sector and low level of health risk awareness among e-waste workers (Akormedi et al., 2013; Yu et al., 2017). The low income and high poverty status of e-waste workers coupled with low social support as well as limited opportunities for alternate gainful employment creates dependency and compels e-waste workers to continue in this trade (Akormedi et al., 2013; Amankwaa, 2013).

The numerous research investigations conducted at Agbogbloshie have contributed to knowledge base revealing challenges associated with informal e-waste recycling. The focus of the majority of

these studies however, have been on the chemical and environmental aspects of e-waste recycling (Burns et al., 2016; Caravanos et al., 2011; Chao et al., 2004; Srigboh et al., 2016; Wittsiepe et al., 2017), and little attention has been paid to the physical work challenges of e-waste recycling and their associated health effects. Few studies have investigated the harsh working conditions and the manner in which e-waste recycling is conducted at Agbogbloshie (Akormedi et al., 2013; Yu et al., 2017). However, these previous studies failed to provide a systematic description of the e-waste recycling process from an ergonomics standpoint which is essential for understanding the physical health hazards associated with the chain of e-waste processing activities. Studies conducted among manual waste collectors have described manual waste collection as requiring varying levels of manual material handling combined with long bouts of sitting and standing in non-neutral postures and walking in unfavourable outdoor environmental conditions (Emmatty & Panicker, 2019; Kuijer et al., 2010). Similar processes and working conditions exist at Agbogbloshie informal e-waste recycling site, but this remains largely unexplored.

Processes involved in e-waste recycling are physically demanding, and characterised by high risk physical activities (Nti et al., 2020; Laskaris et al., 2019; Yu et al., 2017). These forms of physical activities are likely to have adverse effects on the health of workers (Kwon et al., 2011), and particularly when performed under harsh environmental conditions (Kong et al., 2018). The long-term effects of e-waste recycling work on the physical health of e-waste workers, specifically prevalence and causes of cumulative MSDs have not been systematically investigated. Fischer et al. (2020) investigated the health consequences of e-waste workers compared to bystanders and reported a high prevalence of back pain among e-waste workers. This study however limited the investigation of MSDs to back pain. High reports of musculoskeletal pain from poor ergonomic practices among informal consumer waste workers have been reported (Engkvist, 2010; Lavoie &

Guertin, 2001) and similar ergonomic issues are expected among e-waste workers. A high burden of work-related MSDs among a working population could result in serious adverse long-term effects resulting in disability, high cost of living as well as the loss of valuable work time (Buckle, 2005).

Characterising ergonomic exposures in low-resource, unstructured work settings such as e-waste recycling in developing countries remains a challenge for ergonomic practitioners. Observational assessment tool such as OWAS (Ovako Working Posture Analysis System) [Karhu et al., 1977], REBA (Rapid Entire Body Assessment) [Hignett & McAtamney, 2000], RULA (Rapid Upper Limb Assessment) [McAtamney and Corlett, 1993], PATH (Posture Activity Tools Handling) [Buchholz et al., 1996] are used in ergonomic evaluations to provide an initial understanding of the relevant types, durations, and magnitude of exposures. However, most of these assessment methods are time-consuming (Chaffin et al., 2006; Takala et al., 2010), either expensive to implement, require intensive training of observers for proper utilization (Buchholz et al., 1996). Other drawbacks of these methods include their lack of flexibility in unregulated work environments wherein the type and intensity of work performed, even by the same individual, are highly variable within and between days. Thus, applying the existing ergonomics exposure assessment tools to investigate ergonomic hazards among e-waste workers at Agbogbloshie may be problematic. Observation-based tools modified or tailored to effectively investigate ergonomic hazards in this highly variable and unstructured context are needed. A systematic characterization of the types, durations and intensities of ergonomic risk factors associated with e-waste work is necessary in order to understand the magnitude of the risk of work-related MSDs to informal e-waste workers and to propose/implement ergonomics interventions adapted to the local context.

1.3 Conceptual framework

A number of essential factors come into play in the development of cumulative trauma disorders in the musculoskeletal system. Some of these factors have been justified in existing frameworks found in literature in an attempt to explain the occurrence of MSDs in the workplace (Carayon et al., 1999; Oakman et al., 2014; Silverstein et al., 1987). This section presents a conceptual framework aimed at explaining the link between the cumulative effects of identified risk factors such as physical (e.g. force, repetition, contact stress, vibration, and non-neutral postures), individual, organisational and psychosocial factors and the development of work-related MSDs. The framework also shows the need for conducting effective ergonomic risk assessments by developing or selecting ergonomic assessment tools tailored to the specific work environment of interest. Conducting effective ergonomic risk assessments will provide relevant information to help propose interventions to address the specific risk factors identified.

A mismatch between individual capacity and workplace factors leads to an imbalance that results from the cumulative effect of microtrauma and eventually leads to the development of musculoskeletal disorders, as illustrated in Figure 1.1.

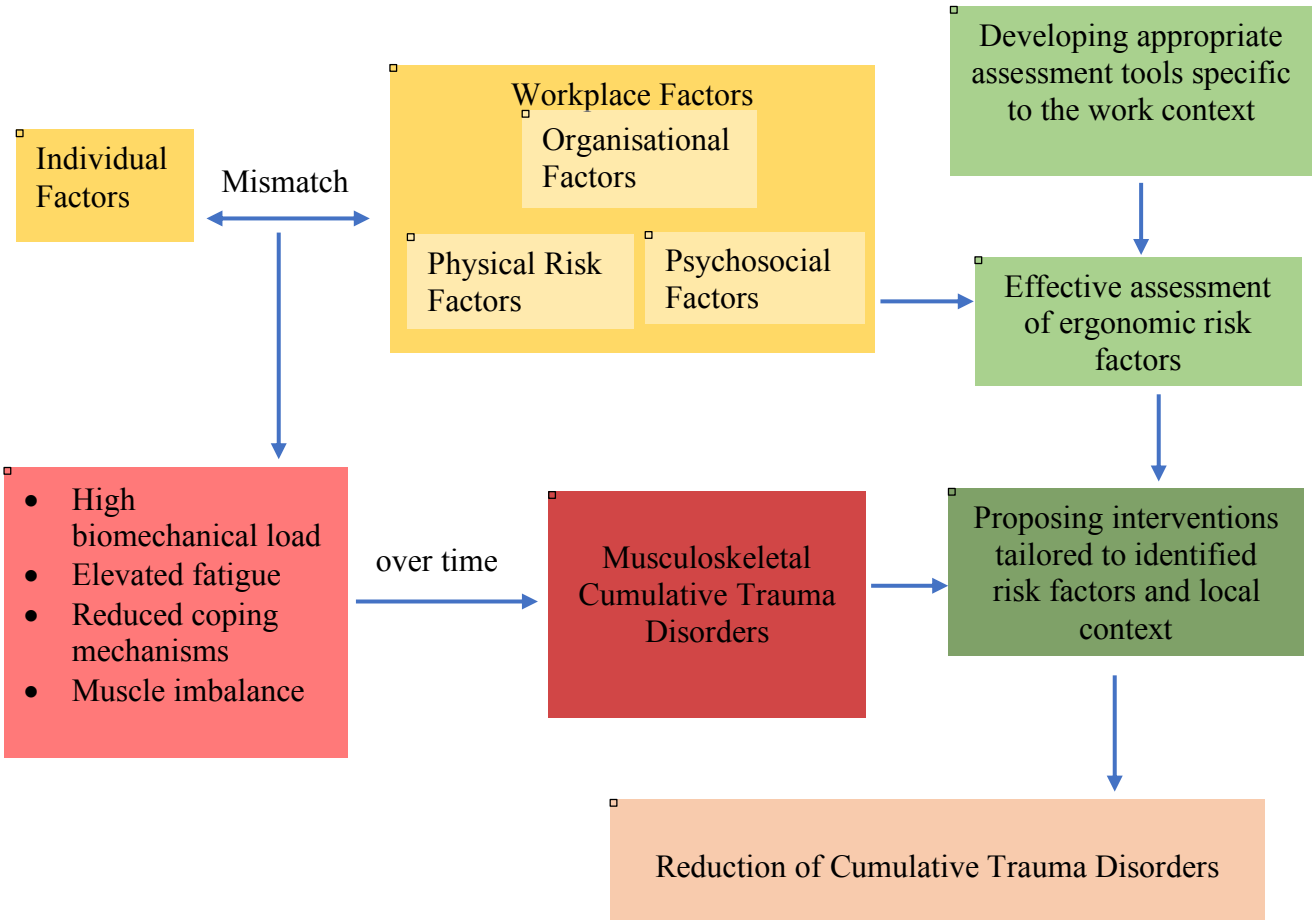


Figure 1.1: Conceptual framework for the development of work-related musculoskeletal cumulative trauma disorders.

Individual factors include age, gender, anthropometry, poor work practices, poor fitness, or nutrition as well as poor rest and recovery habits. There is evidence to suggest that, individual factors significantly influence the occurrence of work-related MSDs (Widanarko et al., 2011). Thus, it is important to adapt work to match different ages, gender, and working capacity of the worker (Oakman et al., 2014). Furthermore, it is equally important that workplace factors align well with individual factors, as a mismatch between individual factors and workplace factors is a major contributor to development of MSDs (see Figure 1.1).

In this conceptual framework, workplace factors are grouped into 3 main categories: organisational factors (Cox & Griffiths, 2005; Oakman et al., 2014), psychosocial factors (Cox & Griffiths, 2005; Eatough et al., 2012; Oakman et al., 2014), and physical factors (Chaffin et al., 2006; Oakman et al., 2014). Physical risk factors tend to be the most obvious and common causes of work-related MSDs. These risk factors are task-specific and include long-term exposure to non-neutral body postures, force exertions (e.g., pushing-pulling, lifting-lowering), repetitive movements (e.g., using hand tools), contact stresses, vibration, and working in extreme temperatures (Buckle, 2005; Chaffin et al., 2006; Gilkey, 2002; Heneweer et al., 2011). The significance of these factors is a function of intensity (or magnitude), exposure duration, frequency (or repetition), and recovery (rest).

Ergonomic risk factors are dependent on the design of workstation or work environment, the size, shape, and weight of objects handled at work; the type of work methods and tools used, as well as the job content (Oakman et al., 2014). These factors are closely linked with organisational factors which consist of the structure of the organisation as well as how work is organised and tasks combined (Oakman et al., 2014). An organisation structure and workflow may influence work design which could also influence the risk of developing work-related MSDs. For example, high work-load, extended working hours and shift, poor work supervision, as well as the absence of appropriate protective and work equipment to facilitate work could contribute to the development of MSDs (Oakman et al., 2014; Widanarko et al., 2014).

Organisational factors may also affect work-related psychosocial factors. Work-related psychosocial factors involve the aspects of work design and management as well as the social and organisational aspects of work that pose psychological or physical harm to workers (Cox &

Griffiths, 2005). These include job strain, high psychological demand of work (Ariëns et al., 2001; Linton, 2001), low social support, job dissatisfaction (Hoogendoorn et al., 2000), work relations, stress, perceived ability to work (Linton, 2001) as well as organisational culture and function (Oakman et al., 2014). Work-related psychosocial factors may overlap closely with organisational factors since organisational structure and work policies play an essential role in the psychological and mental health of workers (Oakman et al., 2014). It is well established that psychosocial work stressors contribute to the development of work-related MSDs (Carayon et al., 1999; Eatough et al., 2012; Hoogendoorn et al., 2000; Linton, 2001).

A poor match between individual factors and workplace factors could, directly and indirectly, lead to the cumulative effects of high biomechanical load, increased fatigue, reduced coping mechanisms, and eventually muscle imbalance. Muscle imbalance occurs as a result of a combination of biomechanical factors from repetitive movements, sustained postures as well as tightness and weakness of some muscle groups (Page et al., 2011). Another contribution to muscle imbalance is the inability of muscles to recover from induced fatigue (Camarda & Denadai, 2012). Thus, the cumulative effect of high biomechanical load, increased fatigue, and decreased coping mechanism of the individual; over time, may create a significant imbalance in muscle strength which when exceeds some limit results in work-related MSDs. It is however important to note, that most of the factors discussed in the framework presented in Figure 1.1 are interrelated and some of these factors on their own contribute directly or indirectly to the development of work-related MSDs.

In order to reduce the occurrence of work-related musculoskeletal disorders, there is the need to conduct a thorough assessment of the potential risk factors associated with the job or occupation

under consideration (David, 2005). Various tools exist for assessment of ergonomic risk factors (Andreas & Grooten, 2018; Buchholz et al., 1996; Kong et al., 2018). Most of these tools however, have been developed to fit structured work environments where there is frequent repetition of work cycles and less variability in tasks performed. Although some of these assessment tools could be used in other work setting other than what they were originally developed for, their use in unstructured work environments presents with numerous challenges. It is highly recommended that ergonomic professionals identify the peculiarity in the work setting they are investigating and select appropriate assessment tools that can fully assess the ergonomic risk associated with the type of job being assessed (David, 2005) [see Figure 1.1]. Where such tools are lacking especially in unstructured work environments, there may be the need to develop appropriate assessment tools to ensure effective ergonomic risk assessments are conducted. An effective ergonomic risk assessment is essential for proposing ergonomic interventions tailored to the specific work environment in order to reduce work-related cumulative trauma disorders.

1.4 Justification

Studies specific to informal e-waste recycling work at worksites in China (Chi et al., 2011), India (Wath et al., 2011), Brazil (Gutberlet & 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. In most developing countries including Ghana, those engaged in recycling activities often belong to vulnerable groups in society (Zhang & Xu, 2016), and their livelihood is fully dependent on earnings from e-waste recycling activities (Amankwaa, 2013). Making e-waste recycling efficient and safer for these workers will go a long way to improve their livelihood,

protect the environment and prevent workers and the community from suffering from the adverse health effects of e-waste.

The purpose of this thesis was to use a systematic and scientific methodology to characterise the processes and physical work methods involved in informal e-waste recycling, and to identify the ergonomic risk factors that potentially contribute to development of work-related MSDs among e-waste workers. This step must precede the development of effective preventive and control measures. This will also provide policy makers and stakeholders critical baseline data in planning appropriate, evidence-based prevention strategies. Early diagnoses and prevention of occupational injuries can be expected to result in reduction of the incidence and severity of these injuries (Iqbal & Alghadir, 2017).

The present thesis represents an ensemble of 5 studies that together evaluates the ergonomic risks associated with informal e-waste recycling at Agbogbloshie and proposes workable approaches that could be used to remedy the identified ergonomic hazards. Data from this thesis will contribute to the literature on ergonomic exposures associated with e-waste recycling and provide data to support the possible associations between these exposures and the development of work-related MSDs. Finally, findings from this thesis will hopefully inform policy to address a subset of ergonomics issues associated with the global challenge of informal e-waste recycling.

1.5 General aim

The overarching aim of this thesis was to determine the ergonomic risk factors and work-related MSDs associated with informal e-waste recycling at Agbogbloshie, Accra Ghana by developing

an exposure assessment method adapted to unregulated and unstructured work in the informal sector.

1.6 Specific objectives

1. Describe the processes involved in manual e-waste recycling at Agbogbloshie, and highlight the health and psychosocial challenges associated with this type of work.
2. Quantify and compare occupational physical activity exposures among the three main job categories of e-waste workers (i.e. collectors, dismantlers and burners) engaged in informal e-waste recycling at Agbogbloshie.
3. Investigate the self-reported prevalence and severity of MSDs among e-waste workers and their interference with the ability to work in comparison to a reference population.
4. Develop a low-cost observation-based ergonomic exposure assessment tool that enables rapid quantification of the intensity and duration of physical exposures in unregulated and unstructured work in an informal sector such as e-waste recycling.
5. Assess and compare the physical exposures associated with e-waste recycling and work-related MSDs across the three main e-waste job categories.

1.7 Research questions

The present thesis addresses the following questions:

1. What are the processes and challenges associated with manual recycling of e-waste at Agbogbloshie?
2. What are the occupational physical activity exposures of e-waste workers engaged in informal e-waste recycling?

3. What is the prevalence and severity of MSDs among e-waste workers compared to a reference population and how do they interfere with their work?
4. Can a cost-effective observation-based ergonomic assessment tool be developed to capture, with sufficient reliability, exposures among e-waste workers?
5. What is the intensity and duration of exposures to physical/ergonomic risk factors among e-waste worker at Agbogbloshie?
6. How do the physical exposures associated with e-waste recycling and work-related MSDs differ across the three main e-waste job categories?

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of key terms and concepts relevant to this thesis as well as an overview of current knowledge on e-waste recycling, work-related MSDs and ergonomic assessment methods. The existing gaps and/or limitations are highlighted and emphasis is placed on the research gaps that this thesis aims to address.

The literature review was conducted via a robust search of the existing literature which included databases such as PubMed, Embase, Medline, CINAL, Cochrane Central Registry as well as google scholar. In addition, other grey literature as well as references of articles of interest were also searched. Key search terms as related to the various subheadings were used to retrieve articles of potential interest. The search results were screened by title and abstracts and the full text of articles that were relevant to the topic of interest selected for review. Narrative summaries of the reviews are presented under selected topics below.

2.2 Ergonomics / human factors

The term "ergonomics" meaning *the science of work* derives from two Greek words "ergon" which means work and "nomos" which means laws (International Ergonomics Association, 2020). Although human factors is more frequently understood as the cognitive side of human machine interaction, the term ergonomics is frequently used interchangeably or complementarily with human factors (Jaffar et al., 2011). The International Ergonomics Association defines ergonomics

as a scientific discipline that is concerned with understanding of the interactions between humans and machines. It is a profession that applies theory, principles, data and methods to design so as to optimise human well-being and overall system performance (International Ergonomics Association, 2020). The goal of human factors and ergonomics is to decrease human error, enhance safety and comfort and increase productivity while focusing on the interaction between the human and the factors of interest (Wickens et al., 1998). Ergonomics warrants that job demands should not exceed the capacity and limitation of the worker. It focuses on ensuring a good fit between products, tasks, the environment and the worker. As stated by (Grandjean, 1969) ergonomics is about "fitting the task to the man". Failing to do so leads to MSDs.

2.3. Musculoskeletal disorders

Musculoskeletal disorders are soft tissue injuries or disorders that occur as a result of awkward postures, repetitive movements, forceful exertion, contact stress, vibration as well as limited rest periods. All these factors can affect the muscles, nerves, tendons, joints and cartilage as well as the spinal discs (CDC, 2019; Iqbal & Alghadir, 2017; Jaffar et al., 2011). These disorders occur usually as a result of accumulation of events rather than a single event occurence (Jaffar et al., 2011) and as such are sometimes refered to as cumulative injuries or repetitive stress injuries.

The term work-related musculoskeletal disorders is often used to refer to MSDs that occurs as a result of occupational risk factors, as demonstrated by epidemiological evidence (Bernard, 1997). work-related MSDs remain one of the major work-related health problems globally (Podniece & Taylor, 2008) and are the most common work-related health problem among working populations in different parts of the world (Podniece & Taylor, 2008; Public Health Agency of Canada, 2014). Musculoskeletal disorders are a primary source of work-related disability (Yelin et al., 1999)

leading to the loss of valuable work time (Buckle, 2005), as illustrated by Figure 2.1. Data in this figure corresponds to the US population for various activities by body part affected. This loss places an enormous economic burden on the employer, employee and the health system (Sultan-Taïeb et al., 2017). Furthermore, in the US, the Institute in Medicine estimated the economic burden of work-related MSDs as measured by compensation costs, lost wages, and lost productivity, as between $45 and $54 billion annually (NIOSH, 2004). While similar statistics on injury and disorder prevalence in Ghana are not readily available, the numbers from the US do help provide some context for the magnitude and severity of the health and economic burden resulting from work-related MSDs.

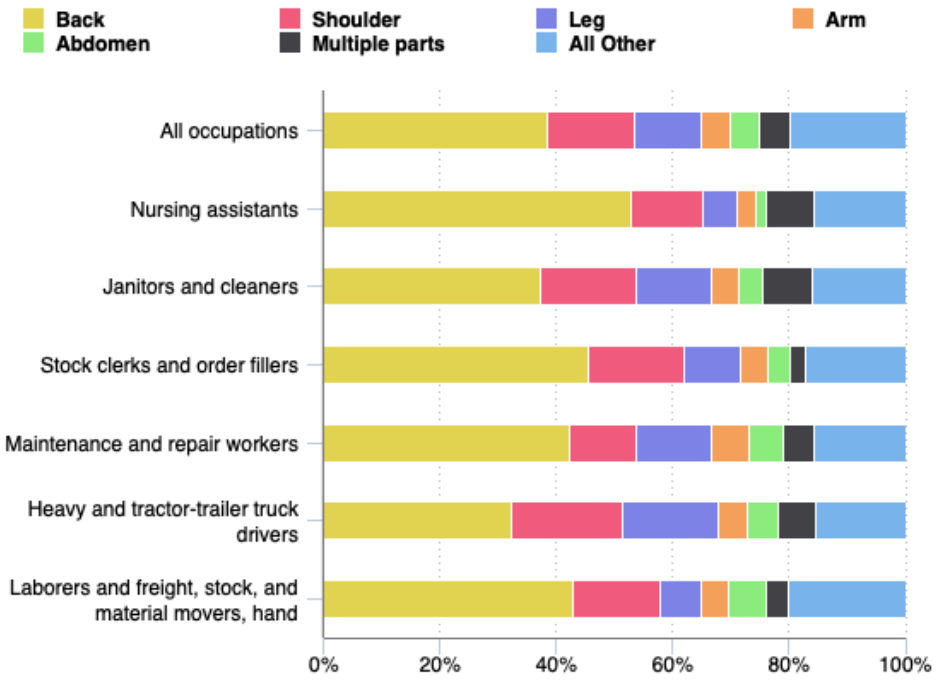


Figure 2.1: Work related musculoskeletal disorder resulting in days away from work in selected occupations by part of body. Source: Bureau of Labor Statistics, 2016.

2.4 Causes / predisposing factors for work-related musculoskeletal disorders

The causes of work-related MSDs are complex and encompass an interaction between a wide range of factors (Jaffar et al., 2011; Oakman et al., 2014; Wiehagen & Turin, 2004) which may be expressed at varying intensities. The predisposing factors to developing work-related MSDs are broadly categorized into individual factors (Bongers et al., 2002; Jaffar et al., 2011), physical or ergonomic factors (Eatough et al., 2012; Kuorinka et al., 1995; Marras, 2008) as well as organizational and psychosocial factors (Bongers et al., 2002; Kuorinka et al., 1995; Oakman et al., 2014).

2.4.1 Individual factors

Individual factors such as age, gender, fitness status or disease state, poor work practices directly or indirectly plays a key role in the development of MSDs (Carayon et al., 1999; Oakman et al., 2014; Widanarko et al., 2011). These factors may reduce tissue tolerance which may subsequently affect workers' biomechanical responses to tissue loading resulting in pain and discomfort in the body part involved (Kuorinka et al., 1995; Oakman et al., 2014). In addition, poor work practices such as improper handling of loads, working within a limited time to complete a task may induce carelessness which could also lead to work related injuries (Kuorinka et al., 1995).

2.4.2 Physical or ergonomic factors

Physical or ergonomic risk factors tend to be one of the most common causes of MSDs. The known primary ergonomic risk factors that causes MSDs include non-neutral postures, repetitive movements, forceful exertion (Kang, et al., 2014), vibration, contact stress, poor workplace environmental factors (Iqbal & Alghadir, 2017) and static loading (Jaffar et al., 2011). Other

physical work factors include: extended reach, close vision work and handling heavy loads (Kuorinka et al., 1995). The weight, size and shape of objects handled; the type of working tools used as well as the nature or characteristics of tasks performed are also significant contributing factors to work-related MSDs (Oakman et al., 2014). Imposed work load of various magnitudes can cause changes in work patterns, coactivation of muscles, and muscle fatigue. When the changes induced by the imposed load exceeds the mechanical tolerance or the ability of the structures involved to withstand the load, tissue damage occurs leading to tissue responses such as swelling and pain (Kuorinka et al., 1995). Furthermore, physiological phenomena associated with fatigue, such as accumulation of calcium (Ca++) , also lead to tissue disorders (Hadrevi et al., 2013; Sejersted & Sjogaard, 2000). Persistent or unresolved tissue damage may result in functional impairments and in the long term disability. Some ergonomic risks factors of interest that were assessed in this thesis are detailed below.

Repetitive movement: Repetitive movement occurs when an indiviudal performs similar movements with the same body part with little or no rest over a specified period (Jaffar et al., 2011). Repetitive movements engage the same muscle groups over a prolonged period allowing limited time for recovery/muscle relaxation. This result in muscle fatigue and subsequently pain and discomfort in the active muscle. Furthermore the repetitive stress imposed on tissues can lead to damages due to a lack of recovery as well (Chaffin et al., 2006). The greater the number of repetition rate, the greater the risk of MSDs (Silverstein et al., 1986, 1987).

Force: Force is an action that changes the state of rest or motion of a body to which it is applied (Chaffin et al., 2006). It can also be defined as the physical effort required to accomplish a specific task or to maintian control of an equipment or tool (Jaffar et al., 2011). Force is usually exerted

during gripping, lifting/carrying, and pushing and pulling tasks. Force exertion overtime, may result in muscle and tendon overload which could eventually lead to pain, discomfort and tissue damage. In addition, excersive force corresponds to excessive stress on the muscles (Jaffar et al., 2011).

Awkward/non-nuetral postures: Posture is the position assumed by the body either with support during the course of a muscle activity or with a coordinated effort from a group of muscles working together to maintian stability (Physiopedia, 2020). A posture is essentially static in sitting, standing or sleeping. However, in dynamic situations , i.e. movements, the range of motion may be large and correspond to joint angles largely deviated from neutral or a comfortable amplitude. It is considered that, the more a joint deviates from the neutral posture the higher the risk of injury (Jaffar et al., 2011). Awkward/non-neutral posture is a contributing factor to MSDs such as low back pain (Lafond et al., 2009), neck pain (Knight & Baber, 2004) or carpal tunnel syndrome (Rempel et al., 1998; Weiss et al., 1995).

Vibration: Vibration can be defined as a rapid back and forth movement a body makes about an equilibrium point (Jaffar et al., 2011). All bodies with mass and elasticity are capable of vibration. Thus, work equipment as well as the human body are liable to vibration (Chaffin et al., 2006). Subjecting body tisues to high vibration magnitude at relatively low frequencies may result in tissue breakdown from the continous resonance or absorbtion of high energy vibration (Jaffar et al., 2011). Furthermore, the sensory mecanoreceptors are sensitive to vibration and their response to this mechanical stimulation affect movement control and contribute to an increase in muscle contractions. The responses to vibration are a function of the vibration frequency, amplitude, direction and the duration of exposure to vibration. Transmissibility of vibration is a function of

vibration characterisitcs as well as body posture, the weight of the body segment involved, and the extent of muscle contraction (Griffin, 1990). Vibration may affect specific body segments such as in hand-arm vibration generated by powered hand tools or the whole body such as in vehicles or aircraft.

Contact stress: Contact stress is produced by the pressure of a hard surface applied to the skin during grasping or manipulating objects or leaning against a hard surface (Jaffar et al., 2011). Common sources of contact stress in workplace include working with the forearm and wrist against the edge of a work surface as well as using the hand as a hammer to firmly secure an object in place. Pressure to the skin from a hard surface may reduce blood flow, injure the nerves beneath the skin and subsequently cause discomfort and pain.

2.4.3 Psychosocial and Organizational hazards

Psychosocial and organizational factors that contribute to work-related MSDs are closely linked and may even overlap in most instances (Oakman et al., 2014). Work-related psychosocial risk factors include the aspects of work design and management as well as the social organizational aspects of work that poses psychological or physical harm to workers (Cox & Griffiths, 2005). Examples include: the attitude and behavior of superiors and co-workers, high work demands (Linton, 2001) and mental loads, inadequate coping resources, lack of job satisfaction and stress (Eatough et al., 2012; Marras, 2008; Oakman et al., 2014; Schoenfisch & Lipscomb, 2009). Organizational factors include structures and policies that influences how work is organised and tasks combined. These include organizational culture and function, work design, extended working hours and shifts, absence of appropriate protective and other work equipment to facilitate work,

and monotony in tasks performed due to the absence of job rotations or variations (Oakman et al., 2014).

It is well established that psychosocial and organisational factors contribute to the development of work-related MSDs (Carayon et al., 1999; Eatough et al., 2012; Kuorinka et al., 1995; Oakman et al., 2014). A review by Marras, (2008), demonstrated that psychosocial hazards were responsible for about 14% to 63% risk of developing back pain while also accounting for about 28% to 84% of risk of developing arm and upper body pain. Aasa et al. (2005) also reported a link between the level of psychological demands and neck-shoulder complaints (Aasa et al., 2005). In addition, Eatough et al. (2012) showed that, high levels of role conflict, low job control and low safety-specific leadership were associated with the increase in employee strain which in turn resulted in high levels of work-related MSDs in the wrist/hand, shoulder and lower back (Eatough et al., 2012). Studies by Unge et al. (2007) as well as Waters et al. (2006) have also highlighted the importance of psychosocial stress in the development of work-related MSDs.

2.5 Occupational health

The joint International Labour Organisation (ILO) and World Health Organisation (WHO) committee on occupational health defined occupational health as a discipline aimed at promoting and maintaining the highest degree of physical, mental and social well-being of workers in all occupations by preventing departure from health, controlling risks and the adaptation of work to people, and people to their jobs (ILO, 2011). According to the ILO, Occupational health focuses on three main objectives: i) maintenance and promotion of workers' health and working capacity, ii) improvement of the working environment to make it safe and healthy, iii) development of work organizations and working cultures in a direction supporting health and safety at work, promoting

positive social interactions and improving productivity. Occupational health problems exist in various work groups (Malmros, et al., 1992; Mobed et al., 1992; Poulsen et al., 1995; Tan, 1991) and if not given the needed attention may be detrimental to the workers' health.

2.6 Electronic waste as an occupational health issue

Electronic waste (e-waste) is a broad term used to describe end-of-life electronic and electrical equipment such as computers, televisions, mobile phones, and other home appliances (Amankwaa, 2013). It is believed to be one of the most rapidly increasing sources of waste globally (Lundgren, 2012) with an estimated 41.8 million tons of e-waste produced in 2014 (Breivik et al., 2014; Heacock et al., 2016). The increase in e-waste has been fuelled by the increase in obsolescence and the desire to keep up with the global advancement in technology.

Furthermore, large quantities of e-waste produced in Europe and North America are "dumped" in developing countries (Amoyaw-Osei et al., 2011; Lundgren, 2012) [see Figure 2.2]. In West Africa, Ghana and Nigeria are the two countries often used as trade routes for importation of electronic equipment (Schleup et al., 2012). The electronic equipment imported into developing countries are usually at their end-of-life often referred to as "second-hand". They are mostly either unusable or can only be used for a short period before it reaches its end-of-life. According to a report by the government of Ghana in 2009, 15% of the second-hand gadgets imported into the country were unusable. They were either broken, could not be powered on or were outdated (Amoyaw-Osei et al., 2011). Developing countries often lack the technical know-how to recycle e-waste in an ecologically safe and sustainable manner and this poses serious public health and environmental concerns.

Figure 2.2: Heaps of electrical and electronic waste and engine parts at Agbogbloshie

2.6.1 Informal recycling of end-of-life electronics

E-waste globally is either recycled as a source of revenue or for making other products or is discarded and end up in landfills. E-waste recycling mainly occurs in the informal sector as a means of livelihood by low-wage, low skilled workers who are largely unaware about the associated exposure risks or about safe work practices to prevent or mitigate related adverse effects (Amankwaa, 2013; Lundgren, 2012; Yu et al., 2017). Informal e-waste recycling and scrap metal recovery consists primarily of scavenging and collecting e-waste items, sorting out items that can be reused or repaired and subsequent manual dismantling of items that are irreparable and/or non-functional as a means of subsistence or to generate income (Akormedi et al., 2013; Binion & Gutberlet, 2012) .

The recycling processes used are largely manual (Figure 2.3). Basic tools such as hammer and screw drivers are used for breaking apart electrical items to retrieve valuable metals such as copper, aluminium, silver, and gold in a process popularly referred to as dismantling (Amankwaa, 2013). Open air burning (Figure 2.4), especially of insulated wires, is used to recover copper, iron and

aluminium from items that cannot be dismantled (Akormedi et al., 2013). Non-valuable fractions of e-waste are discarded at the dumpsite and subsequently burnt to reduce the volume of waste accumulated (Amoyaw-Osei et al., 2011).

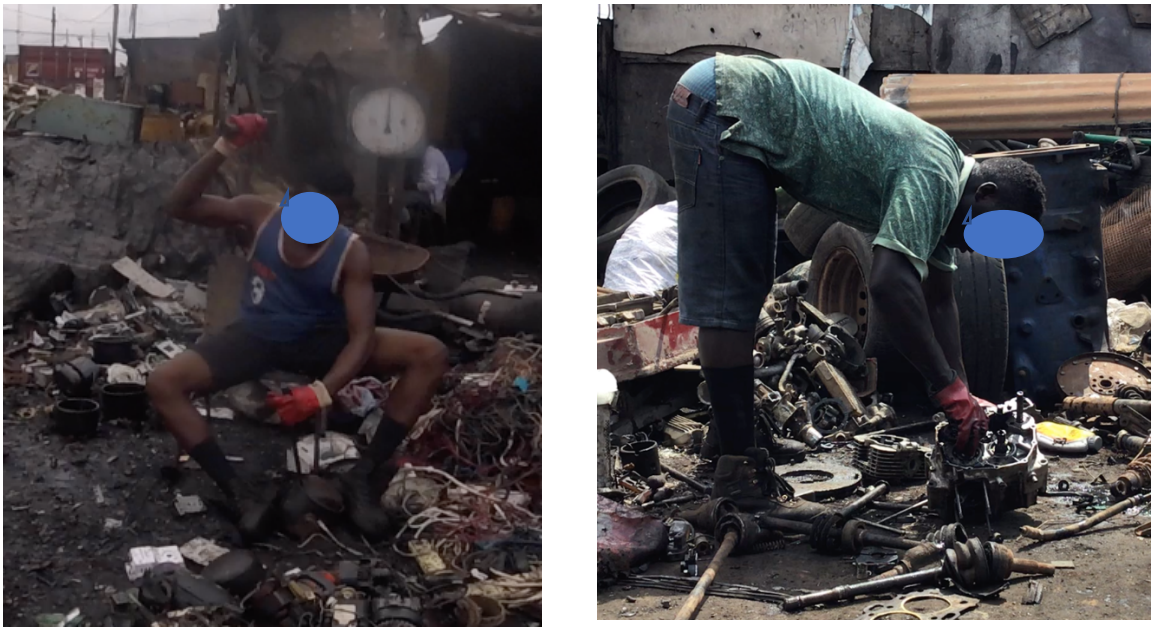


Figure 2.3: Workers dismantling e-waste and scrap metal.

Figure 2.4: E-waste workers burning electrical cables to recover copper wires.

The informal and rudimentary methods used in e-waste recycling are hazardous and poses huge safety risks to workers and the environment (Yu et al., 2017). For example, burning of copper wires results in emission of dioxins and furans (Prakash et al., 2010) while breaking (dismantling) of Cathode Ray Tubes (CRT) monitors with rudimentary tools (stones, hammers, heavy metal rods, chisels) to recover copper and steel, result in the inhalation of hazardous cadmium dust and other pollutants (Prakash et al., 2010). Technological deficiency in recycling compels recyclers in the informal sector to employ these crude recycling methods (Amankwaa, 2013). Despite all the hazards e-waste workers are exposed to, the use of personal protective equipment (PPE) is an extremely rare exception (Akormedi et al., 2013; Neitzel et al., 2013).

In more advanced and formal e-waste recycling setting, ecologically friendly methods such as the use of low temperature roasting have been shown to be efficient in recovering valuable metals from e-waste (Panda et al., 2020). This was demonstrated by the use of low temperature roasting which enabled the recovery of 93% Cu, 100% Ni, 100% Zn and 100% Pb in a study conducted by

Panda et al. (2020). The rudimentary methods used in informal e-waste recycling is however, less effective and results in the loss of an appreciable amount of recoverable metals as well as the production of high volumes of waste (Akormedi et al., 2013). For example, the use of burning as a means of recovering e-waste results in some valuable materials being burnt off as airborne oxides (Akormedi et al., 2013). The poor recycling methods used, tend to push the focus on recovery of copper, aluminium, and steel neglecting other valuable metals such as indium, palladium, gold and silver that are also recoverable from e-waste using the appropriate recycling technology.

2.6.2 Informal e-waste recycling in Agbogbloshie, Accra Ghana

Agbogbloshie in Accra Ghana is one of the major e-waste sites in the world (Akese, 2019). It is estimated that Ghana produces 150,000 tons of e-waste and imports about 280,000 tons of e-waste (Ackah, 2017; Kwarteng et al., 2020). Agbogbloshie, processes about 40-60% of the country's total e-waste (Grant & 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).

In the 1980's, a structural adjustment program from the World Bank and International Monetary Fund's (IMF's) Structural Adjustment Program (SAP) on agriculture resulted in high rates of unemployment especially in the farming communities in Northern Ghana. This triggered migration of Northerners to the south in search of Jobs (Amuzu, 2018). The migration was further heightened by the inter-ethnic conflict between Komkomba and Dagomba in 1995 (Farouk & Owusu, 2012) as well as chieftaincy disputes and other ethnic conflicts in 1990 and 2001 (Akormedi et al., 2013; Twumasi-Ankrah, 1995). The migrants settled in Agbogbloshie which at that time was being used by the government of Ghana as a relocation facility for street hawkers (Amuzu, 2018).

Over time, new forms of livelihood strategies in the form of scrap businesses began to emerge. The scrap business involved generation of income through salvaging of gold, aluminium, coper and other precious metal from electronic waste. This business eventually became more lucrative (Amuzu, 2018) than agriculture as the migrants upon returning home had become better economically than their colleagues who remained in the conflict zone (Akormedi et al., 2013; Twumasi-Ankrah, 1995) . This triggered a wave of mass migration of youth from the North to the South of Ghana to engage in waste picking (Akormedi et al., 2013; Twumasi-Ankrah, 1995). It is estimated that, between 20,300 to 33,600 people are employed in the refurbishing sector in Ghana majority of which originate from the northern part of the country (Prakash et al., 2010).

Although engaging in e-waste recycling does not necessarily ensure higher income, it is still an occupation of choice for various individuals who migrate form the Northern part of Ghana to the south due to the rapid cash flow and regular income from this business. This rapid cashflow is not usually recognized from agriculture which is the predominant occupation in Northern Ghana (Prakash et al., 2010). It is estimated that the mean daily income of an e-waste worker may sometimes be higher than the daily minimum wage in Ghana. Thus, making it a more economically viable livelihood strategy compared to agriculture (Amankwaa, 2013).

E-waste may have significant economic benefits but the improper management and disposal practices could have adverse environmental and health effects. Effective management of e-waste entails the collection, sorting repairing and reuse of e-waste where applicable. Where e-waste cannot be reused, toxic components should be removed and discarded appropriately while appropriate and safe techniques are used to recover valuable substances that could have economic benefits (Namias, 2013).

2.6.3 Environmental and health effects due to informal e-waste recycling

Poor management and recycling practices used in e-waste recycling pose great harm to e-waste workers, the local communities and the entire society (Prakash et al., 2010). A systematic review by Grant et al. (2013) found that 16 of the 23 studies reviewed indicated possible associations between e-waste and physical health outcomes. Health hazards present in e-waste recycling include, chemical hazards, release of particulate matter into ambient environmental, physical trauma as well as ergonomic and musculoskeletal discomfort (Binion & Gutberlet, 2012). These known hazards are potential risk factors for adverse health outcomes such as negative effects on thyroid function, reproductive health, poor lung function, impaired growth, as well as changes to cell function (Grant et al., 2013).

Furthermore, studies have shown that the negative health effects of e-waste recycling is not only evident among workers, but extends to children, developing fetuses (Robinson, 2009) and even bystanders within the recycling vicinity (Fischer et al., 2020). According to Binion and Gutberlet, (2012), children involved in informal recycling have a 2.5 times higher potential of morbidity. Epidemiological studies conducted at e-waste sites have indicated that parents who live close to e-waste recycling sites are likely to have their infants developing congenital malformations (Porta et al., 2009). The available literature also reports high rates of miscarriages, birth defects and cancers from e-waste recycling (Amankwaa, 2013). Other negative effects of e-waste recycling on the nearby communities include high levels of environmental pollution, poor air quality as well as possible contamination of water and food supplies (Lundgren, 2012).

E-waste contains several toxic chemical substances that have either been banned or its use restricted in many countries. Some of these toxic substances include heavy metals, ozone-depleting

substances and persistent organic pollutants (Balde et al., 2015; Matsukami et al., 2016; Zheng et al., 2016). High levels of aluminum, copper, iron, lead and zinc have been reported in personal air samples of informal e-waste workers (Caravanos et al., 2011). Similarly, elevated lead concentrations (Caravanos et al., 2011) as well as high levels of trace metals and polybrominated diphenyl ethers have been reported in soils at informal e-waste sites (Caravanos et al., 2013; Oteng-Ababio et al., 2014). Asante et al. (2011) reported high levels of polybrominate, diphenyl ethers and polychlorinate biphenyls in breast milk of mothers in communities where e-waste is recycled in Ghana. Again, elevated levels of cadmium and lead were found in blood samples of e-waste workers at a recycling site in Ghana (Srigboh et al., 2016; Wittsiepe et al., 2017). In addition, high levels of Polycyclic Aromatic Hydrocarbons (Feldt et al., 2014), cadmium, chromium, nickel (Wittsiepe et al., 2017), iron, antimony, lead and various arsenic species (Asante et al., 2012; Srigboh et al., 2016) have been reported in urine samples of e-waste workers. Chemical hazards from e-waste recycling may have adverse effects such as fetal loss, prematurity, low birthweight, congenital malformations, abnormal thyroid function and development, neurobehavioral disturbances and genotoxicity (Lundgren, 2012; Robinson, 2009).

Other known risk exposure to e-waste recycling includes exposure to physical and ergonomic hazards although these have not been extensively studies as has chemical and environmental hazards. Neitzel et al. (2013) reported the presence of hazards such as noise, repetitive movements, lifting and non-neutral postures among scrap metal workers. The most common health hazards observed were non-neutral postures (see Figure 2.3), noise and repetitive movements which were present in 77%, 71% and 66% of observations respectively. The authors also reported falls, lacerations and cuts as well as exposure to vibrations (Neitzel et al., 2013). Similarly, a study conducted in Sweden to investigate the working conditions in a consumer waste recycling facility

indicated that, workers were exposed to noise, non-neutral postues and ergonomic hazards, (Engkvist, 2010). Workers also reported high occurrences of falls, injuries and musculoskeletal pain related to physical risk factors. Elevated exposure to ergonomic hazards have also been reported in a study of consumer waste recycling conducted in Quebec (Lavoie & Guertin, 2001). Physical work exposures are know to induce adverse health effects to the worker. For example, Fischer et al. (2020) reported significantly higher occurrences of back pain (91.6% e-waste workers vs 79.6% by standers) and work-related injuries (75.0% e-waste and 42.6% bystanders) among e-waste workers compared to bystanders, although the study did not establish a signifiant association between their physical exposures and injuries reported. Also, the authors did not use a standardised definition or assessment tool for measuring pain or injury. On the other hand, Burns et al. (2016, 2019) reported a significant correlation (Spearman's ρ 0.46, $p < 0.001$) between noise exposure and elevated average heart rate as well as injuries.

2.6.4 Work-related MSDs among informal e-waste workers

E-waste workers are prone to work-related MSDs due to the rudimentary methods used in recycling (see Figures 2.3, 2.4 and 2.5). Compared to formal workers (Yohannessen et al., 2019) and other non-ewaste work groups (Fischer et al., 2020), e-waste workers are expected to have significanlty higher occurence of muscloskeletal aches, pain, and discomfort. In the absence of objective clinical data, general body pain has been reported in various studies among e-waste workers as an indicator of underlying MSDs (Asampong et al., 2015; Caravanos et al., 2013; Mishra, 2019; Ohajinwa et al., 2018; Sharma et al., 2017).

E-waste workers are primarily divided in there categories. These are collectors (Figure 2.5), dismantlers (Figure 2.3) and burners (Figure 2.4) of e-waste. 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.

Figure 2.5: E-waste collector pulling a collecting cart

In a cross-sectional study by Fischer et al. (2020) which was conducted at the e-waste site at Agbogbloshie, work-related back pain was reported among 91.6% of e-waste workers. With respect to job sepcific back pain, 100% of collectors, 92.3% of dismantlers and 85% of burners reported work-related back pain. The study however found no association between hard physical work and back pain (Fischer et al., 2020). In another study conducted in Chile by (Yohannessen et al. (2019), wrist or hand pain of 4.9±2.0 on a VAS scale was reported among 51% of participants while 61% reported general muscle soreness from sitting in the same postion for prolonged periods. These two studies focused on MSDs of the back and wrist respectively and did not give an indication of musculoskeletal discomfort in other regions of the body. A cross-sectional survey

based study conducted in Nigeria by Ohajinwa et al. (2018) however, provided an elaborate report on MSDs among e-waste workers which reported on more body regions. Results from the study showed that, 29% of e-waste workers complained of lower back pain, 14% of shoulder pain and 10% neck pain (Ohajinwa et al., 2018).

Overall, these studies indicate a high prevalence of work-related MSDs among e-waste workers in different countries. However, to the best of our knowledge, a comprehensive assessment of MSDs using a standardized assessment questionnaire among e-waste workers in Ghana is lacking. The use of standardized questionnaire would be critical for obtaining reliable and valid data to facilitate comparisons with other worker populations or at different points in time (i.e., longtudinal studies). Thus, this thesis focused on bridging this important gap by investigating work-related MSDs among e-wate workers in Agbogbloshie Accra Ghana. Furthermore, to fully investigate work-related MSDs, evaluation of the associated risk factors in this population is necessary to establish relationships between exposure and work-related MSDs and then propose locally adapted interventions and/or recommendations.

2.7 Ergonomic/physical work exposure assessment of informal non-repetitive work

This section reviews the various assessment methods that have been used to assess ergonomic/physical work exposures in diverse structured work settings. The merits and associated challenges are discussed as well as their appropriateness for investigating exposures in unregulated unstructured work setting. Assessment methods often used to quantify physical work exposures include self-reporting questionnaires, observational methods, direct measurements (Burdorf & van der Beek, 1999; Li & Buckle, 1999) and biomechanical analyses involving specific tools such as

the University of Michigan's 3D Static Strength Prediction Program (3DSSPP) [Chaffin et al., 2006].

2.7.1 Self-report assessment tools

Self-report assessment tools are used in ergonomic assessments to obtain information on participants exposure to physical as well as psychosocial factors. It involves asking the participant to provide some useful information about their work. Self-report assessments are inexpensive and easy to use. Assessment procedures involve the use of worker diaries, interviews and questionnaires (David, 2005a, 2005b) to capture relevant information about a worker's job activities. The use of self-report exposure assessment is known to result in overestimation of the prevalence of some risks/hazards mainly due to the fact that, the respondents tend to have a longer exposure integration period in mind compared to performing a snapshot observation assessment (Neitzel et al., 2013). That notwithstanding, self-report assessment is better suited for collecting certain types of data such as injury experience (Neitzel et al., 2013), discomfort and pain (Hedge et al.,1999), and long-term exposures (Stanton et al., 2004).

2.7.2 Observation based tools

Observational methods are most widely used in assessing physical exposures associated with work-related MSDs mainly because they are cost-effective and applicable in a large variety of workplaces (Rahman et al., 2014). Observations methods tend to present with some level of subjectivity and lower accuracy and precision (Takala et al., 2010). These methods may involve systematically recording and observing a job for work-related ergonomic exposures using an

inspection checklist to help identify areas of the work that needs workplace interventions (David, 2005).

Inspection checklists combined with direct observations have been used in ergonomic exposure assessment especially where the use of direct measurements are unavailable, difficult to obtain, or its usage is limited. Seixas et al. (1998) used a self-developed inspection checklist to identify the presence or absence of risk and the degree of protection from risks or hazards at a US construction site. The checklist was used at random locations within the worksite to assess trips, falls, electrocutions, trenching cave-ins, lacerations and vehicle-related injuries. Hazards and risks were rated on the basis of their frequency and the level of protection (Seixas et al., 1998). In another study, conducted at a construction site in Finland by Laitinen et al. (1999) a combination of walkthrough observation and the use of a tally sheet (check-list) was adopted. This was done by observers recording the number of correct and non-correct work conditions for different safety hazards identified via walkthrough observations. A correct tally indicated that appropriate safety steps were being taken whiles a non-correct tally indicated otherwise for the situation being assessed. Other frequently used observation tools that utilises a checklist are indicated below.

OCRA (Occupational Repetitive Action)

Another common and widely used assessment method that combines observations and checklist is the Occupational Repetitive Action (OCRA) method. OCRA was developed by Colombini, (1998) and latter updated (Colombini et al., 2013). The method was developed to assess tasks that presents with various upper limb risk factors such as force, repetition, awkward postures and movements, lack of recovery periods and other additional factors defined by the assessment method (N. Stanton

et al., 2004). OCRA however is cumbersome as it includes a large number of details, and focusses on repetition and thus lacks flexibility for unstructured work.

QEC (Quick Exposure Checklist)

The QEC (Li & Buckle, 1998) also combines worker observations with the use of a checklist as well as provides a set of questions to be answered by the worker being observed. QEC is a quick tool for the assessment of worker's exposure to risk factors that predispose workers to MSDs. The tool has been tested and validated in both simulated and real time tasks and has been shown to have a high inter- intra-observer reliability, a high level of sensitivity and highly usability (N. Stanton et al., 2004). QEC is applicable for a wide range of tasks in well-structured work environments. Its use however, in informal setting where tasks are highly variable may be challenging.

Observation methods may also employ the use of dedicated software or an assessment scoring system to assess postural variations and other risk factors in tasks performed for highly dynamic activities (David, 2005). An example of such tools are RULA (Rapid Upper Limb Assessment) [McAtamney and Corlett, 1993] and REBA (Rapid Entire Body Assessment) [Hignett & McAtamney, 2000], OWAS (Ovako Working Posture Analysis System) [Karhu et al., 1981; Karhu et al., 1977] and PATH (Posture Activity Tools Handling) [Buchholz et al., 1996].

RULA (Rapid Upper Limb Assessment)

RULA provides an easily calculated rating that indicates the risk of musculoskeletal disorders for tasks in which workers may have a risk of neck and upper-limb injuries (McAtamney & Corlett, 1993b; Stanton et al., 2005). The single score provided is a rating of the posture, force, and movement requirements of the task being assessed. The tool is ideal for assessing posture, force and movement associated with sedentary tasks such as computer tasks, manufacturing and retail tasks where the workers stands or sits in one place for a long time without moving about (Stanton et al., 2005).

REBA (Rapid Entire Body Assessment)

REBA which is very similar to RULA with the addition of leg postures (Hignett & McAtamney, 2000) evaluates working postures in the upper extremities and trunk. It was developed to assess working postures in health-care and other service industries (Stanton et al., 2005). The tool records data on posture, force exertion, repetition, movement types and coupling to generate a single score which is indicative of the risk of MSDs and the level of urgency with which action should be taken.

These tools are however, either limited by the number of body segments considered or by the complexity of the details for each segment and require expertise as well as a long application period which are incompatible with frequent job variations.

OWAS (Ovako Working Posture Analysis System)

OWAS is designed for identifying and evaluating unsuitable working postures only (Karhu et al., 1981; Karhu et al., 1977) and was developed initially for the steel industry although its use has

been applied in other work setting (Karhu et al., 1981, 1977; Kong et al., 2018). It is a time sampling posture assessment tool which provides high generality but low sensitivity (N. Stanton et al., 2004). OWAS is in two parts. The first part comprises of an observation technique for evaluating working postures. Its use requires training and is targeted towards work-study engineers during their daily routine (Karhu et al., 1977). The second part of OWAS includes a set of criteria developed by experienced workers and ergonomic experts for redesigning work methods in work places. The criteria places emphasis on discomfort that occurs as a result of working postures (Karhu et al., 1977).

PATH (Posture Activity Tools Handling)

PATH (Buchholz et al., 1996) is a work sampling-based assessment method developed for characterising ergonomic hazards among construction workers mainly due to the non-repetitive nature and irregular work cycles that exist in construction work compared to production-line jobs. Posture assessment codes used in PATH are based on OWAS with the addition of assessment criteria for tools used, activities performed and load handled. PATH requires extensive training of about 30 hours for it to be used reliably (Buchholz et al., 1996). The long training period required makes it use unsuitable for unexperienced ergonomist or regular researchers looking for an easy to use ergonomic assessment tool to characterise ergonomic exposures in a work environment.

2.7.3 Direct measurements and biomechanical analysis

More advanced ergonomic assessment methods may use a wide range of sensors and direct measurement instruments coupled with dedicated software to analyse ergonomic and biomechanical risks associated with a particular job or task (David, 2005b, 2005a; Juul-Kristensen

et al., 2001). Examples of these include electronic goniometry (Radwin & Li, 1993), wearable mobile sensors (Nath et al., 2017), digital electromyography (Forsman et al., 1999) and biomechanical analysis software such as the 3DSSPP developed by the University of Michigan (Chaffin et al., 2006). Direct measurements and biomechanical analyses provide more accurate values but tend to be expensive (Juul-Kristensen et al., 2001) and less practical in applied settings (Chaffin et al., 2006) despite the new development of wearable technology and computer vision. Unlike direct observations which ensure data collection without significant interference with work, direct measurements may alter the workflow.

2.7.4 Choosing an appropriate ergonomic assessment tool

Although various ergonomic assessment tools exist, the ability of the ergonomic professional to select and use the most appropriate tool for an ergonomic assessment is key. The choice of an ergonomic assessment tool is dependent on the type of assessment and the objective of the study being conducted (David, 2005). Nonetheless, a combination of observations, direct measurements and worker self-report methods can provide a more comprehensive picture of occupational exposures (Neitzel et al., 2013).

In a study that evaluated safety and health hazards associated with scrap metal work (Neitzel et al., 2013), the authors used a combination of hazard assessment methods which included, a self-designed observational tool, direct measurements and self-report questionnaire that required workers to identify their exposure to the risks under investigation. Result from the study showed that, workers reported substantially higher frequencies of exposure to falls, lifting, and machine hazards and lower frequency of exposure to non-neutral postures in self-reported data compared

to data obtained from direct observations. In addition, substantially higher use of PPE during exposures to noise and machine hazards were reported in self-reported data than it was observed.

Despite over reporting of some exposures in the study by Neitzel et al. (2013) other exposures such as repetitive motions and noise were relatively similar between self-reported and direct observation results. Further comparison of self-reported and direct observation results with direct instrumentation (used as the gold standard) revealed that, self-reported as well as direct observations overestimated or underestimated some key exposures although direct observations agreed very well with some instrumentation measurements. There was also substantial variability in self-reported and direct observation results for workers exposure to non-neutral postures.

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 it needs to be performed over long periods and across multiple workers in order to capture a representative exposure profile. Thus, assessment of physical work exposures in informal and irregular work settings appears to necessitate a preliminary job analysis overview and use of multiple measurement methods in order to understand and capture variability.

To date, studies on occupational exposure assessment among low-skilled workers who engage in non-structured, informal work such as waste collection and sorting are relatively scarce (Emmatty & Panicker, 2019; Todd, 2009). The vast majority of studies on occupational exposures to risk factors have focused on formal industrial settings such as manufacturing (Lavender et al., 1999;

Mossa et al., 2016), construction (Parida & Ray, 2012), agriculture (Kong et al., 2018) and healthcare (Czuba et al., 2012; Janowitz et al., 2006; Stucke & Menzel, 2007). Their main goals included the quantification of exposure magnitude (e.g., intensity of force exertions, weight of loads carried, and deviations from non-neutral postures), movement repetitions , and exposure duration (Andreas & Grooten, 2018; Chiasson et al., 2012; Li & Buckle, 1999; Takala et al., 2010).

Occupations such as e-waste recycling and other scrap metal recovery work entails a rapid change in work activities performed over time. This tends to introduce errors in physical exposure assessments (Neitzel et al., 2013). Adoption of existing tools developed for structured type of work to analyse unstructured unregulated type of work such as e-waste recycling may be challenging. Existing ergonomic assessment tools despite their claim of "rapidity", are not compatible with real time assessment of successive tasks that differ significantly. Hence, assessment of physical/ergonomic exposures among e-waste workers may require a dedicated assessment strategy that addresses this challenge as well as the ease of use in the field by evaluators with minimal training.

2.8 Concluding remarks

The reviewed literature suggests that informal e-waste recycling poses an occupational health issue that needs attention as it includes adverse environmental, chemical and physical work conditions. Physical risks investigated among waste collectors and scrap metal workers in other parts of the world revealed a high prevalence of work-related MSDs among these populations. In studies conducted in Ghana, partial highlights indicate the existence of similar issues with e-waste workers. However, there is paucity of literature detailing/analysing body region specific MSDs among e-waste workers, especially in Ghana. In addition, ergonomic assessment of physical risk

factors that could predispose these workers to MSDs are limited in general and non-existent in Ghana. Furthermore, the available literature suggests that, assessment of physical/ergonomic exposures in unregulated type of work such as e-waste recycling may pose a challenge due to the high variability and frequent changes in activities performed by these workers. Thus, the use of already existing tools to assess ergonomic exposures in these types of work present a great challenge. There is therefore the need for further studies aimed at developing ergonomic assessment methods adapted to unregulated type of work and applicable in the context of developing countries.

CHAPTER THREE

METHODS

3.1 Introduction

This chapter describes the materials and methods used to answer the research questions outlined in Chapter one. A general presentation of the study site and its population is provided. This is followed by a description of the study design used in this thesis to address each specific objective. The 5 individual studies conducted sequentially to address objectives 1 to 5 are highlighted. The procedures used in each study as well as the statistical analysis conducted are also presented. The chapter concludes with the quality control and data storage procedures used as well as the ethical considerations for this thesis.

3.2 Study Site

3.2.1 Agbogbloshie

Data collection for this thesis was conducted at the e-waste recovery site at Agbogbloshie (Figure 3.1), which is located close to the central business district in Accra, Ghana, and spans about 0.5km^2. It sits along the banks of the Korle lagoon and the Odaw river and borders a major food market on one side (Davis et al., 2019; Laskaris et al., 2019; Oteng-Ababio, 2012). Agbogbloshie scrap yard has served as a major e-waste hub for decades (Prakash et al., 2010). Scrap metal recovery activities at this site are unregulated and have no formal work structure. Although a scrap dealers association exists, they have no details on the number of workers on the site (Laskaris et al., 2019), nor has there been any introduction of regulatory control over activities done by

individual workers at the site. The distinct majority of workers are migrants from the Northern part of Ghana who come to the south to find jobs.

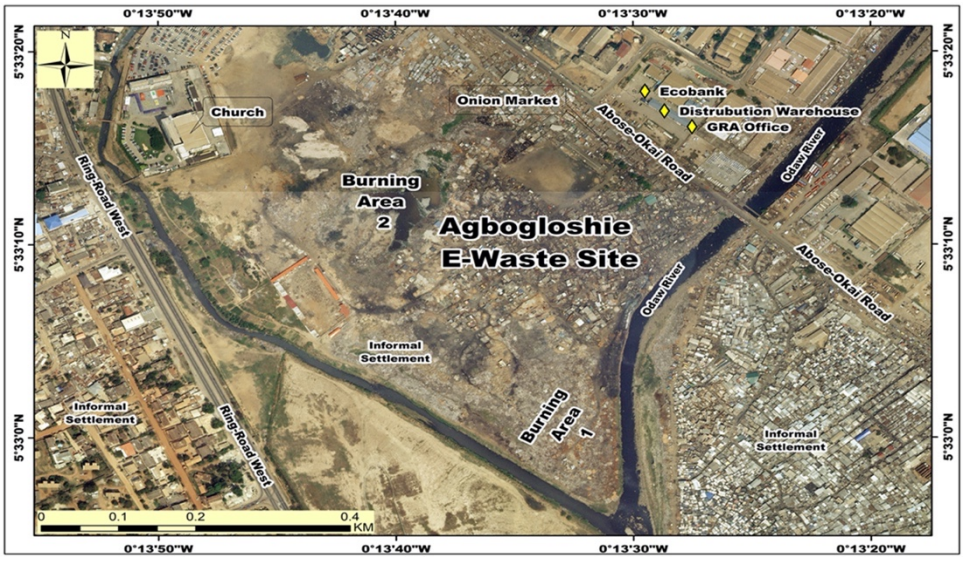


Figure 3.1 Google earth map view of the Agbogbloshie e-waste study site.
Source: (Amoabeng Nti et al., 2020)

3.2.2 Madina Zongo

In addition to the e-waste site, a reference population was sampled from Madina Zongo in Accra (Figure 3.2). Madina Zongo is located in the La Nkwantanang sub-metropolitan district which is about 10km from the e-waste site at Agbogbloshie (Amoabeng Nti et al., 2020). Residents of Madina Zongo are of similar ethnic background to e-waste workers at Agbogbloshie and as such were an ideal reference population for this study. Majority of the residents were also migrants from the Northern part of Ghana similar to e-waste workers and speak Dagbani.

Figure 3.2 Google earth view of the study site at Madina Zongo, Accra.
Source: (Takyi et al., 2020)

3.3 Study design

To answer the research questions and be able to address all the 5 objectives for this thesis, five separate studies were conducted. The first 3 studies were an inceptive approach that provided insight to guide the last two studies. The last two studies focused on development of a new ergonomic assessment tool for assessing ergonomic risk factors among e-waste workers which was a major focus of this thesis.

Each study conducted in this thesis aimed to address consecutively one specific objective outlined in this thesis. Study 1 was a qualitative study employing direct visual observations and interviews to document the processes involved in e-waste recycling. Study 2 was a cross-sectional study involving the use of a questionnaire, direct measurements, and field observations. Questionnaires were used to obtain information on participants occupational physical activity exposures. A subsection of the population was made to wear pedometers which were used to record their step

counts during their work period. Direct field observations were conducted on random days throughout the study period to supplement data obtained through questionnaires and direct measurements. Study 3 used a cross sectional approach to investigate the self-reported prevalence of work-related MSDs among e-waste workers using a standard musculoskeletal questionnaire and compared the findings with a reference population from Madina Zongo (a district of Accra). Study 4 was an observation-based study used to develop an observation-based ergonomic assessment tool to quantify physical exposures in unregulated non-repetitive type of work such as e-waste recycling. Study 5 used the newly developed tool to quantify and compare the intensity and duration of ergonomic exposures and its associated work-related MSDs among e-waste workers.

3.4 Study Participants

Participant recruited for this study were e-waste workers from the Agbogbloshie e-waste site as well as a reference population of non-e-waste workers from Madina Zongo a suburb of Accra. The workers were mostly men, primarily young adults and occasionally minors (< 18 years old). Most of the workers were migrants from the Northern part of Ghana who have migrated to the south to seek employment. The workforce from Agbogbloshie largely consists of itinerant workers who scavenge, aggregate, distribute, and recycle various scrap metals (Davis et al., 2019). This thesis however focused on three main work categories i.e. collectors, dismantlers and burners of e-waste. Participants from Madina Zongo were of similar ethnicity and religion to those from Agbogbloshie. They were engaged in varied occupations other than e-waste recycling.

3.5 Sampling

Participants recruited for this study were sampled via convenience sampling. The unstructured and informal nature of the e-waste recycling site at Agbogbloshie as well as Madina Zongo made it challenging to employ probability sampling. Additionally, participants sampled in the qualitative interview for objective 1 had to be purposively sampled to ensure participants selected were well abreast with knowledge about the e-waste recycling process. This led to 8 e-waste workers being sampled for study 1 (objective 1). All participants that were available to participate in the study were recruited for studies 2 and 3 resulting in the recruitment of 163 participants for study 2 (objective 2) and 217 participants (comprising of 176 e-waste workers and 41 non-e-waste workers form Madina Zongo) for study 3 (objective 3). A smaller sample size was selected for studies 4 and 5. Study 4 was a preliminary study in the development of a new observation-based tool for quantifying ergonomic exposures among e-waste workers. Thus, in study 4 (objective 4), the newly developed tool was piloted on 6 e-waste workers comprising of 3 collectors and 3 dismantlers. For study 5 (objective 5), there was a trade-off in the number of workers and days per worker that was assessed in order to account for the high level of variability that existed within e-waste activities performed between – and within- workers. As such, more emphasis was placed on observing these workers for more working days as a function of the variability that existed in their work. Thus, 6 dismantlers, 6 burners, and 11 collectors were observed for 8, 6 and 3 days respectively.

3.5.1 Inclusion criteria

All e-waste workers available at the time of the study and were actively engaged in recycling activities were recruited for the study. Likewise, non-e-waste workers in the reference population

that were available and willing to participant in the study and had similar cultural and ethnic characteristics as the e-waste workers at Agbogbloshie were recruited. Participants from the reference population were mainly shop attendants, traders, students or had occupations such as teaching, or driving. These occupations hardly entailed manual material handling (MMH) activities or excessive physical activity.

3.5.2 Exclusion criteria

E-waste workers who were engaged in other non-e-waste activities that were physically demanding (for example construction work) were excluded. Also, e-waste workers that were not actively engaged in recycling but primarily played a supervisory role were excluded in studies conducted to address objectives 2 to 5. In the reference population, participants who were involved in activities that required excessive physical exertion were excluded.

3.6 Procedure for data collection

3.6.1 Procedure for data collection for objective 1

Eight (8) e-waste workers were conveniently sampled and engaged in in-depth interviews. The participants were approached while they rested in their working sheds and the purpose of the study explained to them. Their consent was sought, and they were interviewed and observed after they agreed to participate in the study.

3.6.1.1 Interviews and direct field observations

An in-depth interview guide was developed through rigorous literature search. The interview guide required workers to describe in detail, the processes and tools used during e-waste recycling.

Workers were also asked about the reasons for their choice of the specific e-waste job category they worked in, the health challenges they experience from their work, the level of stress or difficulty associated with their work, and their ability to cope with the work stress. Probes were used to obtain elaborate information from participants on specific questions where necessary. A copy of the in-depth interview guide used can be found in Appendix 2. The interviews lasted between 10 to 15 minutes and were recorded using a Sony™ voice recorder. In order to validate the information provided during the interviews, a series of walkthrough observations were conducted for a full working week to supplement and verify the information obtained from the interviews.

3.6.1.2 Data management and analysis for objective 1

The audio recordings from the interviews were transferred onto a computer for transcription and subsequent analysis. The recordings were manually transcribed and statements that related to the three main themes (i.e. processes involved in e-waste recycling, health challenges associated with e-waste recycling, psychosocial challenges associated with e-waste recycling) were aggregated in a data capturing table for thematic analysis. Field observations were documented in a notebook and the information used to supplement the transcribed in-depth interviews. A thematic analysis of data was conducted to identify emergent themes.

3.6.2 Procedure for data collection for objective 2

E-waste workers present at the worksite during the study period were recruited for the study. Workers were sought from different locations of the e-waste site in an attempt to obtain a large

sample of individuals exposed to the different work activities undertaken in e-waste recycling. 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 worked 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. Direct field observations were conducted on random days throughout the study period to supplement data obtained through questionnaires and direct measurements.

3.6.2.1 Questionnaire and assessment instruments

3.6.2.1.1 Demographic Questionnaire: A brief questionnaire (Appendix 3) was developed to obtain information about demographic characteristics (e.g., age, gender), 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 experts/professional 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.

3.6.2.1.2 Modified Occupational Physical Activity Questionnaire (OPAQ): A modified version of 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. The OPAQ is a validated, widely used and reliable self-reported questionnaire for assessing occupational physical activities among working population (Reis et al., 2005). Participants were asked to

indicate the maximum weight handled during carrying, pushing and pulling activities which were categorised as light (5kg or less), moderate (6-10kg), heavy (11-20kg), very heavy (>20kg). For the purposes of this study, the term Manual Material Handling (MMH) was rather used to refer to lifting, carrying, pulling and pushing activities. A pilot study conducted in December 2017 helped to evaluate the appropriateness of the OPAQ to the context and population of e-waste workers. More specifically, the pilot work aimed 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 had difficulty estimating the proportion of time spent sitting, standing and walking or performing MMH activities, the questionnaire was modified to obtain a binary response (Yes/No) to whether the participant performed each activity for (1) at least 1 hour continuously during the work day, and (2) a total of 4 hours in a work day. Second, frequency of sitting and standing were assessed separately as opposed to the original OPAQ which assesses sitting and standing together. Third, the assessment of MMH activities, which form the core component of e-waste recycling, was assessed by asking participants how often they performed lifting, carrying, as well as pushing and/or pulling activities within a work week. The modified version of the OPAQ (Appendix 3) was administered to participants, their responses were documented on the questionnaire and subsequently coded into Stata V15 for analysis.

3.6.2.1.3 Pedometer measurements: From the 163 participants, a random subset of 42 participants were provided a waist belt instrumented with a pedometer (Omron HJ-321) at the start of their work day that was reclaimed at the end of the work day. Participants' weight, stature, and stride length were measured and used 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 toe of the foot taking the first step to the toe of the same foot after the 10th step) and dividing the distance by 10 (Omron, 2019). The pedometers collected data on total steps count, aerobic step counts, average steps per minute, distance walked, and energy expenditure (calories burnt) over an entire work day. Steps were considered aerobic if there were a minimum of 60 steps taken within a minute more than 10-minutes continuously (Duchečková & Forejt, 2014). The Omron pedometer has been validated against other well-known physical activity (PA) 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 & Byrne, 2017; Owoeye et al., 2016; Sampaio et al., 2016; Yusoff et al., 2018). For this study, each participant wore the instrumented belt for at least two work days, and the average readings were used in the analysis. Ten pedometers were acquired for the study; however, 5 pedometers were not returned by participants early in the study which made data collection challenging.

3.6.2.1.4 Data management and analysis for objective 2

All data 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 occupational physical activity. Separate one-way ANOVA tests were used to determine statistical differences in age, years on the job, and hours of work per day across the three categories (i.e., collectors, dismantlers and burners) of e-waste workers. Statistically significant effects were analysed using Dunnett post hoc tests. Chi-squared (χ^2) tests were used to determine associations between primary job category and the proportion of participants that

reported long durations of sitting, standing, and walking postures as well as performing frequent lifting, carrying, pushing and/or pulling tasks as part of their routine work. Pedometer measurements (total and aerobic steps, distance walked, energy expenditure) were not normally distributed, and thus medians and interquartile ranges were reported in order to reduce the effect 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 four pedometer measures. Statistical significance was set a $p<0.05$. Qualitative data obtained from direct observations were used to supplement and contextualize the quantitative results where possible.

3.6.3 Procedure for data collection for objective 3

Study 3 comprised of two sample populations. These were e-waste workers from the Agbogbloshie scrap yard as well as a reference population from a similar ethnic background who were recruited from Madina Zongo, a suburb of Accra. Workers were sampled based on their availability and willingness to participate in the study after the purpose of the study had been explained to them and their consent sought. Detailed occupational history was collected using a questionnaire. Participants from the reference population who were eventually involved in jobs entailing MMH were excluded from the analyses presented in this report.

3.6.3.1 Questionnaire

A modified version of the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) (Hedge et al., 1999; Stanton et al., 2005) was used to obtain information about musculoskeletal symptoms experienced by workers during their working week. The CMDQ (Appendix 4) is an adaptation of

the Nordic questionnaire (Kuorinka et al., 1987). The CMDQ has been widely used in investigating musculoskeletal discomfort among various working populations (Azma et al., 2015; Habibi et al., 2015; Menzel et al., 2004) and has been translated into Spanish, Turkish and Persian (Afifehzadeh-Kashani et al., 2011; Erdinc et al., 2011). The questionnaire uses a body map diagram which distinguishes 11 anatomical regions of the body where the individual may have experienced musculoskeletal discomfort during the past working week. The CMDQ assesses musculoskeletal discomfort under three categories. The first assesses the frequency with which workers experience musculoskeletal symptoms within a working week, categorised as none, 1-2 days/week, 3-4 days/week, once every day and several times a day. The second part assesses the severity (slight, moderate and very uncomfortable) of the reported musculoskeletal complaints. The third part assesses how the musculoskeletal complaints reported by workers interfered with their work as not at all, slightly and substantially. The CMDQ was used because of its inclusion of a component assessing the severity of MSDs. For the purpose of the present study, frequency categories were compressed into 4 groups instead of 5. The new categorisation was none, 1-2 days per week, 3-4 days per week and 5≤ days/week. This was done to reduce ambiguity in categorising MSD frequencies greater than 4 days in a work week as these categories were not accounted for in the original CMDQ but were valid responses provided by participants in the present study.

CMDQ was supplemented with a number of questions added by the authors to obtain information on the participant's age, gender, job category, year of work in current job (for the reference population) or years of work in e-waste recycling (for Agbogbloshie participants), number of working days per week as well as number of hours worked per day.

After explaining the study procedures to participants, a team of 4 research assistants, who had been trained by the Principal Investigator in the use of the CMDQ, interviewed workers at both study sites. It took about 10 minutes per participants to complete the CMDQ and the short demographic and occupational history questionnaire that was attached.

3.6.3.2 Data management and analysis for objective 3

Completed questionnaires were entered into Microsoft Excel and subsequently analysed using STATA V15. Descriptive statistics were used to report the prevalence, frequency of occurrence within a week, severity as well as the level of work interference of musculoskeletal disorders experienced by workers. Musculoskeletal disorders prevalence was computed from the frequency ratings and defined as the proportion of workers by job category that reported discomfort in specific body part at minimum one or more in previous work week. The study used the Z-test for comparing the differences in the proportion of MSDs between e-waste workers and non-e-waste workers from a reference population. Chi-squared test for trends was used to determine the association between demographic/occupational history variables and the prevalence of MSDs. A multivariable regression analysis using a Modified Poisson regression model with robust standard error was used to determine the relationship between job categories and the number of MSDs reported per participant while controlling for age, years of work, number of days of work per week and number of working hours per day. Ordinal logistic regressions were used to determine the relationship between job categories and frequency of MSDs, severity of MSDs as well as level of interference of MSDs with participants work while controlling for age, years of work, number of days of work per week and number of working hours per day. An ordinal logistic regression was

also used to determine the relationship between the frequency of occurrence of MSDs and the severity of MSDs reported. Statistical significance was set a $p<0.05$.

3.6.4 Procedure for data collection for objective 4

A methodology for characterising the key ergonomic exposures in e-waste recycling was developed based on concepts employed in other observational methods including RULA (McAtamney & Corlett, 1993), OWAS (Karhu et al., 1977), PATH (Buchholz et al., 1996), QEC (Li and Buckle, 1998) and tools used to estimate ergonomic exposures in other formal work setting (DP, 2002).

3.6.4.1 Exploring the processes and activities used in e-waste recycling

Multiple field visits, walk-through observations and worker interviews were conducted in studies used to address objectives 1 (Acquah et al., 2019) and 2 in order to fully understand and appropriately document the processes involved in e-waste recycling. Work methods for each job process (i.e. collecting, dismantling and burning) were adequately described to capture the main components of the tasks involved and the work tools used.

3.6.4.2 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.

The body segment postures assessed included neck, trunk, lower and upper limbs as outlined below. For each segment, postures were categorized on an ordinal scale with at most 2 or 3 levels in order to facilitate the pace of coding in real time while obtaining meaningful results in agreement with the relevant literature concerning the risk of MSDs.

- *Neck:* Two postures were coded as either neutral or non-neutral. 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 worker in objective 3 (see Section 4.3.2).

-*Trunk:* Three postures were distinguished and coded as neutral ($<20^0$ flexion), moderate (between 20^0 and 45^0) and severe ($>45^0$) forward flexion and/or lateral bending. The threshold criteria were adapted from prior studies [i.e., the PATH methodology by Buchholz et al. (1996), and 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 were distinguished and coded as hands/arms below waist height, below shoulder height but above waist height, and above shoulder height. These codes were similar

to shoulder/arm posture assessment options used in the Quick Exposure Checklist (Li & Buckle, 1998).

- *Lower limbs*: Three postures were categorised as walking, sitting or standing. 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 $>45^0$. Sitting was coded in 3 subcategories: sitting with either hips and knees at about 90^0, hips and knees greater than 90^0 as well as hips and knees less than 90^0.

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) and high (≥4kg). Repetition was graded 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 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 & 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 (Appendix 5) 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. The coding guide was also provided alongside the coding template as a reminder to facilitate grading of tasks observed.

3.6.4.3 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. The RAs also familiarised themselves with the weights of items and tools frequently handled by workers as well as quick ways of visually estimating force exertion and repetitive movements. They were also trained to identify and quantify risk factors such as posture, repetition, force exertion, contact stress and vibration. 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 between themselves (Latko et al., 1997). 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.

3.6.4.4 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 by two observers simultaneously for 10 minutes. The inter-observer agreement was compared for the neck, trunk, upper and lower limb postures as well as force, repetition, contact stress and vibration by determining the level of agreement between exposures coded by each observer using Cohen's kappa statistic.

3.6.4.5 Piloting of the tool

The newly developed tool (Appendix 5) was piloted on the same 6 workers whose data were used for the inter-observer agreement. Each worker was observed for a full working day and the proportion of time they spent in various ergonomic exposures computed.

3.6.4.5.1 Procedure for data collection for the pilot study

Workers were approached during the field visits and were presented the purpose of the study. Six workers at the time of the visit consented to participate in the pilot study. They were observed from the start of their work day until completion. 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., 2019). 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 where necessary.

3.6.4.6 Data processing and analysis for objective 4

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 and tabulated in Excel. Cohen's kappa statistic was computed in STATA V15 to determine the level of agreement between the two observations for each variable assessed.

3.6.5 Procedure for data collection for objective 5

An observational study was conducted in objective 5 using the newly developed tool described in section 3.5.4. Workers were observed over multiple work days to capture the inherent variability of their work, which is a function of their primary type of e-waste recycling activity. Based on previous observations (Studies for objectives 1, 2 and 4), dismantlers were observed for 8 days, burners for 6 days and collectors for 3 days since variability is the lowest for these latter.

3.6.5.1 Assessment tools

3.6.5.1.1 Ergonomic assessment: The newly developed and validated ergonomic assessment tool adapted to unregulated and unstructured work was used to assess the recognized physical risk factors, the duration of work time each risk factor was present and the time spent in key MMH tasks.

3.6.5.1.2 Musculoskeletal pain / discomfort assessment: Musculoskeletal pain and discomfort was assessed for the neck, shoulder, elbows, wrist/hand, upper back, lower back, hips/thighs, knees as well as ankles/feet using a modified Nordic questionnaire (Kuorinka et al., 1987). The questionnaire was modified to enable quantification of pain/discomfort experienced in each body part during a working week using a Visual Analogue Scale (VAS). The 10 cm horizontal VAS was used to rate musculoskeletal discomfort between 0 and 10 where 0 corresponded to no pain and 10 was the maximum possible pain that one could perceive (referred to in the assessment as "pain that can kill"). The Nordic questionnaire was chosen over the CMDQ in this study because it assesses fewer items and a smaller number of body segments (9 vs 11 in the CMDQ) making it an ideal choice for a quick MSD estimation tool. In addition, the simple nature of the Nordic questionnaire made the modification reasonable to include the 10-point rating scale feasible. The musculoskeletal discomfort assessment was performed before and immediately after the working week including the successive ergonomic assessments. Hence, irrespective of the number of days of observation, musculoskeletal assessment was done to reflect changes over a one-week period. A body chart was provided next to the VAS to help participants correctly indicate the parts or their body that hurt (Appendix 6).

3.6.5.2 Data collection.

Prior to data collection, three research assistants were trained with videos on the use of the observational method / assessment tool. They also contributed to several field visits to familiarise themselves with activities at the e-waste site. The data collection process started with a detailed orientation of e-waste workers, present at the time, on the importance of the study and information

about the processes involved in the various stages of the assessment. Workers who agreed to participate in the study were recruited after signing an informed consent form.

A sampling strategy was adopted in the number of workers per category and number of days of observation to take into account work variability. Based on previous observations (Studies for objectives 2 and 4), the tasks were estimated to be less variable for collectors than dismantler or burners, Hence, six (6) burners and 6 dismantlers were recruited and respectively observed for 6 and 8 days, while 11 collectors were recruited and observed for 3 days. Each worker was observed from the start to end of their work day. Physical exposures were recorded on the data coding sheet at 60 seconds interval for the entire duration of the observation period. All observers wore a video camera (GoPro Inc) as a backup for verification of observations.

3.6.5.3 Data processing and analysis for objective 5

The coded observations, as well as the initial and final assessment of musculoskeletal pain were entered into a spreadsheet (Microsoft Excel). The data were cleaned and verified for possible data entry errors. Conventional methods were used to count the frequency of noted observations. The corresponding proportions of time spent in various postures and activities as well as the active work time and exposure time for each risk factor were computed. Time proportions (TP) for each exposure to a risk factor were computed TP= (Total count of 1 min observation / total number of observations) x 100.

The total active (TA) work time was computed as TA= Total self-reported work time - Total rest time. The active work time spent in each exposure was then computed by using the respective proportion of time spent in those exposures computed earlier to calculate the equivalent absolute

time from the total active work time. For example, active work time for non-neutral neck posture (NNP) was calculated as Active time NNP=Proportion of time in NNP x TA. The obtained data were tabulated in MS Excel.

Musculoskeletal discomfort scores were computed for each body part by calculating the change in MSD score between the initial and final assessment. When the value was negative (implying MSDs regressed from a worse to a better score), the result was replaced by a zero. As a first approach, simple whole-body MSD score was generated by summing all the MSD scores obtained for each of the 9 body parts assessed.

All obtained data were entered into Microsoft excel and exported into SPSS v.24 (IBM Inc) for statistical analysis. Descriptive statistics were used to summarise demographic information and work durations. Box plots for the durations of active work and each exposure variable present by participant and job category were generated to depict the day-to-day variability in durations. Separate statistical analyses for each exposure variable using mixed-effects models were performed with job category as the fixed-effect, participant as random effect, and observation day as repeated measures in order to identify exposures that were statistically relevant and different among job categories ($p < 0.05$). Mixed effect models were used because of its ability to account for repeated measures and unbalanced group sizes and for being relatively robust to departures from data normality. Significant effects of job category were subsequently examined using pair-wise comparisons with the Bonferroni procedure (to adjust for multiple comparisons) and the estimated marginal means and standard errors (SE) for the corresponding significant exposure variables were tabulated.

Two types of statistical analyses on MSD ratings were performed. First, the number of non-zero musculoskeletal complaints at the start (i.e., initial) and end (final) of the work week for each body part were counted and statistically compared between job categories using a Chi-square test ($p < 0.05$) in order to examine associations between individual MSDs and e-waste job categories. Second, the final rating and difference in ratings (final – initial rating) for each body part and the whole body were analysed using separate mixed-effects models with job category as the fixed effect in order to identify MSD ratings across job categories that were relevant ($p < 0.05$). Significant effects of job category were examined using Bonferroni-adjusted pair-wise comparisons and the estimated mean ± SE for the corresponding significant MSD rating tabulated.

3.7 Quality control

This research ensured quality standards were adhered to at all times. Questionnaires used in this study were piloted prior to its use and the necessary modifications made to suit the local context. Research assistants as well as translators used in this research were adequately trained to minimise human errors and to ensure uniformity in data collection procedures.

All data cleaning and analysis were done under the guidance of a qualified statistician. Codes and ID numbers were used to conceal participant identity in data collected and analysed.

3.8 Data storage and sharing

Hard copies of informed consent sheets and questionnaires were stored under lock and key in a safe filing cabinet. Soft copies of data entered into excel, processed in SPSS or STATA as well as all video recordings from direct field observations were stored on a password protected computer. Backups of data were stored in the cloud with appropriate encryption to ensure maximum security.

3.9 Ethical considerations

All studies presented in this thesis were part of the Global Environmental and Occupational Health (GEOHealth) project. A project aimed at investigating environmental and occupational health issues among electronic waste workers in Agbogbloshie, Accra, Ghana. The project was approved by the College of Health Sciences Ethical Review Committee at the University of Ghana, Accra. Appropriate permission was obtained from the Chiefs of Madina and Agbogbloshie prior to the commencement of this project. Permission was also obtained from the heads of the scrap dealers association at Agbogbloshie. Study procedures were adequately explained to participants and written informed consent was obtained from all participants before they were recruited for the study.

3.9.1 Risks of the research

The study did not present any known risk to workers. No invasive procedures were used. Workers were observed in their natural work setting. Observation procedures used ensured that participants' work were not interrupted as much as possible. Interviews and questionnaires where possible, were administered at off-peak working hours to minimise interruption with participants work.

3.9.2 Benefits of the research

Participants were compensated with 30 Ghana Cedis (approximately 5.26 US dollars at the time of data collection) after data collection was completed. Participants were also provided with snacks and a GEOHealth embroidered T-Shirt.

CHAPTER FOUR

RESULTS

4.0 Introduction

This chapter presents the results obtained for each of the 5 specific objectives outlined in this thesis. Results for objective 1 are reported qualitatively in a thematic approach. Results for objectives 2, 3, 4 and 5 were analysed quantitatively and thus, are presented using descriptive statistics in the form of figures and tables as well as relevant inferential statistics based on the specific objective and type of data collected. In addition to the quantitative data reported, observational data are reported descriptively for objectives 2 and 5 to complement the related quantitative analysis.

4.1 Results for specific objective 1: Description of the processes and challenges associated with e-waste recycling

4.1.1 Demographics

The study sample comprised eight (8) male e-waste workers with ages ranging from 19 to 34 years, and mean age of 25.88 ± 5.22 years. Five of the participants had primary education, one had completed junior high school and two had been educated up to senior high school. The number of years they had worked as e-waste workers at Agbogbloshie ranged from 3 years to 10 years with an average of 6.88 ± 3.00 years. Participants worked 3 to 6 days a week depending on the availability of e-waste to recycle.

4.1.2 Description of e-waste recycling activities/processes at Agbogbloshie

Figure 4.1.1 is a flowchart summarising the observed e-waste recycling processes at Agbogbloshie. There are 3 main job categories among e-waste workers at Agbogbloshie, representing the essential activities of collection, dismantling and burning of e-waste and interspersed with other supporting tasks.

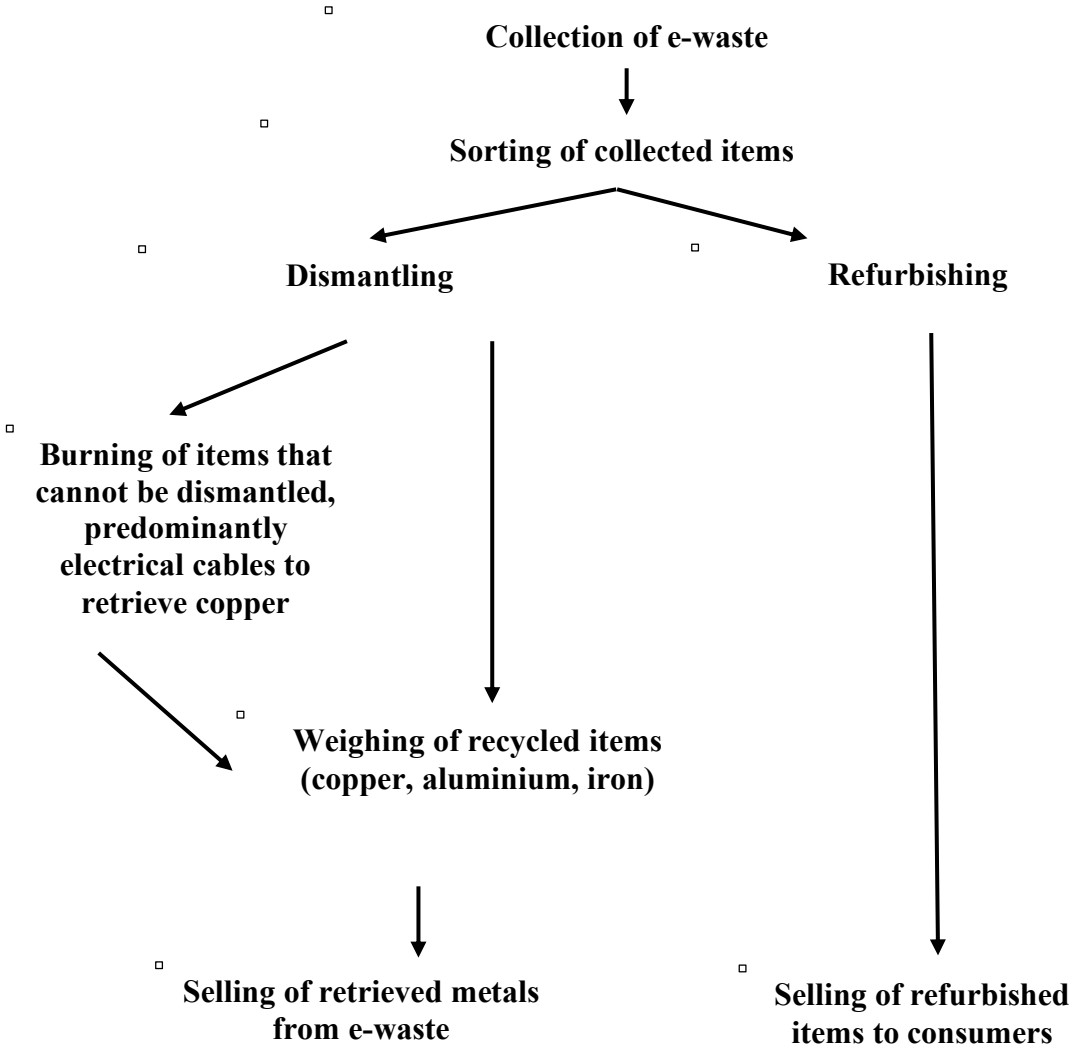


Figure 4.1.1: Flowchart showing e-waste recycling processes at Agbogbloshie.

Collection of e-waste could span the entire working shift which is usually from 6am to 5pm. It involves workers travelling to different neighbourhoods in the city and surrounding towns in search of end-of-life electronics. Workers usually walk to these places pulling a collection cart along as shown in Figure 4.1.2A. E-waste is sometimes collected for free from small local dumps, or are purchased from owners for a small fee. The collected e-waste is loaded onto a cart and pulled to the dismantling site where it is sold to dismantlers or dismantled by the same collectors. Some collectors who may be fortunate to have motor bikes or bicycles may use these as a means of transportation during the collection process. Occasionally, when collectors gather very large quantities of e-waste that may not fit on their bikes or collection carts, they hire the services of transporters who use tricycles to aid in conveying the items to the e-waste site. These tricycles are commonly known among the workers as "motor king". The transporters (motor king riders) are usually stationed adjacent the main dismantling area close to the main Agbogbloshie street awaiting customers who require their transport services. In addition to e-waste purchased from the neighbouring towns, cargo trucks full of imported e-waste were occasionally seen making their way into the e-waste site. The e-waste from these trucks are subsequently sold to e-waste workers for recycling.

E-waste items brought to the dismantling site are sorted initially into two groups as shown in Figure 4.1.1. The first involves an attempt to salvage e-waste that could be reused. Electronic items that may not be completely damaged and could be repaired for reuse are sold to a group of workers called repairers whose main interest is to refurbish e-waste and resell them to consumers. The second process of sorting involves collating of items that can be dismantled which are then sold to dismantlers.

Dismantling involves the use of predominantly locally made simple tools such as hammer and chisel and occasionally screw drivers and spanners to break apart e-waste in order to separate the different metals (Figure 4.1.2B). The metal constituents are usually copper, iron and aluminium. Items usually dismantled includes, computers, fans, refrigerators, air conditioners, photocopy machines, car engines as well as starters and any other item gathered that is likely to contain some metal constituent. A typical dismantling session lasts between 3 to 4 hours.

Dismantling is usually done employing one of three postures. Smaller electrical gadgets are usually dismantled while sitting and supporting the object being dismantled with the feet as illustrated in Figure 4.1.2B. Occasionally, dismantlers may need to stand and bend over to dismantle larger items such as car engine blocks or static condenser components from refrigerators. The third major posture adopted, consists of prolonged upright standing to dismantle very large objects. During the walkthrough observations, some dismantlers were observed dismantling a minibus using this posture. After e-waste items are dismantled, they are then sorted into their respective metallic constituents and items that could not be dismantled are sent for burning to recover the metal constituents (e.g., electric cables) as shown in Figure 4.1.2C.

A: Collectors pulling a cart with e-waste

B: Dismantling of e-waste

C: Carrying cables to burning site (for burning)

Figure 4.1.2: Picture showing the three main e-waste activities performed at Agbogbloshie.

Burning involves setting up fire to items using combustible materials (accelerants) including foam retrieved from out-of-use refrigerators. A single burning session of e-waste lasts between 30 to 45 minutes. A long metal rod is used to rotate/flip the burning items to ensure a uniform distribution of the fire and expose the metal. The final blackened metallic end products, predominantly copper retrieved from burning and dismantling are then sent for weighing.

Weighing of e-waste involves placing the sorted retrieved metals (e.g., copper, aluminium, iron) onto a weighing scale to determine its resale value. Copper is sold at a higher price than aluminium which is also sold at a higher price than iron. The retrieved metals are often sold to middlemen. These middlemen buy processed e-waste from workers in small quantities and gather them into larger piles to be sold at higher rates to industrial companies in Tema, an industrial city in Accra, where these are processed into iron rods, roofing sheets, cooking utensils and gas cookers.

4.1.3 Health risks of e-waste recycling in Agbogbloshie

This study investigated health and psychosocial challenges among the 3 main e-waste job categories (collectors, dismantlers and burners). Participants were interviewed about the health challenges they experience during work. Self-reported symptoms included burns and lacerations, musculoskeletal pains, headaches, fever and respiratory issues (e.g., coughs). A few sample quotes from participants are provided below.

"You see my hand? It is fire that burned it to make it appear this way" – **23-year-old, e-waste burner**

"When the smoke is inhaled by you, you will experience coughing at night. And the phlegm produced are blackish in colour just like the colour of the smoke from the burning. When you cough, it will make you feel pain."- **23-year-old, e-waste burner.**

"When we go back home and sleep, we realize that your body aches……. your body becomes hot. Then you go and buy 'Kwik Action (a brand of pain medication)' and you take it as medication then you sleep…….When it becomes hot, I take Kwik Action to make it cool." **– 28-year-old e-waste burner**.

"I get joint pains and headaches from the hot sun" **29-year-old e-waste collector.**

Six out of the 8 workers interviewed reported body pains as a frequently experienced health challenge. These workers rely extensively on pain medications to cope with the symptoms. This is captured in the following quotes from workers as reported below.

"You see when it comes and maybe you get some pain killer, maybe it will take a day or two and it will just go" – **24-year-old, e-waste dismantler,**

"You need to take pain killers before you can sleep" – **19-year-old, e-waste dismantler.**

4.1.4 Psychosocial challenges in e-waste recycling

Interviewed workers overwhelmingly considered the work of e-waste recycling to be stressful and difficult to perform. Below are some reports from the workers interviewed:

"The job is very difficult to do….. I want to quit it. The last time, I was injured by it and I want to quit" **23-year-old, e-waste burner.**

"Every aspect of the work is difficult……It's not good for a human being to do this work." **30-year-old, e-waste burner.**

Interviewed workers complained about the high physical demands of e-waste recycling which makes it a difficult job to cope with. The desire to quit e-waste recycling was obvious among participants. Participants also expressed concerns that, although their work presented injury risk, a leave of absence from work presented the risk of losing prior customers to other workers. Thus, workers felt the need to push themselves to the limit and work every day despite their injuries.

Workers also complained about the low revenue they earn from e-waste recycling as indicated in the quote below:

"I work for long hours and I only earn a little money….when I make enough money, I will quit this job and find a less risky job" **23-year-old, e-waste burner.**

One of the participants reported earning between GH¢20 to GH¢50 Ghana cedis (about $4 to $10) a week. According to the worker this income is inadequate and does not allow saving to generate some capital to change job.

Burning of e-waste usually requires very little or no revenue to operate. Thus, workers who lack the financial resources needed to buy e-waste resort to engaging in e-waste burning. One burner admitted that although high risks are associated with burning of e-waste, he does not have enough money to buy e-waste from collectors to dismantle and as such continues in his current job until he can raise enough money to find another job.

"I don't have a job and I don't have money to buy from the others to dismantle. That's why I am doing this work little by little." **23-year-old, e-waste burner.**

For this worker, since, burning of e-waste does not really require purchasing of items, it was much easier to cope with. Thus, he waits for his other colleagues to dismantle their purchased good and then help them recover metals via burning at a fee from items such as copper wires that cannot be dismantled.

The e-waste job category an e-waste worker was enrolled into was largely influenced by the person who initially introduced them to e-waste recycling and provided the initial financial support to work with. Thus, workers were compelled to continue work in the same e-waste job category as their financiers.

4.2 Results for specific objective 2: Assessment of e-waste occupational physical activity exposures

4.2.1 Demographic characteristics of participants

The age of participants ranged from 11 years (minors) to 43 years. Of the 163 participants in the study sample, 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 age range. Only 6 participants (3.8%) out of those who reported their ages were older than 40 years. Regarding the number of years worked in e-waste recycling, participants' work experience 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 in most cases reported working at least 6 days (88%) or 7 days (54%) per week. The mean reported work duration per day was 9.95 ± 2.43 hours and ranged from 2 hours to 14 hours depending on the

availability of work and the type of e-waste recycling activity being performed. Direct field observation data revealed an average work duration of 6.26 ± 2.63 hours per day, and ranging from about 2 to 12 hours per day with some intermittent breaks that varied considerably from 10 minutes to about 4 hours 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. Some participants also reported performing a secondary work activity, with 9 participants (5.52%) involved in both collecting and dismantling of e-waste, 3 (1.84%) involved in both collecting and burning, and 2 (1.23%) involved in both dismantling and burning of e-waste. All of the subsequent data were stratified by the primary job category reported by participants.

Table 4.2.1 summarises the age distribution, the number of years of experience in e-waste work, number of working days 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 mean 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 working days per week ($p = 0.292$) or average hours worked per day ($p = 0.277$) across the three categories of e-waste workers (Table 4.2.1).

Table 4.2.1: 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 (7days) - 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 working days 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 $p<0.05$

4.2.2 Occupational physical exposures of e-waste workers

4.2.2.1 Sitting, standing and walking as integral part of daily work activity

Direct field observations showed that all of the participants performed their e-waste work while either sitting, standing or walking during their shift. 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 degrees. When not walking to search for and collect items, the collectors' mode of sitting varied widely. It involved either sitting on their collection cart which corresponds to a sit-stand posture with hips and knees included angle greater than 90 degrees or occasionally sitting on the ground or on a piece of log or rock along the route they travel on in search of e-waste. A considerable amount of sitting was observed among workers during their idle time at work. Dismantlers and burners were observed sitting and resting under a work shed upon completing the available work or in the case of burners while they waited for other e-waste workers to bring them items to burn. Collectors were also observed sitting to rest at random intervals and varying duration during their commute times while in search of e-waste in nearby communities. Standing and walking among all workers were done on uneven surfaces. These surfaces were soft and muddy during rainy periods or hard and bumpy during the dry weather. Walking performed by dismantlers was primarily for transporting insulated components, cables, and wires to the burners for the extraction of metal. 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. In addition to burning copper wires for dismantlers at a fee, some burners would also spend time gathering leftover pieces of metal scrap littered across the burning sites for sale. This was a common occurrence among entry-level burners.

Table 4.2.2 summarizes the proportion of collectors, dismantlers and burners who reported engaging in sitting, standing or walking continuously for 1 hour or more in a work day during the previous work week. Table 4.2.2 also lists the proportion of participants who spent a total of 4 hours or more in each of these working conditions during a shift. Sitting continuously for 1 hour

or more during a work day was reported mostly by dismantlers (91.8%) while standing continuously for 1 hour or more during a work day was reported mostly by burners (95%). Fisher's exact test 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 hour or more during a work day. However, the proportion of participants who reported 1 hour or more of continuous walking differed significantly by job category ($p = 0.018$). Post hoc comparisons revealed that a significantly higher proportion of collectors (92.9%) reported continuous walking for 1 hour or more during a work day when compared to dismantlers (78.1%; $p = 0.029$) and burners (75.0%; $p = 0.096$).

The proportion of participants that spent more than 4 hours per work day in sitting, standing and walking differed significantly by job category (Fisher's exact $p < 0.001$) for each of the three working postures (Table 4.2.2). The proportion of participants that reported sitting for a total of 4 hours or more during a work day was significantly higher among dismantlers (82.2%) and burners (65.0%) compared to collectors (30.0%; $p < 0.001$ and $p = 0.003$, respectively). The difference in proportions between dismantlers and burners was not statistically significant ($p = 0.204$). The proportion of participants that reported standing for a total of 4 hours or more 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). The difference in proportions between dismantlers and burners was not statistically significant ($p = 0.554$). Walking for a total of 4 hours or more was reported mostly by collectors (88.5%) compared to dismantlers (54.8%; $p <0.001$) and burners (65%; $p = 0.060$). The difference in proportions between dismantlers and burners were not statistically significant ($p = 0.544$).

Table 4.2.2 E-waste workers stratified by job category who engaged in sitting, standing, and walking activities.

		Proportion of participants		
Variable (Per day's work)	**Job Category (n)**	**Yes (%)**	**No (%)**	**Chi-square p-value FET**
Sitting continuously for ≥ 1 hour	Collectors (70)	56 (80.0%)	14 (20.0%)	$\chi^2 = 4.487$,
	Dismantlers (73)	67 (91.8%)	6 (8.2%)	$p = 0.106$,
	Burners (20)	18 (90.0%)	2 (10.0%)	FET $p = 0.119$
Standing continuously for ≥ 1 hour	Collectors (70)	53 (75.7%)	17 (24.3%)	$\chi^2 = 4.881$,
	Dismantlers (73)	52 (71.2%)	21 (28.8%)	$p = 0.087$,
	Burners (20)	19 (95.0%)	1 (5.0%)	FET $p = 0.070$
Walking continuously for ≥ 1 hour	Collectors (70)	65 (92.9%)	5 (7.1%)	$\chi^2 = 7.211$,
	Dismantlers (73)	57 (78.1%)	16 (21.9%)	$p = 0.027$,
	Burners (20)	15 (75.0%)	5 (25.0%)	FET $p = 0.018$*
Sitting for a total of ≥ 4 hours	Collectors (70)	21 (30.0%)	49 (70.0%)	$\chi^2 = 40.376$,
	Dismantlers (73)	60 (82.2%)	13 (17.8%)	$p = 0.001$,
	Burners (20)	13 (65.0%)	7 (35.0%)	FET $p = 0.001$*
Standing for a total of ≥ 4 hours	Collectors (70)	13 (18.6%)	57 (81.4%)	$\chi^2 = 19.384$,
	Dismantlers (73)	36 (49.3%)	37 (50.7%)	$p = 0.001$,
	Burners (20)	12 (60.0%)	8 (40.0%)	FET $p = 0.001$*
Walking for a total of ≥ 4 hours	Collectors (70)	62 (88.5%)	8 (11.4%)	$\chi^2 = 19.961$,
	Dismantlers (73)	40 (54.8%)	33 (45.2%)	$p = 0.001$,
	Burners (20)	13 (65.0%)	7 (35.0%)	FET $p = 0.001$*

* indicates significant main effects at $p < 0.05$, FET – Fisher's Exact Test

4.2.2.2 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. It was observed that the weight and volume of the load handled differed by the task performed and the item manipulated. 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. The weight of the cart and the items collected varied from day to day as a function of what items were located for recycling. 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 and non-neutral postures when dismantling appliances using tools such as hammers, chisel and screwdrivers. The load handled by burners was mainly from the weight of the components (e.g., insulated cables, wires) being burnt. Lifting and carrying among burners involved using a long metal rod to lift burning copper wires. This was usually done with the trunk in slight flexion. Occasionally, burners would lift and carry items from a wheelbarrow onto the ground for burning and this involved moderate to severe forward flexion of the trunk for short intervals.

Table 4.2.3 summarizes the proportion of participants by job category, who performed tasks that involved varying levels of lifting, carrying, as well as pushing and/or pulling activities within a typical work week. The differences in the proportions across job categories were statistically significant for lifting, carrying, and pushing and/or pulling (Fisher's exact $p < 0.001$). More burners (94.1%) and collectors (91.2%) reported performing lifting activities 5 or more days in a

week compared to dismantlers (65.8%). Post hoc analysis showed lifting was significantly more frequent among collectors compared to dismantlers (p = 0.008) but not statistically different between burners and dismantlers (p = 0.083) or burners and collectors (p = 0.976). Carrying was performed on 5 or more days per week mostly by collectors (91.2%) compared to burners (82.4%) and dismantlers (62.5%). Post hoc analysis indicated that carrying was significantly more frequent among collectors compared to dismantlers (p = 0.002) but not statistically different from burners (p = *0.184*). Reports of pushing and/or pulling of a hand-drawn cart was significantly more frequent among collectors (68.2%) compared to dismantlers (26.4%; $p < 0.001$) and burners (26.3%; p = 0.001). The difference in proportions between dismantlers and burners who reported pushing or pulling was not statistically significant (p = 0.943).

Table 4.2.3: Frequency of self-reported manual material handling activities of e-waste workers within a work week stratified by job category.

Activity type	Job Category (n)	None or rarely	1-2 days /week	3-4 days /week	≥ 5 days /week	Chi-square *p*-value FET
Lifting	Collectors (68)	1 (1.5%)	2 (2.9%)	3 (4.4%)	62 (91.2%)	$\chi^2 = 20.524$,
	Dismantlers (73)	0 (0.0%)	7 (9.6%)	18 (24.7%)	48 (65.8%)	$p = 0.002$, FET $p = 0.001$*
	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%)	$\chi^2 = 26.656$,
	Dismantlers (72)	2 (2.8%)	9 (12.5%)	16 (22.2%)	45 (62.5%)	$p < 0.001$, FET $p < 0.001$*
	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%)	$\chi^2 = 37.053$, $p < 0.001$, FET $p < 0.001$*
	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 $p < 0.05$, FET – Fisher's Exact Test

Table 4.2.4 summarizes the maximum self-reported weight usually handled by workers coded on an ordinal scale from light (5kg or less) to very heavy (>20kg). Over 86% of all study participants reported the maximum weight they handled at work to be very heavy (>20kg). The proportion of participants handling weights heavier than 20kg was highest among collectors (95.6%) followed by dismantlers (81.9%) and then burners (68.4%). Results from a Chi-squared test indicated a statistically significant difference ($p = 0.011$) in the maximum weights handled among the three job categories.

Table 4.2.4: Stratification of maximum weight handled within a work week by job category

Job Category (n)	Maximum weight handled, n (%)				Chi-square *p*-value FET
	Light (< 5 kg)	Moderate (6 – 10 kg)	Heavy (10 – 20 kg)	Very heavy (> 20 kg)	
Collectors (70)	0 (0.00%)	1 (1.47%)	2 (2.94%)	65 (95.59%)	$\chi^2 = 15.686$,
Dismantlers (73)	2 (2.78%)	5 (6.94%)	6 (8.33%)	59 (81.94%)	$p = 0.016$,
Burners (20)	2 (10.53%)	3 (15.79%)	1 (5.26%)	13 (68.42%)	FET $p = 0.011$*

* indicates significant main effects at $p < 0.05$, FET – Fisher's Exact Test

4.2.2.3 Pedometer measurements

Table 4.2.5 summarizes the median values and interquartile ranges for regular steps, aerobic steps, steps per minute, distance covered and energy expenditure (kilocalories; 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 pedometer measurements ($p > 0.05$). However, collectors performed slightly more regular and aerobic steps than burners and dismantlers. Notably, median aerobic steps among dismantlers was zero. The median distance covered by participants in each category was 5.4 km 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).

Table 4.2.5: Pedometer measurements obtained from a sub-set of study participants (n = 42) averaged over 2 work days and stratified by job category.

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

4.3 Results for objective 3: Prevalence and severity of self-reported MSDs

4.3.1 Demographic characteristics of e-waste workers and non-e-waste workers

A total of 217 participants comprising of 176 e-waste workers and 41 participants from Madina Zongo (reference population) were recruited for this study. E-waste workers were made up of three categories, which were collectors (73), dismantlers (82) and burners (21). Occasionally, an e-waste worker may perform more than one job task and as such may be involved in more than one job category. Thus, workers' self-reported primary job task was used for all the data analysis. The ages of the participants ranged from 11 to 55 years and they worked 1 to 7 days a week for between 1-15 hours depending on the type of work and job availability.

The mean age of participants was 25.9±7.2 years. The mean age for e-waste workers was 24.7±6.3 years while that of non-e-waste workers was 31.2±9.0 years. Seven (7) participants were less than 18 years (minors) of which six were e-waste workers (collectors) and one non-e-waste worker. All participants recruited for this study were males. Their average number of working days per week was 6.0±1.0 days with an average working duration of 9.9±2.7 hours per day. Participants' mean years of work experience in their present job was 6.7±5.8 years with a range 0.0192 years (7 days) to 30 years. The mean number of years of work for e-waste workers was 6.3±5.4 while that of non-e-waste workers was 8.3±7.5 years.

4.3.2 Prevalence of MSDs in 11 anatomical regions of the body

The overall prevalence of reporting at least one (of any severity) work-related MSD among e-waste workers was 89.2(95% CI: 83.7-93.4) % compared to 70.7(95% CI: 54.5-83.9) % among non-e-waste workers (p-value = 0.002). The body region specific prevalence of MSDs reported by

workers in 11 anatomical regions of the body are presented in Table 4.3.1. There were higher reports of MSDs in the neck, shoulder, upper arm, forearm, wrist, upper back, lower back, knees and lower leg among e-waste workers compared to the reference population (see Table4.3.1). These higher proportion of MSDs reported among e-waste workers was statistically significant for only the upper arm (p=0.001). On the other hand, the reference population reported a higher prevalence of MSDs in the hip/buttocks as well as the thigh, but the difference in proportions compared with e-waste workers was not statistically significant (Table 4.3.1). Among both groups, low back pain was the most prevalent MSD reported (65.9(95% CI: 58.4-72.9)% in e-waste workers vs 51.2(95% CI: 35.1-67.1)% in non-e-waste workers).

Table 4.3.1: Prevalence of work-related MSDs among e-waste and non-e-waste workers in 11 regions of the body.

Body Region	E-waste workers (n=176) Percentage (95% CI)	Non-e-waste workers (n=41) Percentage (95% CI)	Z test for comparing difference in proportion Z score, P-value
Neck	26.1(19.8-33.3)	22.0(10.6-37.6)	z=0.55, p=0.579
Shoulder	37.5(30.3-45.1)	31.7(18.1-48.1)	z=0.69, p=0.488
Upper Arm	28.4(21.9-35.7)	2.4(0.1-12.9)	z= 3.53, p=0.001*
Forearm	4.5(2.0-8.8)	0.0(0.0-8.6)	z=1.39, p=0.164
Wrist	11.4(7.0-17.0)	7.3(1.5-19.9)	z= 0.76, p=0.448
Upper Back	14.7(9.9-20.9)	14.6(5.6-29.2)	z=0.02, p=0.982
Lower Back	65.9(58.4-72.9)	51.2(35.1-67.1)	z=1.76, p=0.079
Hip/Buttocks	1.1(0.1-4.0)	2.4(0.1-12.9)	z=-0.64, p=0.520
Thigh	4.0(1.6-8.0)	7.3(1.5-19.9)	z=-0.92, p=0.358
Knee	37.5(30.3-45.1)	24.4(12.4-40.3)	z=1.58, p=0.113
Lower Leg	26.7(20.3-33.9)	19.5(8.8-34.9)	z=0.95, p=0.340
Overall MSD	89.2(83.7-93.4)	70.7(54.5-83.9)	z=3.04, p=0.002*

* indicates significant main effects at $p < 0.05$

The prevalence of MSDs per body region among the various work categories are shown in Figure 4.3.1. As shown in the graph, pain and discomfort in the neck, upper back, lower back, shoulder, upper arm and wrist was highly reported among dismantlers compared to the other work categories. This difference was statistically significant for pain and discomfort reported in the upper arm ($p<0.001$). Forearm pain was highest among burners although the difference was not statistically significant ($p<0.284$). Pain and discomfort in the hip/buttocks, thigh, knee and lower leg were highest among collectors compared to the other job categories (see Figure 4.3.1). This difference was statistically significant for pain and discomfort reported in the knee ($p<0.002$) and lower leg ($p<0.001$).

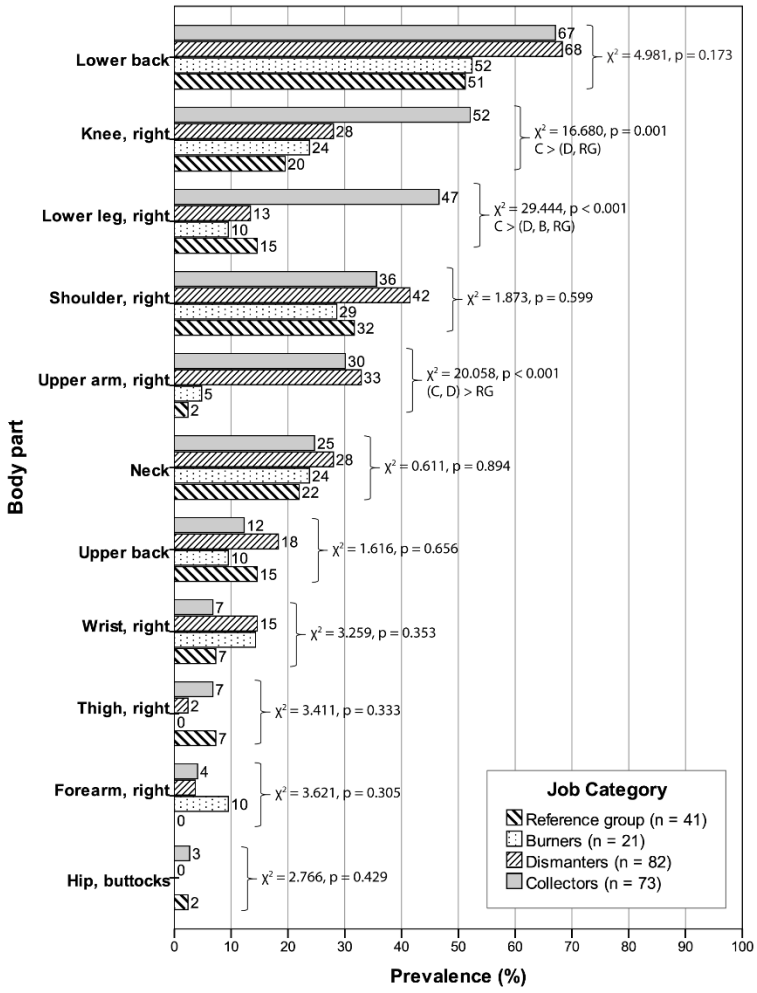


Figure 4.3.1: Proportion of e-waste workers by job category who reported MSDs in 11 regions of the body.

Note: Bars for each anatomic region is a comparison of the total number of participants in each work category who reported MSDs in the anatomical region under consideration. Only MSDs for right body parts are reported for regions with both left and right as the differences in number of persons with MSDs reported were negligible.

4.3.3 Relationship between demographic characteristics of participants and prevalence of MSDs

A modified Poisson regression, taking into account the number of MSDs reported by each participant was used to determine the relationship between age, years of work, number of days of work per week and number of hours of work per day. The model controlled for the job category the participant belonged to. The results from the model showed that, age and hours of work per day were associated with MSDs. Minors (<18 years) had a 1.53(95% CI:1.02-2.30) risk of developing MSDs compared to participants 18-29 years while participants ≥40 had a 0.59(95% CI:0.34-1.00) risk of developing MSDs compared to those in the 18-29-year group. Also, participants who worked 11-15 hours as day had a 1.43(95% CI:1.02-2.00) risk of developing MSDs compared to those who worked 0-5 hours a day. There was however no association between number of years of work or number of days of work in a week and the occurrence of MSDs (see Table 4.3.2).

Table 4.3.2: Relationship between demographic characteristics of participants and prevalence of MSDs

Variable	MSD n (%)	No MSD n (%)	aPR (95%CI)	P-value
Age Category (n=208)				
<18 (7)	6(85.7)	1(14.3)	1.53(1.02-2.30)	0.042*
18-29 (146)	128(87.7)	18(12.3)	reference	
30-39 (42)	36(85.7)	6(14.3)	0.95(0.67-1.35)	0.780
≥40 (13)	10(76.9)	3(23.1)	0.59(0.34-1.00)	0.049*
Years of work on the job (n=212)				
<1 (22)	21(95.5)	1(4.6)	reference	
1-5 (90)	77(85.6)	13(14.4)	0.87(0.62-1.22)	0.418
6-10 (61)	51(83.6)	10(16.4)	0.95(0.62-1.44)	0.795
11-15 (21)	19(90.5)	2(9.5)	0.97(0.61-1.54)	0.894
16-20 (11)	11(100.0)	0(0.0)	0.77(0.42-1.43)	0.410
>20 (7)	6(85.7)	1(14.3)	1.18(0.59-2.36)	0.649
Days of work (n=214)				
1-3 days per week (6)	4(66.7)	2(33.3)	reference	
4-5 days (27)	23(85.2)	4(14.8)	1.14(0.51-2.53)	0.750
6-7 days (181)	158(87.3)	23(12.7)	0.95(0.45-2.03)	0.899
Hours of work per day (n=214)				
0-5 hours (17)	15(88.2)	2(11.8)	reference	
6-10 hours (96)	77(80.2)	19(19.8)	1.19(0.84-1.68)	0.327
11-15 hours (101)	93(92.1)	8(7.9)	1.43(1.02-2.00)	0.036*

* indicates significant main effects at $p < 0.05$, aPR – Adjusted prevalence ratio. Note: The model adjusted for job categories.

4.3.4 Relationship between type of e-waste recycling activity or job category and prevalence of MSDs

A modified Poisson regression model was used to determine the relationship between e-waste recycling activities and MSDs using non-waste workers as a reference and subsequently collectors as a reference while controlling for age, work experience, number of working days per week as well as number of hours of work per day (see Table 4.3.3A and 4.3.3B). Results from the analysis showed that, compared to the reference population, collectors have a 1.62 (95% CI:1.13-2.33) risk of developing MSDs and this was statistically significant (p<0.009). Again, compared to the reference population, dismantlers had a 1.39 (95% CI:1.00-1.95) risk of developing MSDs although this showed weak statistical significance (p<0.054) as shown in Table 4.3.3A. Compared to collectors, burners had 0.62 (95% CI:0.41-0.92) risk of developing MSDs while non-e-waste workers also had a 0.62 (95% CI:0.43-0.88) risk of developing MSDs and these were statistically significant (p<0.019 and 0.009 respectively) as shown in Table 4.3.3B.

Table 4.3.3A: Relationship between type of e-waste recycling activity or job category and prevalence of MSDs: modified Poisson regression and negative binomial regression using non-e-waste workers as reference.

	Poisson Regression		Negative binomial regression	
Covariate	**aPR (95%CI),**	**p-value**	**aPR(95%CI)**	**p-value**
Job Category				
Ref=non-e-waste workers				
-Collectors	1.62(1.13-2.33)	0.009*	1.64(1.14-2.36)	0.008*
-Dismantlers	1.39(1.00-1.95)	0.054*	1.36(0.97-1.91)	0.075
-Burners	1.00(0.61-1.66)	0.990	1.00(0.61-1.66)	0.985

* indicates significant main effects at $p < 0.05$, aPR – Adjusted prevalence ratio. Note: The model adjusted for age, years of work, number of working days per week, number of working hours per day.

Table 4.3.3B: Relationship between type of e-waste recycling activity or job category and prevalence of MSD: modified Poisson regression and negative binomial regression using collectors as reference.

	Poisson Regression		Negative binomial regression	
Covariate	**aPR (95%CI),**	**p-value**	**aPR(95%CI)**	**p-value**
Job Category				
Ref=Collectors				
-Dismantlers	0.86(0.67-1.10)	0.221	0.83(0.64-1.07)	0.154
-Burners	0.62(0.41-0.92)	0.019*	0.61(0.41-0.92)	0.019*
- non-e-waste workers	0.62(0.43-0.88)	0.009*	0.61(0.42-0.88)	0.008*

* indicates significant main effects at $p < 0.05$, aPR – Adjusted prevalence ratio. Note: The model adjusted for age, years of work, number of working days per week, number of working hours per day.

4.3.5 Frequency of MSDs reported within a week among e-waste workers and non-e-waste workers

Among participants recruited for the study, 81(37.3%) reported MSDs 5 or more days in a week while 31(14.3%) reported no MSDs at all. Within the job categories, most collectors (54.8%) reported MSDs 5 or more days in a week; most dismantlers (34.2%) reported MSDs 1-2 days a week; most burners (33.3%) reported MSDs 3-4 days a week; most participants from the reference population (31.7%) reported MSDs 5 or more days in a week (see Table 4.3.4). The differences in proportion of workers who reported various frequencies of MSDs were statistically significant (χ^2=10.47, p=0.0149) controlling for age, years of work, number of working days per week and number of working hours per day. Compared to the reference population, collectors had 2.66 odds of experiencing a greater number of days of MSDs per week and this was statistically significant (p<0.032).

4.3.6 Severity of MSDs among participant.

Among participants who reported MSDs, 56.8% were severe, 23.8% were moderate and 19.5% were mild. Within the job categories, most participants with MSDs experienced high severity (74.2% collectors, 48.0% dismantlers, 47.1% burners and 44.8% non-e-waste workers) as shown in Table 4.3.4. There was no significant difference in MSD severity reported among collector, dismantlers and burners when each was compared to non-e-waste workers (Table 4.3.5A). However, compared to collectors, dismantlers had 0.41 odds of experiencing severe MSDs while burners had 0.34 odds of experiencing severe MSDs and these were statistically significant ($p=0.018$ and $p=0.044$ respectively) as shown in Table 4.3.5B.

4.3.7 Interference of MSD with participants work

Out of the participants that reported MSDs, 25.4% experienced a substantial interference in their work as a result of MSDs. About 37.9% however, did not experience any interference in their work despite the MSDs they had. Among collectors, 36.9% reported substantial interference of MSDs with their work while 36.9% reported no interference of MSDs with their work. Majority of dismantlers with MSDs (40.3%) did not experience any interference of MSDs with their work. Similarly, majority of participants in the reference population who had MSDs (47.8%) reported no interference of MSDs with their work. On the other hand, majority of burners with MSDs (64.7%) reported slight interference of MSDs with their work (see Table 4.3.4). There was no significant difference in level of interference of MSDs reported among the various participant groups when compared against each other (see Table 4.3.5A and 4.3.5B).

Table 4.3.4: Frequency, severity, and level of interference of work among e-waste workers due to MSDs.

	Job Categories (n)			
Frequency of MSD	**Collectors (73)**	**Dismantlers (82)**	**Burners (21)**	**Non-e-waste workers (41)**
None	6(8.22%)	9(11.0%)	4(19.1%)	12(29.3%)
1-2 days	13(17.8%)	28(34.2%)	6(28.6%)	10(24.4%)
3-4 days	14(19.2%)	21(25.6%)	7(33.3%)	6(14.6%)
≥5 days	40(54.8%)	24(29.3%)	4(19.1%)	13(31.7%)
Severity of MSD	**Collectors (66)**	**Dismantlers (73)**	**Burners (17)**	**Non-e-waste workers (29)**
Mild	8(12.12%)	14(19.18%)	4(23.53%)	10(34.48%)
Moderate	9(13.64%)	24(32.88%)	5(29.41%)	6(20.69%)
High	49(74.24%)	35(47.95%)	8(47.06%)	13(44.83%)
Interference of MSD	**Collectors (65)**	**Dismantlers (72)**	**Burners (17)**	**Non-e-waste workers (23)**
Not at all	24(36.92%)	29(40.28%)	3(17.65%)	11(47.83%)
Slight interference	17(26.15%)	27(37.50%)	11(64.71%)	10(43.48%)
Substantial interference	24(36.92%)	16(22.22%)	3(17.65%)	2(8.70%)

Table 4.3.5A: Relationship between e-waste recycling activities and the frequency, severity, and level of interference of MSD: Ordinal logistic regression using non-e-waste workers as reference

	MSD Frequency	**MSD Severity**	**MSD level of interference**
Covariate	**aPOR(95%CI)**	**aPOR(95%CI)**	**aPOR(95%CI)**
Job Category	(χ^2=10.47, p=0.0149*)	(χ^2=7.20, p=0.0659)	(χ^2=0.95, p=0.8137)
- non-e-waste workers	reference	reference	reference
- Collectors	2.66(1.09-6.52)*	2.45(0.84-7.15)	1.49(0.52-4.27)
- Dismantlers	1.09(0.48-2.51)	1.01(0.38-2.70)	1.19(0.44-3.21)
- Burners	0.94(0.31-2.87)	0.82(0.22-3.00)	1.62(0.46-5.67)

Abbreviation – aPOR = Adjusted proportional odds ratio, p-value notation *** p<0.001, **p<0.01, *p<0.05. Note: The model adjusted for age, years of work, number of working days per week, number of working hours per day.

Table 4.3.5B: Relationship between e-waste recycling activities and the frequency, severity, and level of interference of MSD: Ordinal logistic regression using collectors as reference

	MSD Frequency	**MSD Severity**	**MSD level of interference**
Covariate			
Job Category	(Overall χ^2=10.47, p=0.0149)	(Overall χ^2=7.20, p=0.0659)	(Overall χ^2=0.95, p=0.8137)
	aPOR(95%CI)	**aPOR(95%CI)**	**aPOR(95%CI)**
- Collectors	reference	reference	reference
- Dismantlers	0.41(0.22-0.76)**	0.41(0.20-0.86)*	0.80(0.41-1.55)
- Burners	0.35(0.14-0.88)*	0.34(0.12-0.97)*	1.09(0.42-2.78)
- non-e-waste workers	0.38(0.15-0.92)*	0.41(0.14-1.20)	0.67(0.23-1.91)

Abbreviation – aPOR = Adjusted proportional odds ratio, p-value notation *** p<0.001, **p<0.01, *p<0.05. Note: The model adjusted for age, years of work, number of working days per week, number of working hours per day.

4.4 Results for specific objective 4: Development of an ergonomic assessment tool for use in an informal work setting

In order to assess ergonomic exposures among e-waste workers while accounting for the high level of variability that exists in the task they perform, a new ergonomic assessment tool adapted to unstructured type of work such as e-waste recycling was developed. The results of comparing the inter-observer agreement between two observers as well as results from piloting the tool are presented below.

4.4.1 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 4.4.1 summarizes the percent agreement and kappa statistic for other areas. Pooled data showed 89.17% to 100% agreement for all risk factors observed.

Table 4.4.1: 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	100.00%
Force	0.754	95.00	0.636	86.67%	0.878	94.17%
Repetition	0.610	85.00%	**	**	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.

4.4.2 Pilot data (exposure profile for 6 workers)

The total duration participants were observed for the pilot study 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 90^0. Dismantlers spent 85.1% of their work time sitting (with their hips and knees less than 90^0) and 13.9% in neutral standing. Figure 4.4.1 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 4.4.2 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).

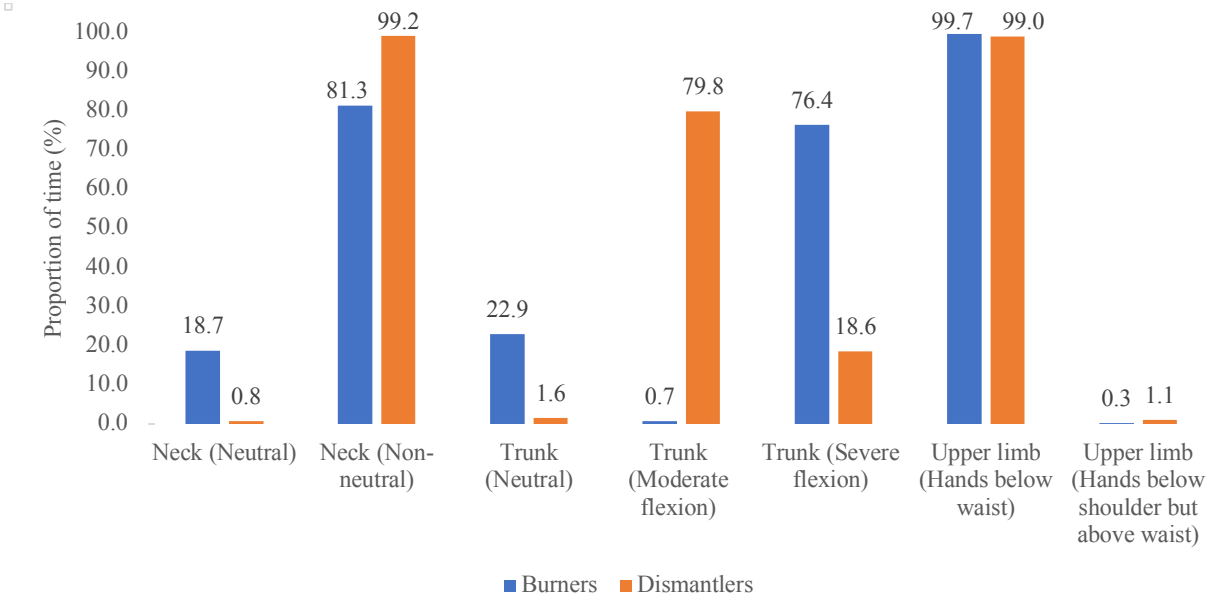


Figure 4.4.1: Proportion of time (%) spent by burners (n = 3) and dismantlers (n = 3) in different work postures.

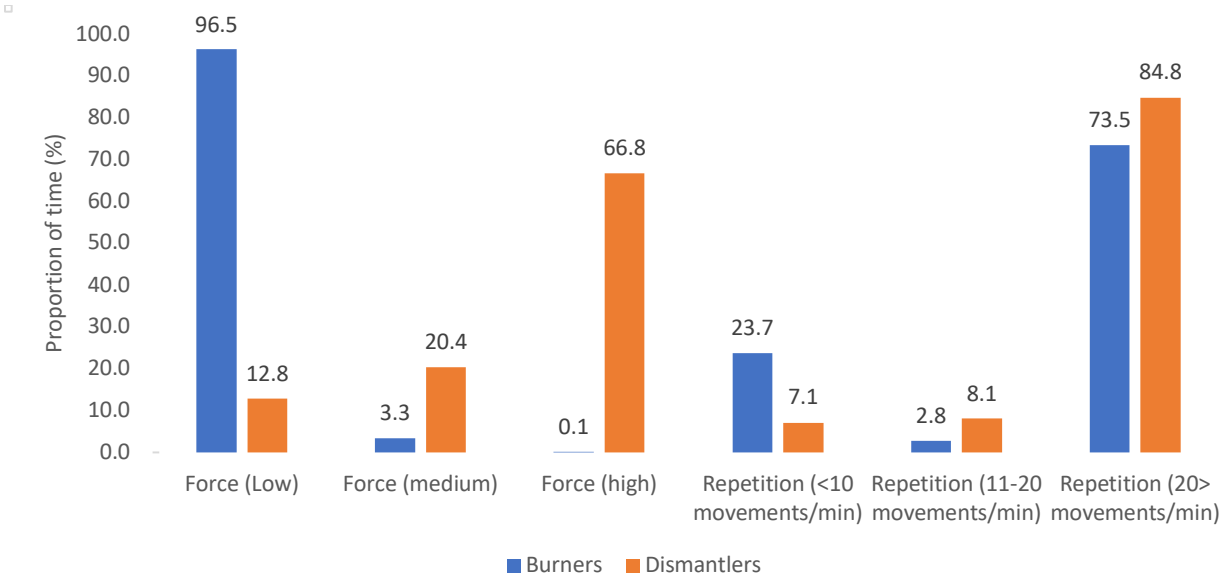


Figure 4.4.2: Proportion of time (%) burners (n = 3) and dismantlers (n = 3) were exposed to different intensity levels of force and repetition

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).

4.5 Results for objective 5: Assessment and comparison of ergonomic risk factors and MSDs among e-waste workers

4.5.1 Sample demographics and occupational background

All 23 participants were males. Table 4.5.1 summarizes the demographic characteristics of the study sample by job category. Their ages ranged from 20 years to 40 years with a mean ± SD age of 25.87 ± 5.25 years. Participant ages did not differ by job category. Participant weights ranged from 60kg to 85kg with a sample mean of 68.74 ± 7.47kg, and with dismantlers weighing

significantly heavier than collectors (t = 2.60, p = 0.048) and burners (t = 3.43, p = 0.007). The height of participants ranged from 160cm to about 193cm with a mean ± SD of 173.09 ± 7.89cm. On average, burners were significantly shorter compared to collectors (t = 3.31, p = 0.009) and dismantlers (t = 2.98, p = 0.020). Four (4) of the participants were left hand dominant while the remaining 19 were right hand dominant as self-determined. However, these differences are not of practical significance for the present investigation. Nine (9) participants had attained primary education, 8 completed secondary education, one participant attended university, and the remaining 5 participants had no formal education.

The participants had worked in e-waste recycling for an average ± SD of 4.02 ± 3.87 years with a minimum experience of 3 weeks and a maximum of 15 years. On average, collectors worked slightly fewer years than dismantlers and burners, however the differences among job categories were not statistically significant (p = 0.401).

Table 4.5.1: Demographic characteristics of study participants (n = 23) stratified by primary job category.

Variable	Job Category(n)	Range	Mean ± SD	ANOVA results	
Age in years	Collectors (11)	20-40	27.64±6.89	F = 1.26, p = 0.305	
	Dismantlers (6)	20-28	23.83±3.06		
	Burners (6)	22-27	24.67±1.86		
	All Workers (23)	20-40	25.87±5.25		
Weight (kg)	Collectors (11)	60-80	67.73±7.20	F = 5.40, p = 0.013*	
	Dismantlers (6)	65-85	75.50±6.75		
	Burners (6)	60-67	63.83±3.19		
	All Workers (23)	60-85	68.74±7.47		
Height (cm)	Collectors (11)	165-185	175.73±5.85	F = 5.54, p = 0.012*	
	Dismantlers (6)	170-193	176.00±8.49		
	Burners (6)	160-175	165.33±5.99		
	All Workers (23)	160-193	173.09±7.89		
Years of work at e-waste site	Collectors (11)	0.6-15	2.91±4.48	F = 0.96, p = 0.401	
	Dismantlers (6)	1-10	4.58±3.41		
	Burners (6)	1-8	5.5±2.88		
	All Workers (23)	0.06-15	4.02±3.87		
		None	**Primary**	**Secondary**	**Tertiary**
Level of education	Collectors (11)	4	4	3	0
	Dismantlers (6)	1	3	2	0
	Burners (6)	0	2	3	1
	All Workers (23)	5	9	8	1

*** indicates significance at p<0.05**

4.5.2 Summary of work days and durations

The work schedule of participants was highly variable between and within days, which was mainly determined by the availability of work. The start and end work time were as follow: burners usually started between 7:30 and 8 :00 am and ended between 3 and 6pm. Collectors departed to their collecting areas between 5:30am and 6:30am and returned between 1pm and 6pm depending upon the distance to be covered to find e-waste. The most variable start and stop times were observed for dismantlers who started between 6am and 9am and stopped as a function of the quantity of items to dismantle.

Table 4.5.2 summarizes the observed times, total working time per day, rest time and active work time (i.e., working time per day minus rest time) for the observed workers stratified by primary job category. A total of 117 days of observation were accumulated [11 collectors x 3 days, 6 dismantlers x 8 days, and 6 burners x 6 days]. The mean ± SD work time per day observed while at the e-waste site were 212.3 ± 72.2 minutes for collectors, 142.5 ± 78.4 minutes for dismantlers, and 195.4 ± 104.5 minutes for burners. The mean ± SD self-reported total work time (based on the start and completion of work) were 454.1 ± 97.9 minutes for collectors, 257.4 ± 161.1 minutes for dismantlers, 429.4 ± 163.2 minutes for burners. The mean ± SD observed rest time per day were 109.0 ± 29.8 minutes for collectors, 15.0 ± 27.9 minutes for dismantlers, and 104.4 ± 68.4 minutes for burners. Active work time was computed as the difference between the total work time and the rest time for each working day. Figure 4.5.1 graphically summarizes the active work time per worker across the observed working days stratified by job category. This figure illustrates the high variability in active work time both, within worker (error bars across work days) and between workers across job categories. The mean ± SD active work time was 345.1 ± 77.3 minutes for

collectors, 242.4 ± 146.1 minutes for dismantlers, and 325.0 ± 153.1 minutes for burners. Thus, the average active work time of dismantlers was about 70% of that of collectors and burners.

Table 4.5.2: Descriptive summary of the observed times, total working time per day, rest time, and active work time (i.e., working time per day minus rest time) stratified by primary job category.

	Collectors (n = 11)	**Dismantlers (n = 6)**	**Burners (n = 6)**	**Combined (n = 23)**
Work days observed	33 = 11 workers x 3 days	48 = 6 workers x 8 days	36 = 6 workers x 6 days	117 days
Observed Time per working day (mins)				
Mean (SD)	212.3 (72.2)	142.5 (78.4)	195.4 (104.5)	178.5 (90.4)
Median	240	133.5	176.5	90.4
Min - Max	82 - 345	30 - 389	15 -505	15 -505
Total Work Time per working day (mins)				
Mean (SD)	454.1 (97.9)	257.4 (161.1)	429.4 (163.2)	365.8 (171.9)
Median	463	202	462.5	390
Min - Max	306 - 660	60 - 780	15 - 720	15 - 780
Rest Time per working day (mins)				
Mean (SD)	109.0 (29.8)	15.0 (27.9)	104.4 (68.4)	69.0 (63.4)
Median	114.5	0	100	63
Min - Max	30 - 158	0 - 120	0 - 264	0 - 264
Active Work Time per working day (mins)				
Mean (SD)	345.1 (77.3)	242.4 (146.1)	325.0 (153.1)	296.8 (139.7)
Median	361	198.5	329.5	300
Min - Max	209 - 502	52 - 660	15 - 652	15 -660

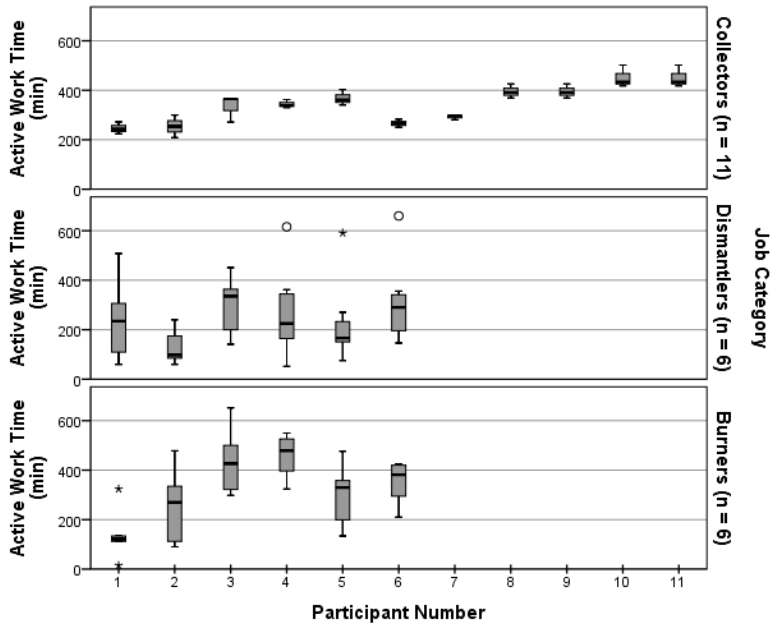


Figure 4.5.1: Active work time for each participant across the observed work day stratified by job category.

4.5.3 Ergonomic exposure profile of e-waste workers

All recognized risk factors were assessed. To illustrate the results and emphasize the high variability of unregulated and unstructured work, the most relevant exposures in term of prominence/prevalence and severity and contrast between job categories, are detailed in this section. The active time spent in each exposure are reported. In a few instances, the proportion of time spent in some exposures are also reported. The active work time spent in each exposure was computed using the proportion of observed time (observed duration for the exposure in question divided by the total observed duration) spent in those exposures multiplied by the total active work time per working day. Detailed results on ergonomic exposure profile for each risk factor assessed are presented in Appendix 7.

4.5.3.1 Working postures

4.5.3.1.1 Walking, standing, sitting

Walking was predominantly observed among collectors, while walking was almost negligible for burners and dismantlers (Appendix 7.1). Hence, walking may not be a factor to consider in further assessments concerning burners and dismantlers. In addition, walking while pulling/pushing a cart was an activity only observed among collectors with variable durations spent in this activity among the 11 collectors observed (Appendix 7.1B). Standing was predominantly observed for dismantlers and burners (Appendix 7.2) as collectors spend the greatest part of their time walking (Appendix 7.1). The average standing time was 2.8 x longer for Burners than dismantlers and about 6 times longer for Burners than collectors. Sitting was predominantly observed for dismantlers (Appendix 7.3). Of the three types of sitting evaluated, sitting with hips and knees <90 degrees were the common mode of sitting among workers (Appendix 7.3A).

4.5.3.1.2 Neck, trunk and upper limb postures

Time in non-neutral neck postures was relatively higher for burners as shown in Appendix 7.4. The comparison of absolute and percent time of working in non-neutral neck postures, indicate that dismantlers spend approximately between 80% to 100% of their total active working time in non-neutral neck postures compared to between 60 to 80% for burners. Although the absolute time in non-neutral neck posture is somehow similar for all workers categories, the relative time varies largely between collectors (Appendix 7.4B, upper panel), which is most likely inherent to their individual style of walking and may also be dependent on the cart load. The active working times in neutral, moderate or severe trunk flexion are presented in Appendix 7.5. The figure shows

variable durations spent in neutral, moderate and severe trunk flexion within worker categories and between workers from day to day. Notably, burners spend about twice as much time as collectors and dismantlers in severe trunk postures. The active work time spent in upper limb postures are presented in Appendix 7.6. Generally, e-waste workers performed their activities predominantly with their hands below waist height. Comparing collectors and burners, with dismantlers, the latter spend approximately about 2/3rd of their total work time with their hands below waist.

4.5.3.2 Force, repetition, contact stress and vibration

Force exertion among collectors was predominantly medium for about 150 to 300 minutes of their absolute working time (Appendix 7.7B) while dismantlers exerted predominantly high force for about 100 to 200 minutes of their active time (Appendix 7.7C). Force exertion was predominantly low for burners, which corresponded to about 300 to 500 minutes of their active time. Collectors were mainly exposed to low repetition which constituted about 200 to 400 minutes of their active working time (Appendix 7.8A). Dismantlers and burners however were mainly exposed to high repetitions which corresponded to about 100 to 200 minutes of the dismantlers' active working time and about 100 to 300 minutes of the burners' active working time (Appendix 7.8C).

Contact stress was predominant among collectors and dismantlers with exposure durations of 200 to 300 minutes of collectors' active working time and of 100 to 200 minutes of dismantlers' active working time (Appendix 7.9). With respect to vibration, dismantlers were most affected due to the predominant use of hammer and chisels to extract valuable components of e-waste. Their exposure duration was from 100 to 200 minutes of the active work time (Appendix 7.10).

4.5.3.3 Manual Material Handling: carrying, lifting, pushing, pulling

Carrying and lifting involved predominantly handling of moderate weight (6-10kg) by collectors, moderate and heavy weight (11-20kg) by dismantlers and handling of light (5kg or less) and moderate weight by burners (see Appendix 7.11 for comparative graphs). Carrying were done for short durations with median durations mostly less than 20 minutes. Similar results were observed for lifting; hence corresponding results are not presented. Pushing and pulling were performed only by collectors as have been previously indicated in Appendix 7.11B. Short pushing of a wheelbarrow could occur for burners; however, this activity was very limited.

4.5.6 Summary of key exposures

A mixed effect model was used to determine significant exposures among the three work categories. The estimated marginal means and standard errors are reported in Table 4.5.3. Significant physical exposures peculiar to only collectors included walking and pushing a loaded cart, while standing bent, sitting with hips and knees <90deg as well as lifting/lowering heavy items were significant exposures peculiar to only dismantlers. Standing, non-neutral neck posture, working with hands below waist height, medium and high force exertion and contact stress were significant exposure for all three worker categories. Severe trunk flexion, and high repetition were peculiar to dismantlers and burners. Details of these exposures are summarized in Table 4.5.3.

Table 4.5.3: Relevant exposures (significant at p < 0.05) by job category with estimated marginal mean ± standard errors in minutes.

Exposure Variable	Collectors (n = 11)	Dismantlers (n = 6)	Burners (n = 6)
Ordinary walking	79.4 ± 11.7	-	-
Walking pulling cart	208.6 ± 10.2	-	-
Pushing loaded wheelbarrow	-	-	-
Pushing loaded cart	50.2 ± 6.2	-	-
Standing	45.1 ± 20.9	95.6 ± 23.8 [a]	268.3 ± 24.8 [a]
Standing bent	-	10.0 ± 2.5	-
Sitting with hips and knees < 90deg	-	126.5 ± 24.4	-
Non-neutral neck posture	226.1 ± 25.3	230.7 ± 26.5	249.9 ± 28.2
Trunk flexion - severe	-	98.3 ± 24.6	188.7 ± 25.4
Hand/arm below waist	329.9 ± 27.1	229.3 ± 30.2	320.1 ± 31.7
Hand/arm above shoulder	-	-	-
Force exertion: combined medium + high force	228.3 ± 20.1 [b]	177.3 ± 20.4 [b]	60.7 ± 21.9
Repetition – high (>20x per min)	-	186.9 ± 20.9	178.8 ± 22.5
Contact stress	229.3 ± 20.5 [b]	179.0 ± 21.1 [b]	75.7 ± 22.6
Vibration	-	129.4 ± 16.0	-
Lifting-lowering: combined heavy + very heavy	-	2.8 ± 0.4	-
Carrying: (heavy + very heavy)	1.3 ± 0.6	2.1 ± 0.5	-
Kicking, stamping, rattling, supporting items with foot	-	97.3 ± 17.3	-

[a] values for dismantlers and burners significantly greater than for collectors ($p < 0.05$).

[b] values for collectors and dismantlers significantly greater than for burners ($p < 0.05$).

4.5.7 Observed use of hand tools and PPE

Overall, tools used by e-waste workers included: a) chisel, hammer, pliers, screw drivers, spanner for dismantlers; b) long metallic rod, short wooden stick, hammers, metallic bases/plates (used as anvils) and collecting sack for burners; c) collecting cart, sacks, and anchoring ropes for collectors. With the exception of 4 participants who wore gloves, no other participant wore formal PPE.

Twelve participants wore only boots or shoes (without toe protection) and regular clothes, 1 wore only socks and regular clothes, 4 workers wore gloves, boots and long clothing, 3 workers wore boots and long clothing only. Three out of the 23 participants had no form of personal protection. None of the participants wore face masks.

The most difficult task performed as reported by the participants were poking of the fire with a long metal rod and turning burning items by burners, hammering, and chiselling of scrap metals, especially engine parts by dismantlers, and pulling a collecting cart along their work routes while scouting for end-of-life electronic waste by collectors.

4.5.8 Number of MSD complaints at the start and end of the assessment week

Table 4.5.4 summarises number of MSD complaints (i.e., non-zero MSD rating) at the start and end of the work week containing the observation period. At the end of the work week, the high number of MSDs were reported by collectors and dismantlers in the lower back (10/11 for collectors and 4/6 for dismantlers) and the shoulder (7/11 for collectors and 5/6 for dismantlers). Dismantlers also reported high MSDs in the wrist (4/6). Burners reported high MSDs in the lower back (4/6) and neck (3/6) at the end of the working week.

The number of collectors reporting MSD complaints in at least one body part increased from 4 of 11 at the start of the work week to 11 of 11 at the end of the work week. All 6 dismantlers reported at least one MSD complaint prior to their working week and at the end of their work week. Among burners, 4/6 reported MSDs prior to their working week and the same 4/6 reported MSDs at the end of their working week. Two burners reported no MSD complaints at either the start or end of the work week.

Table 4.5.4: Number of MSD complaints of e-waste workers stratified by primary job category

Neck	Collectors (n =11)	Dismantlers (6)	Burners (6)
Initial Count n(%)	0 (0)	0 (0)	0 (0)
Final Count n(%)	2 (18)	1 (17)	3 (50)
Shoulder			
Initial Count n(%)	1 (9)*	5 (83)*	1 (17)*
Final Count n(%)	7 (64)	5 (83)	1 (17)
Upper Back			
Initial Count n(%)	2 (18)	1 (17)	0 (0)
Final Count n(%)	3 (27)	1 (17)	0 (0)
Lower back			
Initial Count n(%)	4 (36)	4 (67)	3 (50)
Final Count n(%)	10 (91)	4 (67)	4 (67)
Elbow/upper arm			
Initial Count n(%)	1 (9)	0 (0)	1 (17)
Final Count n(%)	2 (18)	0 (0)	2 (33)
Wrist/hand			
Initial Count n(%)	0 (0)	2 (33)	2 (33)
Final Count n(%)	0 (0)*	4 (67)*	1 (17)*
Hips/thigh			
Initial Count n(%)	0 (0)	0 (0)	0 (0)
Final Count n(%)	2 (18)	1 (17)	0 (0)
Knee			
Initial Count n(%)	2 (18)	3 (50)	1 (17)
Final Count n(%)	3 (27)	2 (33)	2 (33)
Ankle/foot			
Initial Count n(%)	0 (0)	1 (17)	0 (0)
Final Count n(%)	2 (18)	1 (17)	1 (17)
Over all			
Initial Count n(%)	4 (37)*	6 (100)*	4 (67)*
Final Count n(%)	11 (100)	6 (100)	4 (67)

*Chi-square test significant at $p < 0.05$

4.5.9 Summary of MSD rating by individual body regions and cumulative body regions

Table 4.5.5 summarises the estimated marginal means and standard errors for MSD ratings that were relevant to the various job categories. The final MSDs rating (0-10 VA scale) and the difference between final and initial MSDs ratings were used in the mixed effect model. Among collectors, the most substantive MSD ratings were in the lower back, shoulder, knees, and upper back. Notably the mean difference in MSD ratings for the lower back (4.5 ± 0.8) and shoulder (3.3 ± 0.9) among collectors exceeded 3.0, which is typically considered as a clinically relevant change in pain rating on a 10-point scale. The most substantive MSD ratings among dismantlers were in the shoulder, hand/wrist, and lower back. For burners, the most substantive MSDs were in the lower back and neck with the mean difference in the lower back rating (4.2 ± 1.1) exceeding 3.0 which implies a clinically relevant change.

Consider together, the combined sum of final ratings for all body parts were significant but did not differ by job category. The combined difference in ratings was significantly higher among collectors compared to dismantlers and burners.

Table 4.5.5: Estimated marginal means ± SE for significant final MSD ratings and difference in MSD ratings ($p < 0.05$) by body region and primary job category.

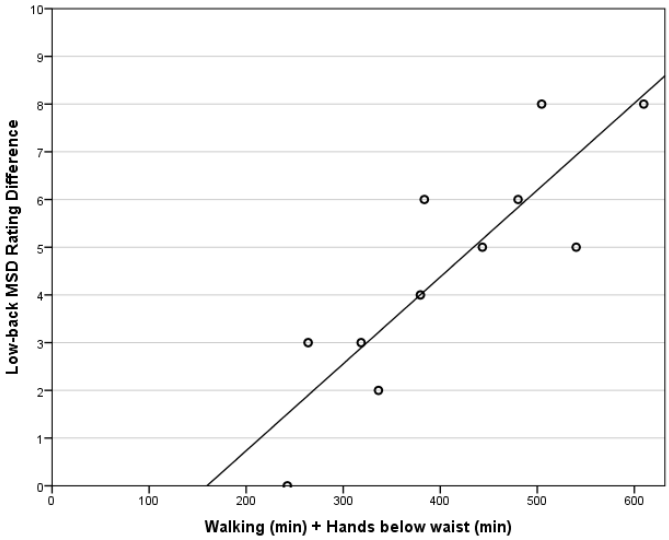
Body region	Type of rating	Collectors (n = 11)	Dismantlers (n = 6)	Burners (n = 6)
Neck	Ratings, final	-	-	2.2 ± 0.9
	Ratings, difference	-	-	2.2 ± 0.9
Shoulder	Ratings, final	3.4 ± 0.8	3.0 ± 1.1	-
	Ratings, difference	3.3 ± 0.9	-	-
Upper Arms	Ratings, final	-	-	-
	Ratings, difference	-	-	-
Hands and wrists	Ratings, final	-	2.5 ± 0.6	-
	Ratings, difference	-	1.5 ± 0.7	-
Upper Back	Ratings, final	1.5 ± 0.6	-	-
	Ratings, difference	-	-	-
Lower Back	Ratings, final	5.3 ± 0.8	2.5 ± 1.1	4.2 ± 1.1
	Ratings, difference	4.5 ± 0.8	-	-
Hips and Thighs	Ratings, final	-	-	-
	Ratings, difference	-	-	-
Knees	Ratings, final	1.8 ± 0.8	-	-
	Ratings, difference	-	-	-
Feet	Ratings, final	-	-	-
	Ratings, difference	-	-	-
Combined Sum	Ratings, final	15.6 ± 3.0	12.5 ± 4.0	11.8 ± 4.0
	Ratings, difference	13.8 ± 3.0	-	-

4.5.10 Relationship between ergonomic exposures and work-related MSDs

The study was not sufficiently powered to determine statistically significant relationships between most of the exposure variables and musculoskeletal disorder ratings except for a regression model which tested relationship between a sum of ordinary walking (walking without pulling a cart) plus working with the hands below the waist and lower back pain rating among collectors. This is

presented as an example of the possible associations that could be explored with a larger sample size.

The model showed a significant relationship (p=0.001) between the combined duration of collectors walking without a cart plus durations spent working with the hands below the waist and lower back pain (see Figure 4.5.2).



*P<0.001, R^2=0.717

Figure 4.5.2: Relationship between duration spent in walking + working with the hands below the waist and lower back pain.

CHAPTER 5

DISCUSSION

5.0 Introduction

The major findings for each of the 5 studies conducted in this thesis are briefly discussed and then integrated into a general discussion in line with the general aim of this thesis. The ergonomic risk factors and work-related MSDs associated with informal e-waste recycling at Agbogbloshie were estimated and an observation-based assessment method adapted to unregulated and unstructured work in an informal sector developed to determine exposure and its association with MSDs.

5.1 Demographic characteristics of participants

E-waste workers in this research were mostly dismantlers and collectors. The fewer number of burners may have been due to most workers shunning away from burning tasks due to the large volume of fumes generated from burning (Acquah et al., 2019; Amoabeng Nti et al., 2020). E-waste workers in this study were also noticed to occasionally performed e-waste recycling jobs other than their primary job. For example, a dismantler who did not have enough items to dismantle may assume a collecting role and go out into the community in search of more e-waste items to dismantle. Likewise, a burner not having items to burn may assume a dismantling role by helping other dismantlers at a fee or in exchange for some of the extracted metal. These irregular alternations may present the benefit of job rotation (Coşgel & Miceli, 1999; Frazer et al., 2003) but highlight the loose work organisation and social structure which poses a challenge in quantifying exposures among these workers.

Our study also confirmed prior reports that e-waste recycling at Agbogbloshie is performed almost uniquely by men (Akormedi et al., 2013). Akormedi et al. (2013) attributed the absence of women to the high physical demands of manual e-waste recycling and reported that women opted for less strenuous supportive roles such as food and water vending for drinking or cooling burnt items. The worker cohort were also relatively young with a mean age in the low twenties and 15.3% of the study cohort in objective 2 comprising of minors. All of these minors were collectors assisting more senior workers to scavenge and collect e-waste items. They were observed helping them push the hand-drawn cart from the rear. It is typical for entry-level workers who came to the e-waste site at Agbogbloshie to assist other workers until they gain some experience and build enough capital prior to working on their own. The substantial proportion of minors working at the site is particularly concerning since Ghana is a signatory to multiple international agreements that prohibit child 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).

Experience for the study cohort was least among collectors and highest among dismantlers. This difference could result from the progression aspiration of collectors and potentially burners toward more technical and lucrative roles of dismantlers over time. Collecting of e-waste involves a lot of walking (e.g., over 75% of collectors performed over 10,000 steps daily) with low certainty of obtaining any e-waste items on any day.

E-waste recycling was performed any 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.

5.2 Description of the processes and challenges associated with e-waste recycling

This objective was a first step to describe the processes involved in e-waste recycling at Agbogbloshie, Accra, Ghana, as well as to explore the health and psychosocial challenges encountered by workers in an informal, unstructured, and unregulated sector.

5.2.1 The processes involved in manual e-waste recycling at Agbogbloshie

E-waste collecting, dismantling, and open-air burning are the primary activities used to retrieve essential metals from e-waste during the recycling process (see Figure 4.1.2). The e-waste recycling process relies on the use of simple manual tools such as human-pulled collection carts; hammers, chisels, spanners, and screw drivers for dismantling often without the use of PPEs. Furthermore, those engaged in burning use long metal rods or pipes to roll or move electrical cables during the burning process until plastic coverings are completely burnt, thus exposing blackened copper wires. These inexpensive methods, exposes workers to high risks of musculoskeletal injury.

5.2.2 Health and psychosocial challenges of e-waste recycling

Body pains due to the effect of physical activities was a major health challenge reported among workers. E-waste recycling at Agbogbloshie was observed to entail multiple instances of manual material handling (e.g., lifting, carrying, pushing/pulling), forceful exertions, and prolonged periods of work in non-neutral postures such as bending and twisting (see Figures 2.2, 2.3, 2.4).

Body pains have been associated with other work activities involving use of physical force and less machinery (Wai et al., 2010) and cumulative trauma disorders (Chaffin et al., 2006; Iqbal & Alghadir, 2017; Silverstein et al., 1986). In an attempt to manage their pain, e-waste workers resort to excessive use of self-prescribed pain medications. The over-dependence and inevitable abuse of these medications is a worrying health concern. In the past few years, media reports in Ghana have indicated a surge in Tramadol abuse (GhanaWeb, 2018), which was particularly evident during our field observations. Workers were seen mixing Tramadol with energy drinks and consumed the mixture during work. During personal interviews, these workers indicated that these formulations helped them to work for longer periods without experiencing body pain or fatigue. The self-medication habits as well as the possible abuse of tramadol may result in long term health consequences.

The associated health challenges of e-waste recycling made it difficult for worker to cope with their job. Workers reported the recycling process to be physically demanding and stressful and expressed great dissatisfaction with their jobs. Although e-waste recycling provides some form of livelihood, little income is earned by workers despite the excessive physical demands of the job. Psychosocial risk factors such as high job demands and low job satisfaction have been shown to increase the level of stress of workers and subsequently increases their chances of experiencing MSDs (Bongers et al., 1993; Netherlands Organisation for Applied Scientific Research, 2017). Hence, it is assumed that, some of the psychosocial challenges experienced by e-waste workers at Agbogbloshie may have a bearing on the musculoskeletal symptoms experienced by these workers.

In conclusion, the rudimentary methods used in recycling predisposes e-waste workers to physical risk factors leading to undesirable health implications such as musculoskeletal pain and risk of cumulative trauma disorders. However, the exact nature of the physical work exposures and related prevalence of work-related MSDs in this specific work domain are not known. Further, the different work processes identified, namely, collecting, dismantling, and burning, may present distinct physical exposures that might have different implications for workers engaged in these respective tasks. Thus, investigating the physical exposures of e-waste worker to better understand the work-related physical hazards that predisposes workers to MSDs is critical.

5.3 Assessment of e-waste occupational physical activity exposures

In a second step the self-reported physical activity of e-waste workers at Agbogbloshie based on the occupational physical activity questionnaire (Reis et al., 2005) complemented with direct field observations was used to estimate the prominent exposures for the three main categories of workers (collectors, dismantlers, and burners) and to some extent occasional exposures due to alternation in activity. PA exposures differed substantially between job categories.

5.3.1. Occupational physical exposures of e-waste workers

Self-reported sitting, standing, walking, and performing manual material handling activities such as carrying, lifting, and pushing/pulling of collection carts differed by primary job category. Prolonged sitting was most frequently reported among dismantlers, who assumed very non-neutral seated postures from sitting on a low stool or a non-functional appliance, with excessive forward flexion, and twisting of the trunk while dismantling appliances at ground level. Burning on the other hand entailed a lot of standing. Thus, it was not surprising that 95% of burners reported

standing continuously for 1 hour or more during a working day. Standing during burning of e-waste was observed to be compounded with forward flexion and twisting of the trunk which could result in increased low back muscle fatigue, high spinal disc compression and shear forces, and an increased risk of low back disorders (Chaffin et al., 2006; Marras et al., 1998; Marras & Granata, 1995). Walking for long periods was characteristic among collectors. Furthermore, collectors pulled along a hand drawn collecting cart over uneven, unpaved terrain in harsh outdoor environments including hot and humid climate which compounded their health risks (see Figure 2.5 and Figure 4.1.2A). Pedometer data corroborated findings from self-reported walking indicating higher median step counts in collectors compared to dismantlers and burners. The difference in step counts, distance walked and energy expenditure measured using the pedometer was, however, not-statistically significant across the three job categories. The lack of statistical significance could have been due to the small sample size of participants (42 out of the 163 participants) used in this subsection of the study as well as some workers occasionally performing more than one job (e.g. burners doing collecting tasks and collectors doing dismantling tasks).

All e-waste workers reported performing manual material handling activities frequently within the day. Objective 2 provided a necessary overview of work characteristics, but did not quantify exposure in terms of magnitude and duration due to the inherent limitations of self-assessment questionnaires. Furthermore, the validity of self-reported exposure data is limited due to potential recall bias, i.e., it relies on participants' ability to recall information about past exposures to different work activities performed. This is particularly challenging in non-routine work, wherein the exposures vary considerably among workers, and for the same worker from day to day.

In conclusion, from a methodological perspective, the current study used to address objective 2 draws attention to the need for new, validated methods to measure physical work exposures among workers engaged in informal e-waste recycling. The key findings from objective 2 were indications of high variability in sitting, standing, walking, and performing manual material handling activities among e-waste workers. Importantly, the corresponding exposure levels differed substantially between primary job categories. Furthermore, the variability in physical work exposures between days, within workers, and between workers in the same job category may be fundamental characteristics of unstructured and unregulated work, which may complicate exposure evaluations and associations between risk factors and MSDs. Suitable exposure assessment methods that can accommodate and account for such variability are needed. Objective 2 thus, provided important lessons and motivation for subsequent studies in this thesis to objectively quantify physical exposures and associated work-related MSDs in the informal e-waste recycling sector by developing an ergonomic assessment tool tailored for unregulated and unstructured work.

5.4 Prevalence and severity of self-reported MSDs

After describing the processes (objective 1) and a preliminary approach to estimate major exposures and exposure patterns (objective 2), objective 3 focused on investigating the prevalence of MSDs among e-waste workers in comparison to a reference population of residents at Madina Zongo known to be engaged in less physically demanding jobs. The self-reported prevalence, severity as well as the level of interference of MSDs with work output were compared among the three e-waste job categories and the reference population.

5.4.1 Prevalence of musculoskeletal disorders

Supporting our hypothesis, the prevalence of MSDs was significantly higher among e-waste workers than the reference population. The disparity was likely due to the physical stresses associated with e-waste recycling compared to less physically stressful jobs among the reference population. As reported in objective 2 (assessment of e-waste PA exposures), e-waste workers are exposed to frequent force exertions from material handling, non-neutral work postures, and prolonged durations of, walking, standing, and sitting low to the ground (e.g. squat posture see Figure 4.1.2B). These activities, commonly coupled with repetitive movements of the upper extremity, and twisting and bending of the torso, are known to cause MSDs (Chandrasakaran et al., 2003; Iqbal & Alghadir, 2017; Kang, et al., 2014; Latko et al., 1999; Musa et al., 2000; Wai et al., 2010a; Werner et al., 2005).

MSDs were significantly more prevalent in the upper limbs among dismantlers (33%) and in the lower limb among collectors (47%). Dismantling of e-waste involves activities such as screwing/unscrewing, hammering, and chiselling that require high force exertions and repetitive movements, which are known risk factors for developing MSDs (Iqbal & Alghadir, 2017; Kang et al., 2014). Conversely, Collectors were involved in prolonged walking over uneven terrains in strenuous environmental conditions while pulling along a collection cart (see Figure 4.1.2A), which is expected to induce a high stress on the lower weight-bearing joints, namely, the knees and ankles. It was therefore not surprising that collectors reported high prevalence of lower limb MSDs.

Low back pain was the most prevalent MSD reported among all three e-waste job categories (66%) as well as in the reference population (51%). Low back pain is one of the most common MSD

reported among various work populations (Deyo et al., 2006; Meucci et al., 2015; Parno et al., 2017). Prior studies have similarly reported a high prevalence of low back pain among informal waste collection and processing workers (Emmatty & Panicker, 2019; Ohajinwa et al., 2018) as well as e-waste workers (Fischer et al., 2020). Hence, the present study sample was no exception to this general trend. One common characteristic between the e-waste worker sample group and the reference population is that both groups may be exposed to prolonged sitting and standing, which are known risk factors for low back pain (Chandrasakaran et al., 2003; Hoogendoorn et al., 1999; Levine, 2015; Musa et al., 2000; Roffey et al., 2010).

5.4.2 Frequency, severity, and level of interference of musculoskeletal disorders with e-waste recycling activities

About half of the workers who reported high frequency of MSDs (i.e. 5 or more days within the week) were collectors. In the same vein, collectors reported higher severity and level of interference of MSDs with their work than dismantlers or burners. This difference may be attributed to the long durations of walking and pushing/pulling of carts, as well as frequent loading and offloading activities at vending (to recyclers) and buying (from sources) locations. Average working duration of 10.3 ± 1.8 hours were reported for collectors. In addition, about 75% of collectors walked as much as 6 km per day in search of e-waste items. This is quite a significant distance to be walking outdoors over uneven terrain and often while pulling along a heavy cart.

In addition, collectors are likely to work more days in a week compared to burners and dismantlers since their success at finding e-waste items is highly unpredictable and they may return empty-handed on some days resulting in low to no income compared to the other categories of worker (Acquah et al., 2019). Furthermore, unlike dismantlers and burners, collectors cannot build a

stockpile, which allows workers in the former categories to work while supplies last or rest when the stock is out. Hence, longer hours and more days of work may promote a higher risk of MSDs for collectors than dismantlers or burners.

However, despite the high prevalence of MSDs, 38% of the study participants did not report any interference with their work. E-waste workers at Agbogbloshie, have a persistent motivation to work and make ends meet despite the adverse effects of their job. As such these workers are likely to push themselves to the limit and prevent pain and discomfort from interrupting with their work, which is assisted by abuse of self-medication (Acquah et al., 2019) , as indicated in objective 1. Personal interaction with some of the workers during data collection at the e-waste site revealed that occasionally workers are unable to cope with the harsh working conditions despite all attempts to alleviate pain. As a result, they resort to staying off work for a longer period to allow recovery from their injuries although this comes at the risk of losing income.

5.4.3 Correlates of MSDs

Objective 3 also examined relationships between demographics, occupational history of participants and the occurrence of MSDs. The prevalence of MSDs was positively associated with the number of work hours per day. The presence of MDSs was 1.43 times higher among those who worked 11 - 15 hours/day compared to those who worked 0 - 5 hours /day. Similar associations between MSD prevalence and hours worked were also reported in a study of nurses by Lipscomb et al. (2002). In addition, the presence of MSDs promotes fatigue which decreases productivity (Daneshmandi et al., 2017), which for e-waste workers is likely to result in a substantial loss of a revenue which is already limited.

A significant association between job categories and the development of MSDs was also observed. When compared to the reference population, the risk of developing MSDs was 1.6 times higher for collectors and 1.4 higher for dismantlers, which in the long term could result in work disability, high cost for treatment/rehabilitation as well as a reduction of their valuable working time (Buckle, 2005). In turn, the long-term effects could render disabled workers dependent on friends and family in the absence of any other safety net (e.g., workers compensation, social security income).

The study used to address objective 3 was a cross-sectional study and as such was unable to investigate the incidence of MSDs as could have been achieved in a prospective cohort study. The unstructured and informal work setting at Agbogbloshie poses a great challenge in investigating incidence of MSDs. This is due to the fact that, most e-waste workers originating from the Northern part of Ghana and occasionally travel back home seasonally to farm or visit their families during religious festivities thus making it difficult to follow workers over a prolonged period. Again, MSDs in this study were self-reported which introduces some subjectivity in participants' responses compared to an objective medical examination by qualified medical personnel. This objective assessment approach is however costlier and more time-consuming and would have been difficult to achieve during the limited study period. Self-reported assessments of MSDs however have been used in several studies (Abou-ElWafa et al., 2012; Azma et al., 2015; Jansen et al., 2012; Reddy & Yasobant, 2015) and have provided reliable results especially where standardised assessment tools were used, thus influencing the use of the Cornell Musculoskeletal Discomfort Questionnaire in this study.

In summary, the prevalence of self-reported MSDs was higher for e-waste workers at Agbogbloshie than the reference population who perform less physically demanding jobs. The

high prevalence of MSDs was associated with long work durations and differed significantly among primary job categories. Compared to the reference population, e-waste collectors and dismantlers had a significantly higher risk of developing MSDs however the body regions affected by disorders were different. These findings suggest differences in the work content and related physical work exposures. In order to reduce the high occurrence of MSDs among e-waste workers, a detailed investigation of the physical risk factors that lead to MSDs is necessary. Such an investigation would need to acknowledge potential differences in work durations and exposure variables between and within e-waste job categories.

5.5 Development of an ergonomic assessment tool for use in an informal work setting

A novel observation-based method adapted to the context of a developing country was developed to quantify in real time, ergonomic exposures in unstructured and unregulated type of work such as e-waste recycling. The inter-observer agreement as well as preliminary data coded in real-time indicates that the developed tool provides adequately reliable and valid information necessary to estimate physical work exposures associated with informal e-waste work.

Inter-observer agreement for upper and lower limb postures was high since the coding scheme allowed for easy identification and classification into a few distinct categories. However, visual coding of trunk postures (as well as other factors) in real-time (every 60s), which required discrimination between neutral ($<20^0$ flexion) and slight trunk flexion (between 20^0 and 45^0) was more challenging and susceptible to misclassification resulting in lower agreement between observers. The misclassifications were random (i.e., some variables over estimated and others under estimated) among observers.

Other common coding misclassifications were related to the presence or absence of contact stress and vibration, especially for burners. These risk factors were easily identifiable among dismantlers since their tasks were performed with high force intensity using hammers and chisels while burners predominantly exerted low forces most of the time. Repetition was not easy 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, the observers during the training period had to get familiar with visual approaches to quickly and easily estimate these counts effectively. Additional instructions and heuristics during training for observing and recording information about repetitions may be warranted. Finally, judging moderate vs. severe force was also a challenge for observers, which is an issue for observational coding of hand forces into multiple nominal categories (Latko et al., 1997). A potential resolution may involve coding hand forces into a binary variable, e.g., low vs. high, in order to reduce coding time and improve inter-observer agreement.

The 60s sampling is based on recommendations by Buchholz et al. (1996). When quantifying physical exposure, direct observations are usually done at 45 or 60s sampling interval; with 45s being the minimum duration required to maintain reliability (Buchholz et al., 1996; Paquet et al., 2001). This study however adopted 60s based on two reasons. 1) The variables observed in this study were more than those assessed in PATH which used 45s observation intervals; thus, this study needed ample time to make good judgement on risk factors assessed influencing the choice of 60s observation intervals. 2) This study used a pen and paper-based approach and as such part of the time was consumed by documenting observations on paper. During initial development phase of the tool, both 45s and 60s were tested but 60s was more ideal based on the reasons explained above. The full work day was observed compared to observing only a portion of workers

shift due to the high variability in work content. In e-waste recycling, workers perform different tasks at different time schedules across worker categories compared to the uniform work pattern observed in office work environment as well as some factory assembling lines. Thus, sampling only a portion of workers' shift will not be representative of their actual work content. It was also important that at the initial phase of this tool development, the full work day is observed. The findings from objective 4 and 5 (e-waste ergonomic risk factors assessment) could be used to simplify the assessment tool better to provide a more thoughtful and systematic work sampling strategy that is tailored to e-waste work at Agbogbloshie. The new tool provided a more reliable and objective assessment of physical exposures that was not possible with the OPAQ used in objective 2. In addition, compared to other observation tools like PATH which required 30 hours of training (Buchholz et al., 1996), this tool requires less training duration and is easier to quantify exposures based on the simplified coding guide provided and sampling strategy used.

Objective 4 however, only focused on inter-observer reliability (agreement) of the tool. Assessment of intra-observer agreement, would have required observers to code the same content again after 1-2 weeks and the results compared with the initial assessment. This however, would require video-based coding and was not possible in real-time observations. Likewise, accuracy of the observation coding would require objective ground-truth data for comparison; which presents some challenges in the particular work environment. However, this may be the focus of future studies, particularly if guided by knowledge of which specific dimensions of exposure variables (i.e., intensity/magnitude, duration, and/or repetition) are most relevant in terms of their association to MSD risk.

In summary, the newly developed tool was effective in capturing in real-time the relative duration and intensity of key risk factors. Specifically, the developed tools yield information on broader range of exposure variables and with more specificity compared to the self-reported occupational physical activity questionnaire used in objective 2 (assessment of e-waste PA exposures). The observational exposure assessment tool allowed to adequately estimate the duration of sustained 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 takes into account the variability in work days durations between and within workers; which makes this tool amenable to unregulated work environments. In addition, 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. Thus, this tool was essential in evaluating the relationship between ergonomic exposures and work-related MSDs in objective 5.

5.6 Assessment and comparison of ergonomic risk factors and MSDs among e-waste workers

Objective 5 was to assess and compared the physical/ergonomic exposures associated with e-waste recycling and work-related musculoskeletal discomfort among the three main e-waste job categories using a direct field observation method developed in objective 4. Variability in active work durations and physical exposures within and between job categories was quite high. Taking into account variability, the analysis performed in this study revealed the most important factors

the different categories of workers were exposed to and the MSDs they were affected by as illustrated in Tables 4.5.3 and 4.5.4.

5.6.1 Physical/ergonomic exposures among e-waste workers

Physical exposures differ significantly between job categories, as crudely envisioned from objective 2. Dismantlers were exposed to prolonged durations of non-neutral postures from sitting low (hip and knees joint angles < 90°) as well as moderate to severe trunk flexion from bending over to reach work parts placed on the floor (see Figure 2.3). Another unusual exposure of dismantlers captured in this study was the prolonged duration of force exertion with the lower-legs and feet to hold work items on the ground. This working posture, included acute hip flexion and internal rotation of the leg with hip adduction. Occasionally, dismantlers may also stand bent over to dismantle items such as engine blocks resting on the ground (see Figure 2.3). Dismantling is done with basic tools such as chisel and hammer which subjects workers to contact stress and vibration in highly repetitive movements of the upper limb holding the hammer. Vibration was a risk factor specific to dismantlers. Although some minimal vibration could have been transmitted to the hand of burners when using their rod/stick to hit burning items repeatedly, this exposure was judged negligible in terms of duration or magnitude.

Burners were primarily exposed to standing with severe trunk flexion and high repetition. Burning involves prolonged standing by open air fires (see Figure 2.4) while using either a long metallic rod or a wooden stick to turn burning items (Acquah et al., 2019). After burning was completed for a pile of items, mostly copper wires, burners used short sticks to stir the remains while searching for small pieces of metals fallen on the ground during burning. This activity was done with severe trunk flexion to reach the ground and repetitive movement from frequently stirring the

burning remains as well as picking and sorting out items with the hands. Occasionally, burners needed to produce high force exertion from turning a huge pile of burning wires; However, force exertion was generally lower for burners than collectors or dismantlers.

The primary exposure among collectors was walking while pushing/pulling a loaded cart (see Figure 2.5 and Figure 4.1.2A). Pushing/pulling of a loaded cart is accompanied with high force exertion and contact stress. In addition, a bent over working posture as well as having the hands below the waist was observed most of the time among collectors. Bent over postures (trunk flexion) were rather severe during loading items onto the collecting cart or offloading from the cart to the floor, and more moderate when pulling the cart. However, trunk flexions were of shorter duration for collectors than dismantlers and burners due to the time distribution of activities.

Some physical exposures were common to all job categories. Among these were non-neutral neck postures which were of a similar total duration of about 200 minutes. However, when considering the total work time these 200 min represent 80 to 100% of work time for dismantlers. Furthermore, for these latter, non-neutral neck postures were induced by the awkward seated posture (low sitting with severe to moderate trunk flexion) which required neck flexion, bending and rotation to maintain visual control of their task. In some instances, the neck was bent laterally to avoid the hammer trajectory. For collectors, neck flexion and rotations were highly variable between days and were primarily driven by the torso flexion used to pull their heavy cart and looking out for traffic and pedestrians. However, these non-neutral postures were relatively less prominent in terms of percentage of work time, when compared to dismantlers and burners. Non-neutral neck postures for burners were mainly observed while burning to control the process taking place on the ground and while searching for residual metal fallen to the ground during and after burning.

Working with the hands below waist was also common to all workers: to recover items on the ground by burners, work on parts on the ground by dismantlers as well as lift parts from the ground for collectors. These were often accompanied by moderate to severe trunk flexion. Working with the hands below the waist is outside the preferred working range i.e. between the shoulder and waist height often referred to as "the power-zone". Working outside of the "power-zone" coupled with repetitive movements of the upper extremity as well as twisting and bending of the torso are known to cause MSDs (Chandrasakaran et al., 2003; Iqbal & Alghadir, 2017; Kang, et al., 2014; Latko et al., 1999; Musa et al., 2000; Wai et al., 2010a; Werner et al., 2005). In general, e-waste workers rarely performed their tasks with their hands above shoulder height.

Comparing results from self-reported lifting and carrying in objective 2 and observed lifting and carrying in objective 5, e-waste workers over estimated their lifting/carrying activities. Between 68 to 96% of e-waste workers in objective 2 reported handling a maximum weight greater than 20kg in a work week; However, this was not the case (see in Appendix 7.11D figure illustrating workers active time spent in lifting/carrying activities). Collectors predominantly handled moderate weight (6-10kg) while dismantlers were more likely to handle heavy weights (11-20kg) and burners light weight (5kg or less). Workers were seldomly observed handling very heavy weights (20kg) although this may be done occasionally. In addition, durations of lifting or carrying activities were brief for all workers irrespective of the weight handled. Over estimation of self-reported lifting and carrying was not surprising as this is one of the known drawbacks of self-reported assessment methods reported in literature (Neitzel et al., 2013).

Overall, the observational method allows to characterize exposures with some precision in terms of duration, magnitude, and body part. The outcome of the analysis also delineates differentiations

between job category that need to be considered when investigating the relationships between exposures and MSDs.

5.6.2 Comparison of direct observation assessment of physical/ergonomic exposures with self-reported data

A direct observational approach was used in objective 5 to quantify the physical/ergonomic exposures of e-waste workers, as opposed to the use of a self-reported questionnaire approach in objective 2 (assessment of e-waste PA exposures). Direct observation is very laborious and time consuming compared to using self-reported data from questionnaires. Direct observation is however, rewarded by the benefit of better and a more objective quantification of ergonomic exposures in a characteristically unstructured unregulated type of work. Duration and magnitude of physical exposures could be estimated and body parts involved more specifically identified. Objective 5 also addressed the challenge faced by some participants to recall durations and key tasks performed as well as total work duration per day. In addition, objective 5 assessed exposure to non-neutral posture, forceful exertion, repetitive movements, contact stress, and vibration which are more difficult or impossible to assess with a questionnaire. Hence the comparison of studies conducted in objective 5 and 2 exposes and/or confirm the limitations of the OPAQ.

In addition, drawing from preliminary studies in objectives 1 and 2, the sampling strategy adopted in objective 5 which included multiple observation days and number of workers per categories helped to exhibit and quantify variabilities in term of exposure time, type of dominant exposure, and average magnitude of exposure among workers. Therefore, by considering variability, objective 5 helped distinguish risk factors that differed across job categories.

5.6.3 MSD rating by individual body regions and cumulative body regions

Changes in MSD ratings from before to the end of the work sampling week were significant for all worker categories in objective 5. Combined final MSD ratings were highest for collectors than dismantlers and burners. This finding was not surprising as results from objective 3 (prevalence of work-related MSDs) showed a high risk of MSDs for collectors. Also, findings from objective 3 indicated a high frequency of occurrence (5 or more days in a week) and severity of MSDs for collectors. These results are compatible with the longer work days and greater number of work days for collectors as work duration is a significant factor in the development of MSDs (Lipscomb et al., 2002).

The average difference in low back pain severity rating between the beginning and the end of the observation week exceeded 3 points on the 10-point scale for collectors and dismantlers. High ratings were expected considering the frequent twisting, turning and sustained bending of the lumbar spine observed for these workers, which are associated with the development of low back work-related MSDs (Chandrasakaran et al., 2003; Musa et al., 2000; Wai et al., 2010a). This result is in agreement with the prevalence of MSDs reported by e-waste workers in objective 3 and with similar findings from other studies reporting high prevalence of low back pain among informal waste workers (Emmatty & Panicker, 2019; Fischer et al., 2020; Ohajinwa et al., 2018).

Another clinically relevant change in MSD rating concerned shoulder pain in collectors and dismantlers, which was also expected due to the high force high repetitive movement of the upper limb during dismantling and the sustained shoulder extension observed among collectors while pulling a loaded cart.

Overall, MSD findings in objective 5 corroborated findings from objective 3 and these findings agreed with findings from the available literature. Musculoskeletal disorders ratings were highest for the low back both between and within worker categories; with the highest rating reported by collectors.

5.6.4 Relationship between ergonomic exposures and MSDs

A significant association between the combined walking and working with the hands below waist and low back pain was observed for collectors. This is not surprising according to the high prevalence low back pain for collectors, as indicated above.

Other statistical models exploring associations between physical exposures and MSD ratings did not show any significant relationships although some correlations were expected based on the available literature (Chandrasakaran et al., 2003; Musa et al., 2000; Roffey et al., 2010; Darren M. Roffey et al., 2010; Wai et al., 2010b; Wai et al., 2010a). The small sample size as well as the high variability in exposures across job categories made it challenging to combine exposures within different job categories into a meaningful statistical model. The multiple days of observations (117 days in all) together with having to observe workers over the entire work day made it challenging to recruit more participants for this study; considering the limited time frame available for data collection in objective 5 and the small number of trained observers.

This study, which is the first to quantify ergonomic exposures among e-waste workers in Agbogbloshie, provides many lessons to retain and ground work necessary for the improvement of future ergonomic assessment studies in unregulated unstructured type of work. This work shows that in such context, prior observation-based knowledge is essential to determine the most relevant

physical exposures among e-waste workers in order to facilitate and simplify the assessment of risk factors in real time using the developed tool. Thus, future assessments can be adapted to focus on recording exposures specific to worker categories. This will speed up the process and free time to enlarge the sample size to be used. Finally, the present study considered a simple aggregation of risk factors, which most likely limited the prediction of MSDs based on a linear score. A cumulative ergonomic score adapted to the context of unregulated and unstructured work needs to be developed to improve MSDs predictions based on exposure quantification.

5.7 General discussion

E-waste recycling at Agbogbloshie is characterized by high and frequent/long duration exposure to ergonomic risk factors associated with a high prevalence of work-related MSDs. The recycling process employed by workers were rudimentary, informal, unstructured and unregulated which introduces a high level of variability in tasks performed and associated exposures. The high level of variability in tasks as well as variability in the type, duration, intensity, and frequency of exposures makes the assessment of these exposure using regular ergonomic tools/methods particularly challenging. Regular ergonomic assessment tools/methods such as RULA, REBA, OCRA, and OWAS are primarily designed for well-structured and regulated work. This thesis contributed to the development of a low cost adaptable observational method, easy to use and effective in quantifying ergonomic exposures in unstructured and unregulated type of work such as e-waste recycling at Agbogbloshie.

The findings of this thesis indicated an alarming prevalence of work-related MSDs and especially pronounced low back pain among e-waste workers. This high prevalence appears as a direct consequence of the poor work methods and tools used. Amendment of work strategies and

education of workers on the implications of poor working methods should help workers to develop a more enlightened approach towards work. Work modifications such as using cable strippers to recover copper from wires instead of open-air burring; dismantling of e-waste on elevated surfaces with clamps in place to hold items being dismantled and the use of motorised transportations such as tricycles will help reduce MSDs and other adverse health consequences of e-waste recycling. However, some solutions, even possible in the context of Agbogbloshie, may come at some cost that workers may not be able to afford or may not want to consider as they may reduce their already low income. A discussion about social and financial issues is beyond the scope of the present work.

Furthermore, although the present study provided an efficient method in assessing ergonomic exposures among unstructured unregulated type of work, the new tool needs further improvements to enable its adoption and wide use by ergonomists. An essential component required in the new tool is the development of a unified scoring system which combines all the exposure variables into a single score predictive of MSDs.

In summary, this thesis highlights the ergonomic risk factors that predisposes e-waste workers to MSDs. Important among these risk factors were non-neutral neck postures, severe trunk flexion, high force exertion, repetitive movements and contact stress. The need for ensuring safer work methods to, at least, reduce the impact of the hazardous recycling processes currently used in e-waste recycling at Agbogbloshie is evident. The thesis also demonstrated how these risk factors differ among collectors, dismantlers, and burners in terms of the type of exposure, and its duration, intensity/magnitude, and repetition. This has direct implications for prioritizing and tailoring interventions to specific job categories in an otherwise resource constrained work environment. That notwithstanding, the lack of needed financial, social and governmental support required to

address the increasing problem of e-waste recycling, has impeded the process for change. Appropriate stakeholder engagement may be required to bring some urgent attention to the needs of these workers. Some suggested recommendations to address the challenges with e-waste recycling at Agbogbloshie are outlined in Chapter 6.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This concluding chapter summarizes the thesis and draws conclusions based on research findings, as well as make recommendations, highlighting on contribution to current knowledge and make suggestions for further studies.

The rapid assessment tool developed in this study, although simplified compared to other existing tools facilitated relatively quick assessment of ergonomic exposures using only pen and paper. The tool proved to be efficient at generating exposure profiles tailored to informal e-waste recycling, providing more detail than existing self-reported and observational exposure assessment tools (e.g., OPAQ used in objective 2). Importantly, the tool enabled the identification of the risk factors that were most relevant for each job category while also able to determine the variability in type, duration, intensity and frequency of different ergonomic exposures.

The physical nature of e-waste recycling expose workers to a myriad of ergonomic risk factors such as non-neutral postures, forceful exertion, repetition, contact stress and vibration over long periods. The type, duration, and intensity of these exposures differed substantially between primary job categories and were responsible for high prevalence of work-related MSDs among e-waste workers in Agbogbloshie.

Although workers were unsatisfied with the tedious nature of their job and the associated musculoskeletal discomfort as well as the harsh environmental conditions they work in, the

absence of alternate forms of livelihood compels workers to continue this occupational activity. Implementation of context-adapted ergonomic interventions that will help reduce the adverse occupational effects of e-waste recycling are essential for creating a healthier and conducive work environment. Simultaneously, there is the need to disseminate information to teach adapted practices to the workers.

6.2 Recommendations

The following recommendations are made in the context of unstructured, unregulated e-waste recycling in a developing country.

6.2.1 Public Health recommendations

The ultimate recommendation for reducing work-related MSDs according to the European Agency for Safety and Health at Work is to "avoid musculoskeletal disorders. Although a laudable suggestion, this may be challenging for e-waste workers at Agbogbloshie. As an alternative suggestion, e-waste workers can be educated on basic ergonomic work practices (e.g., safe lifting), early detection and treatment of work-related injuries (e.g., modulating workload vs. rest breaks, recovery periods) and subsequently encouraged to seek medical care as well as adopt simple solutions built with available "things" to reduce some risks. For example, using a large object with a flat surface as a table/support can help reduce torso flexion; using an object to sit on may favour alternation between standing and seating. Medical care for work-related injuries could be facilitated by the Ghana Health Service through the newly built health post at Agbogbloshie.

Effective use of personal protective equipment should be promoted to help reduce ergonomic risks among e-waste workers. Use of basic PPE should be encouraged to help reduce ergonomic risk

factors. Consistent with this, the use of gloves which could prevent or reduce hand vibration and grip forces during tool use or pulling/pushing of a collecting cart should be encouraged. Where possible, environmental protection organisations should support e-waste workers who cannot afford these PPEs to aid their work and reduce health consequences.

Furthermore, it may be beneficial to the environmental and health sectors of Ghana to invest into simple and cost-effective engineering solutions that provides e-waste workers with efficient working tools that present less health risks. Other simple ergonomic solutions that could be adopted include using of cable strippers to extract copper from insulated wires rather than burning and encouraging the use of motorised collecting carts such as tricycles so as to reduce excessive walking by collectors. In additions, introduction of job rotation strategies may also help reduce physical exposures. For instance, this research revealed that burners are exposed to prolonged standing and severe trunk flexions, thus they could rotate jobs with collectors who are exposed to walking and slight trunk flexion. Such alternation will reduce the respective exposures.

6.2.2 Policy recommendations

The Government of Ghana through the environmental protection agency could strengthen laws and policies that govern importation of end-of-life electronics into the country as this is one of the major sources of electronic waste in Ghana. In addition, a comprehensive injury prevention policy should be designed and implemented, keeping in mind the available resources and technology, work conditions as well as socio-cultural background of e-waste workers so as to improve compliance to these policies. Furthermore, the government and the relevant agencies should advocate against the engagement/employment of minors in e-waste recycling.

As an additional step, formalising of e-waste recycling in Ghana may be a major step towards improving the infrastructure and techniques required to manage e-waste. This will also pave the way for implementing structured ergonomic interventions aimed at reducing occupational hazards without the loss of productivity and also promote work safety standards.

6.2.3 Future research recommendation

Further studies that prioritises the reduction of specific physical exposures among e-waste workers at Agbogbloshie are needed. To achieve this, further implementation/refinement of the assessment tool used in this thesis is recommended. The present thesis has provided sufficient data that will guide refinement of the tool to improve its efficiency and usability in ergonomic risk assessments. The new tool needs to be simplified further to focus more particularly on the risk factors most relevant to specific job categories based on the findings from objective 4 and 5. This will help speed up the observation process and enable more participants to be assessed within the available time frame. Furthermore, the questionnaire and assessment approach used to identify MSDs and their respective severity requires attention. The use of questionnaires may have contributed to uncertainties in the reporting of MSDs among some workers. Thus, future studies should explore the use of more objective medical assessment of MSDs among e-waste workers.

In addition, the pen and paper-based method used in this thesis needs to be developed further into a version that can be used on tablets and other portable computer devices. This will provide a quick and easy way to assess ergonomic exposures and also significantly reduce data processing time so as to provide quick information on ergonomic risks to inform decision making processes. Furthermore, a scoring system that provides a risk score predictive of MSDs needs to be developed to allow easy interpretation of results while using the new tool.

Assessment of the relationship between ergonomic exposures and work-related musculoskeletal disorders (objective 5) needs to be repeated with a large sample size that provides the statistical power needed to detect possible associations between ergonomic exposures and the risk of developing MSDs.

Finally, it may be important for future studies to investigate interactions between environmental issues such as exposure to toxic substances and physical exposures as these were estimated separately as part of a broader study. Other issues such as nutrition are also worth considering.

6.3 Limitations

The unstructured nature of e-waste recycling at Agbogbloshie made it difficult to apply probability sampling to this work. Hence, non-probability purposive sampling was adopted. Probability sampling ensures a representative sample whereas non-probability sampling may be biased in selection of a representative sample. To minimise selection bias, participants in this thesis were sampled at different locations within the e-waste site representing areas where the various recycling activities were performed (i.e., burning site, dismantling site and collectors waiting area). Participants were also observed on multiple days to obtain a sample representative of their work.

The trade-offs in number of workers observed as well as number of days per worker observed in order to account for variability in exposures resulted in a small sample size in Study 5. A key factor that influenced the present sample size was the need for obtaining longitudinal data due to the day-to-day within-worker variability. This reduced the statistical power needed to establish possible associations between ergonomic risk factors and work-related MSDs. Study 2 (e-waste PA exposures) and study 3 (e-waste work-related MSDs) however, included a substantial sample size

that provided a rich source of self-reported data to explain some ergonomic risk factors and work-related MSDs.

This research was also limited by the use of self-reported data. A known limitation with self-reported data is its reliance on participants' ability to recall information about past exposures to different work activities performed. This is particularly challenging in non-routine work, wherein the exposures vary considerably from day to day for each worker and between workers performing different jobs. For instance, in Study 2 (e-waste PA exposures), some participants did not provide a response to questions about MMH activities, which reduced the effective sample size as illustrated in Tables 4.2.3 and 4.2.4.

To reduce the bias of self-reported data, direct field observations and the use of an instrument such as the pedometer were employed to supplement and validate the self-reported data. The use of pedometers was hindered by the theft of 5 of the 10 acquired for the study which reduced the sample size for pedometer data (n = 42 of 163). In addition, the inability to separate work-related vs. non-work-related step counts, sitting and standing from pedometers poses a challenge for informal work settings. These factors limited the identification of potential associations between pedometer data and job categories, and also highlight the challenges of using direct instrumentation (e.g., wearable sensors) for long-duration exposure assessment in informal work settings. Furthermore, to overcome the subjective limitations of self-reported data, study 4 (ergonomic assessment tool development) and study 5 (e-waste ergonomic risk factors assessment) focused on developing and implementing a real-time observation-based tool, respectively, for quantifying ergonomic exposures in the present context. These studies represent a major contribution to the quantification of ergonomic exposures in informal manual work settings.

Questionnaires are also prone to bias due to low literacy and nuances in local dialects among respondents leading to differences in comprehension and interpretation of the questions. That notwithstanding, the use of questionnaire is irreplaceable to obtain subjective information about variables relevant to the perception of the job and variables that cannot be assessed by instruments or direct observations. To minimize the possible bias in questionnaire responses, professional field staff/interviewers familiar with English and the local language Dagbani administered the questionnaires. The format of the self-reported response variables, whether continuous, ordinal or categorical was also taken into consideration due to the low literacy and language differences among e-waste workers. Where necessary, some variables were categorised to facilitate/simplify the formulation of responses. In addition, as stated above distinction between discomfort, pain and disorder was probably not clear from the perspective of the workers. A more accurate distinction is necessary.

6.4 Contribution to knowledge

This thesis contributes to the limited literature on physical exposures and work conditions that predisposes e-waste workers to MSDs. This research to the best of my knowledge is the first detailed ergonomic risk assessment conducted in one of the largest e-waste dumpsites in the world and may probably be the first ergonomic assessment conducted among e-waste workers globally. The thesis is also novel in its development of an observation-based tool specifically designed at low cost for assessing ergonomic exposures in unstructured work environments. Findings from 3 of the studies in this thesis have been published/accepted for publication in reputable journals in the field of ergonomics and human factors.

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APPENDIX 1A

Participant's Information Sheet

Title of Research: Evaluation of Ergonomic Risk Factors and Work-Related Musculoskeletal Disorders Associated with Informal Electronic Waste Recycling at Agbogbloshie

Principal Researcher: Acquah Appah Augustine

Name of Institution: Department of Biological, Environmental and Occupational Health Sciences, School of Public Health, College of Health Sciences, University of Ghana, Legon – Accra

Supervisors: Professor Isabella Quakyi

Professor Julius Fobil

Dr. John Arko-Mensah

Please read the information below carefully before deciding to partake in this study. Your participation is voluntary and you are free to exit at any time if you change your mind about participating in the study. If you agree to participant, you will be required to sign this consent form.

Introduction:

My name is Augustine A. Acquah. I am a PhD student at the Department of Biological, Environmental and Occupational Health Sciences, School of Public Health, University of Ghana. I am the principal investigator for this research.

Nature of research:

The main aim of this research is to understand the ergonomic risk factors associated with e-waste recycling by developing an observation-based assessment method specific to the context of e-waste recycling. In line with that you will be required to complete a questionnaire. Alongside the questionnaire, you will be observed during your work week while going about your daily work activities.

Risks and Benefits:

There are no known risks or potential risks associated with this study. You will be compensated with 30 cedis at the end of the study period. The information you provide will contribute to development of training and interventions programmes in the future that will help reduce the risk of work-related musculoskeletal discomfort among workers.

Confidentiality:

Participant confidentiality will be ensured at all times. Codes rather than names will be used for identification of participants.

Voluntary participation and withdrawal:

Taking part is this study is voluntary. You are allowed to exit the study at any time if you change your mind about participating. You may choose not to answer questions you are not comfortable with.

Who to contact for clarification:

If you need more clarification on this study or have any questions, please do not hesitate to contact

Augustine A. Acquah,
Department of Biological Environmental and Occupational Health Sciences, University of Ghana. Email: aaacquah@st.ug.edu.gh Tel: 0267776060

APPENDIX 1B

Informed Consent Form

Statement of person obtaining informed consent:

I have been invited to take part in this study for the research titled above. My role in this study is to complete an attached questionnaire and be observed while I work.

I acknowledge that the research procedures have been explained to me and that any questions that I have asked have been explained to my satisfaction. I understand that my participation is totally voluntary.

I have been informed that the confidentiality of my information will be safeguarded and that my privacy and anonymity will be ensured in the collection, storage and publication of the research material.

I …….have fully understood the aims, methods and conditions to participate in this study. I therefore consent to participate.

…… .....

Participant's signature Date

…… ……..

Researcher's Signature Date

APPENDIX 1C

Ethical Clearance

UNIVERSITY OF GHANA
COLLEGE OF HEALTH SCIENCES
ETHICAL AND PROTOCOL REVIEW COMMITTEE

My Ref. No.....

14th January, 2016.

Prof. Julius Fobil
Department of Biological,
Environmental and Occupational Health,
School of Public Health,
University of Ghana
Legon, Accra

ETHICAL CLEARANCE

Protocol Identification Number: **CHS-Et/M.4 – P 3.9/2015-2016**

The Ethical and Protocol Review Committee of the College of Health Sciences unanimously approved your research proposal.

TITLE OF PROTOCOL: **The West Africa-Michigan collaborative Health Alliance for Reshaping Training, Education and Research for Global Environmental and Occupationa Health – Investing in Innovation (Short Title: 1/2 The West Africa-Michigan CHARTER II for GEOHealth)**

PRINCIPAL INVESTIGATORS: **Prof. Julius Fobil**

This approval requires that you submit six-monthly review reports of the protocol to the Committee and a final full review to the Ethical and Protocol Review Committee at the completion of the study. The Committee may observe, or cause to be observed, procedures and records of the study during and after implementation.

Please note that any significant modification of this project must be submitted to the Committee for review and approval before its implementation.

You are required to report all serious adverse events related to this study to the Ethical and Protocol Review Committee within seven (7) days verbally and fourteen (14) days in writing.

As part of the review process, it is the Committee's duty to review the ethical aspects of any manuscript that may be produced from this study. You will therefore be required to furnish the Committee with any manuscript for publication.

This ethical clearance is valid till 31st January, 2020.

Please always quote the protocol identification number in all future correspondence in relation to this protocol.

Signed:.....
PROFESSOR ANDREW A. ADJEI
CHAIRPERSON, ETHICAL AND PROTOCOL REVIEW COMMITTEE

cc: Provost, CHS
Dean, SMD
Head of Department

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UNIVERSITY OF GHANA
COLLEGE OF HEALTH SCIENCES
ETHICAL AND PROTOCOL REVIEW COMMITTEE

Ref. No.: EPRC/MAY/2018 May 23, 2018

Professor Julius Fobil
Department Biological, Environmental and Occupational Health
School of Public Health
Legon

ETHICAL CLEARANCE - AMENDMENT

Protocol Identification Number: ***CHS-Et/M.4 – P3.9/2015-2016***

The Ethical and Protocol Review Committee of the College of Health Sciences on April 26, 2018 reviewed and approved your request for amendment to your research protocol.

Title of Protocol: **"½ The West Africa-Michigan CHARTER II in GEOHealth"**

Principal Investigator: **Professor Julius Fobil**

This approval requires that you submit six-monthly review reports of the protocol to the Committee and a final full review to the Ethical and Protocol Review Committee at the completion of the study. The Committee may observe, or cause to be observed, procedures and records of the study during and after implementation.

Please note that any significant modification of this project must be submitted to the Committee for review and approval before its implementation.

You are required to report all serious adverse events related to this study to the Ethical and Protocol Review Committee within seven (7) days verbally and fourteen (14) days in writing.

As part of the review process, it is the Committee's duty to review the ethical aspects of any manuscript that may be produced from this study. You will therefore be required to furnish the Committee with any manuscript for publication.

This ethical clearance is valid till January 31, 2020.

Please always quote the protocol identification number in all future correspondence in relation to this protocol.

Signed: .....
Rev. Dr. Thomas A. Ndanu
For: Chair, Ethical and Protocol Review Committee

Cc: Provost, CHS
Dean, SPH
Head, Dept. of BEOHS

• P. O. Box KB 52, Korle Bu, Accra, Ghana. • Telephone: +233 (0) 306 665103/4 • Fax: +233 (0) 302 660762
• Email: admin.chs@ug.edu.gh / provost.chs@ug.edu.gh • Website: www.chs.ug.edu.gh

APPENDIX 2

In-Depth Interview Guide

Interviewer: _____

Notetaker (if applicable): _____

Date:_____

Time discussion started: _____ Time ended:_____

Demographic Data

Participant ID_____ Age_____

Educational Status_____

Gender_____

How long have you work at Agbogbloshie e-waste site?_____

INTRODUCE INTERVIEWER, NOTE-TAKER:

INTRODUCE THE PURPOSE OF THE GROUP:

My name is _____ and this is my colleague _____. We work on the Global Environmental and Occupational Health (GEOHealth) PROJECT. We are interested in studying the effect of e-waste on the health of e-waste workers at Agbogbloshie. The information we obtain from you today will be used solely for research purposes and we will ensure your identity is not revealed in any way. We really want to hear what you have to say and want you to feel comfortable in answering questions however you want to. There are no right or wrong answers.

My colleague will be taking notes on what you say to ensure we don't miss anything you have said. This interview will last approximately 15 minutes

Do you have any questions before we begin?

JOB DESCRIPTION

We are interested in knowing the details about the job you do and how you do them

- What job do you do at Agbogbloshie?
- How long have you been doing this job?
- Can you describe in details what you do?
- Can you describe in details how you do it?
    - PROBE: Ask about tools used
- How long do you do this work in a day?
- How often do you do this work in a week?
- Why do you do this specific job?

WORK-RELATED INJURIES / HAZARDS

- Do you usually get injuries from your work?
    - PROBE: Ask about type of injuries, do you get body pains? Which part of your body? Can you describe the type of pain at each part?
- What effect do you think these injuries have on you?
    - What about your work?

PSYCHOSOCIAL ERGONOMIC RISK FACTORS

- Do you consider your job risky? Why?
- In general how do you find this Job?
    - PROBE: Do you think the job is stressful? Explain.
- So in what way does the stressful nature of your job affect you?
    - PROBE: How does it affect your job?
- Do you have difficulty coping with your job? Why or Why not?
    - PROBE: Do you have to work under pressure? Can you explain? Do you have a lot of responsibilities associated with your job? What are the challenging aspects of your work?
- Do you have the resources required to do this job?
    - PROBE: Ask about financing the job, labour, do you require any special training or skill to do this job? Do you have the skills required to do this job?

APPENDIX 3

Modified version of the OPAQ used for data collection

Q1. In the last work week, did you do the following during your work schedule?

**** Sitting activities***

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

**** Standing activities***

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

**** Walking***

	Yes	**No**
Prolonged walking (4 hours or more per day)	☐	☐
Walking for 1 hour 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	☐	☐	☐	☐

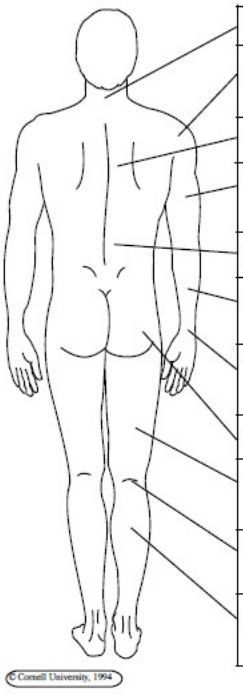
Q3. If you did any of the above, what is the maximum weight you usually handle while performing these tasks?

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

APPENDIX 4

Cornell Musculoskeletal Discomfort Questionnaire

The diagram below shows the approximate position of the body parts referred to in the questionnaire. Please answer by marking the appropriate box.



	During the last work week how often did you experience ache, pain, discomfort in:					If you experienced ache, pain, discomfort, how uncomfortable was this?			If you experienced ache, pain, discomfort, did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Back	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Arm (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Arm (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Back	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forearm (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forearm (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wrist (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wrist (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hip/Buttocks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thigh (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thigh (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knee (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knee (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Leg (Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Leg (Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

APPENDIX 5

Ergonomic exposure assessment tool for unregulated unstructured work

DEMOGRAPHIC INFORMATION AND WORK HISTORY

Worker ID: ……

Day and date of observation: ……

Job Category/Name: ……

Name of Worker / Telephone number: ……

Age: ……

Educational Status: ……

Worker Anthropometry: Height (cms):…… Weight (kgs):……

Hand Dominance: Right / Left/ Both (ambidextrous)

Years of work / Experience: ……

Work Schedule (start and end time): ……

Tools used: ……..

Most difficult task performed: ……

Personal protective equipment used: ……

Work methods: ……..

Irregular activities: ……..

CODING GUIDE

POSTURE			OTHER RISK FACTORS		MANUAL MATERIAL HANDLING	
NECK	0 = Neutral		FORCE EXERTION	0 = Hand activity with low force exertion	LIFTING/ LOWERING	0 = Light weight 5kg or less
				1 = Hand activity with medium force exertion		1 = Moderate weight (6 to 10kg)
	1 = Non-neutral			2 = Hand activity with high force exertion		2 = Heavy weight (11-20kg)
						3= Very heavy weight (>20kg)
TRUNK	0 = Neutral		REPETITIVE MOVEMENT	0 = Low (<10x per min)	CARRYING	0 = Light weight 5kg or less
	1 = Moderate forward flexion and or lateral bending			1 = Medium (11-20X per min)		1 = Moderate weight (6 to 10kg)
	2 = Severe forward flexion and or lateral bending			2 = High (20>x per min)		2 = Heavy weight (11-20kg)
						3= Very heavy weight (>20kg)
UPPER LIMBS	0 = Hands below waist height		CONTACT STRESS	0 = very minimal or absent		
	1 = Hands/arms below shoulder height but above waist height			1 = contact stress present		
	2 = Hands/arms above shoulder height					
LOWER LIMBS	Walking	0=Normal/ordinary walking	VIBRATION	0 = very minimal or absent	PUSHING WHEEL BARROW	0 = empty
		1 = Walking and pulling a cart (or wheel barrow)		1 = vibration present		1 = loaded
	Standing	0 = Neutral				
		1 = Non-neutral (knees bent > 45^0)			PUSHING CART	0 = empty

	Sitting	0 = Hips and knees at about 90^0				1 = loaded
		1 = Hips and knees greater than 90^0			OTHER	0 = Absent
		2 = Hips and knees less than 90^0				1 = Present

Data Coding Sheet

Worker ID:…….. Day no.:…… Sheet no.:……. Date:…… Temp.:…… ^oC

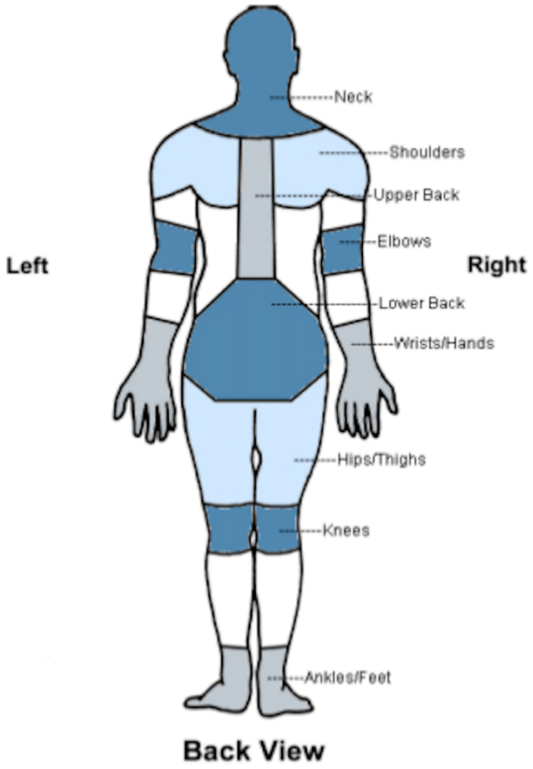
		Observed video frame number (60 seconds interval)																												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
POSTURE	**Walking**																														
	Standing																														
	Sitting																														
	Neck																														
	Trunk																														
	Upper limbs																														
RISK FACTORS	***Force exertion**																														
	***Repetitive movement**																														
	***Contact stress**																														
	***Vibration**																														
M M H	**Lifting/ lowering**																														
	Carrying																														

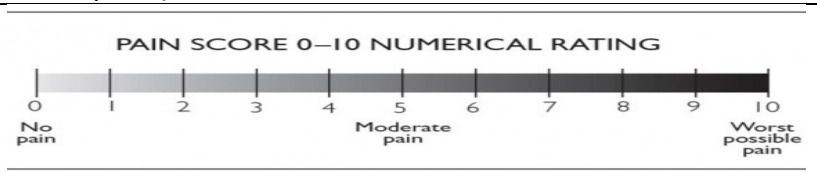
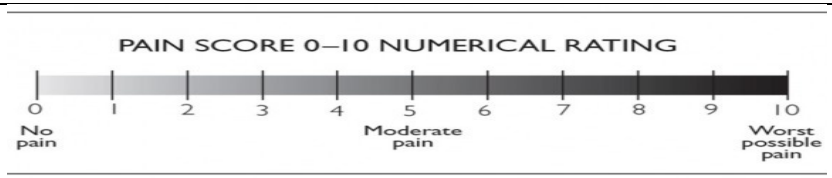
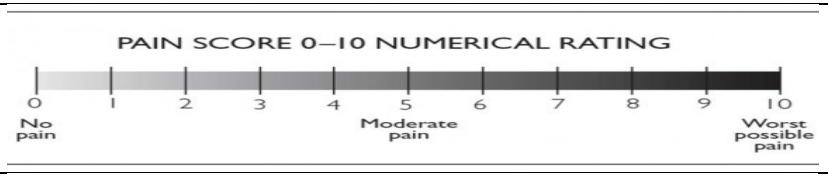
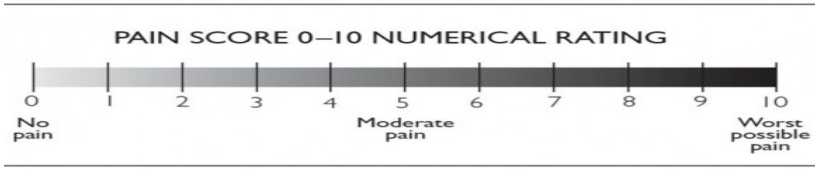
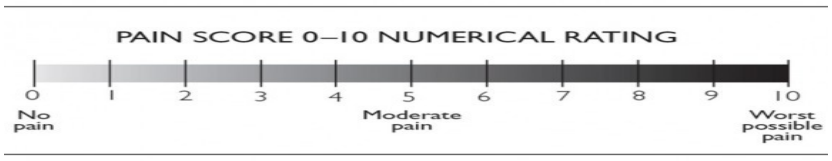
	Pushing wheelbarrow																													
	Pulling cart																													
OTHER	***other - (Kicking, stamping with feet, rattling of cart handle)**																													

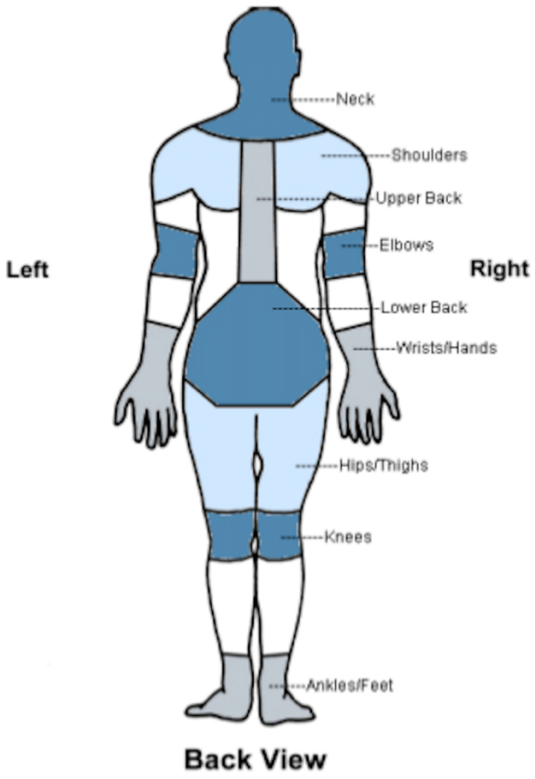
APPENDIX 6

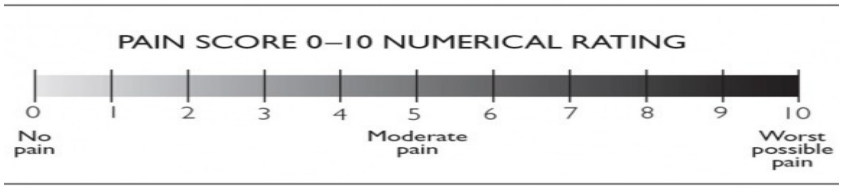
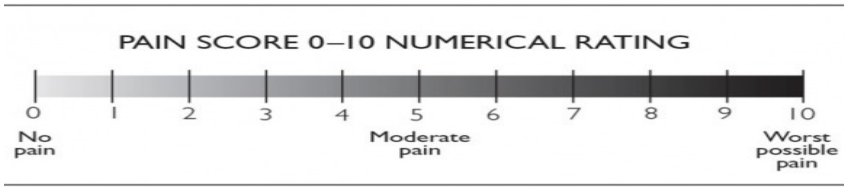
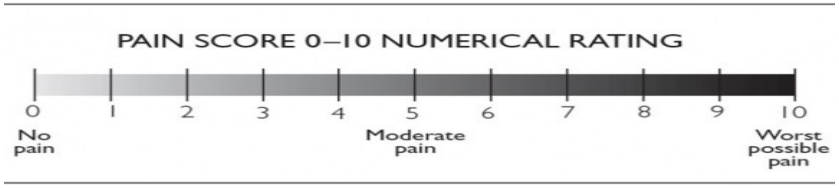
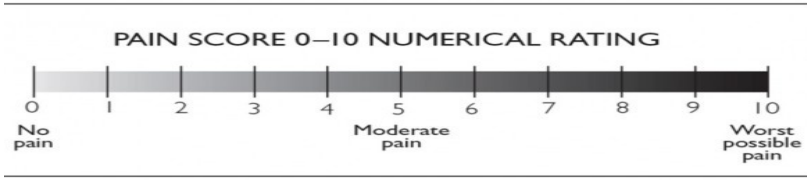
Pain / Discomfort Assessment Questionnaire

Worker ID:…….. Date:……. Assessment (select an option): Initial / Final

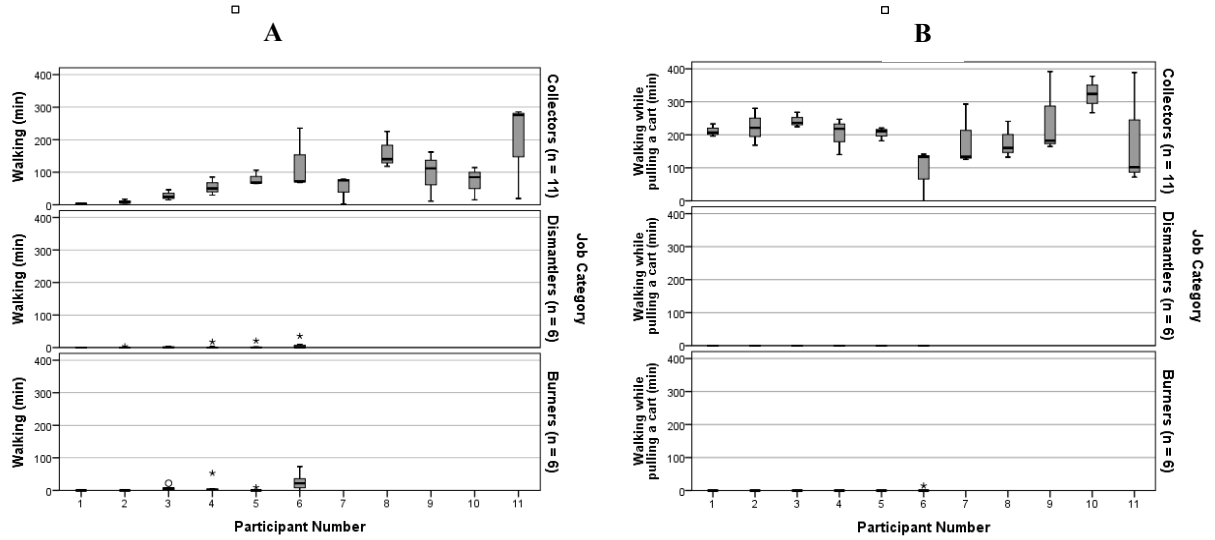


NECK	
SHOULDERS	
UPPER BACK	
ELBOWS	
LOWER BACK	

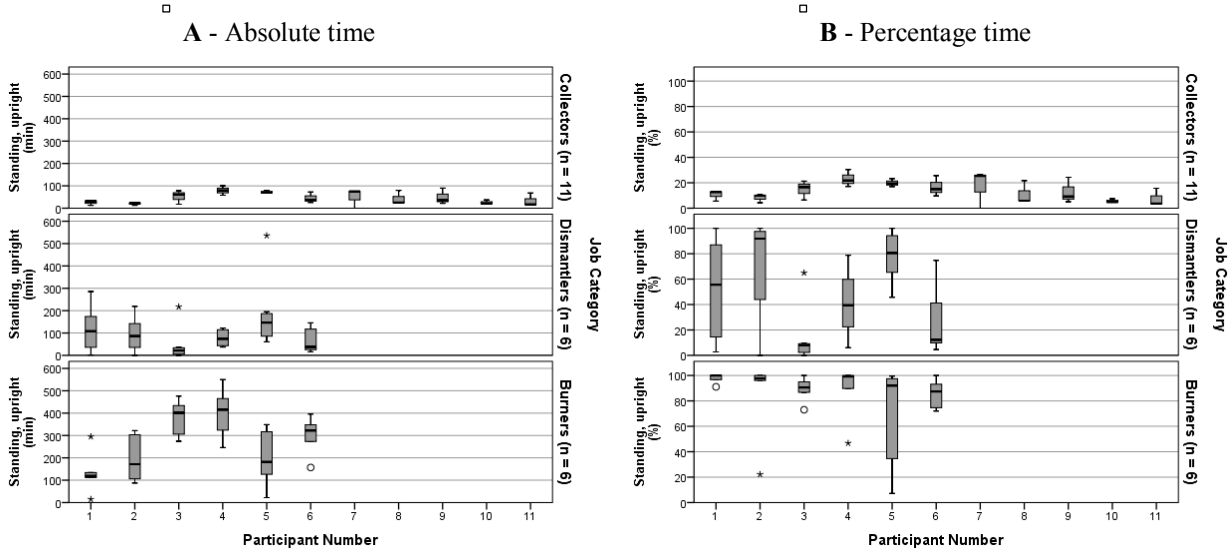


WRIST / HANDS	
HIPS / THIGHS	
KNEES	
ANKLES / FEET	

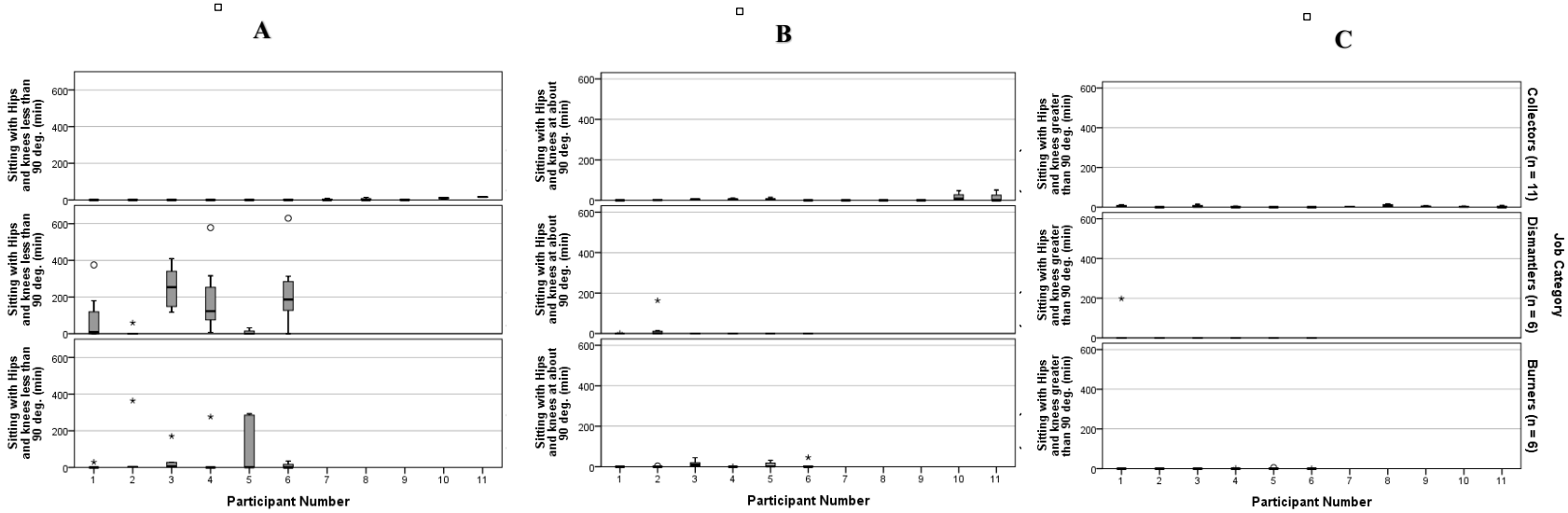
APPENDIX 7 (SUPPLEMENTARY FIGURES)



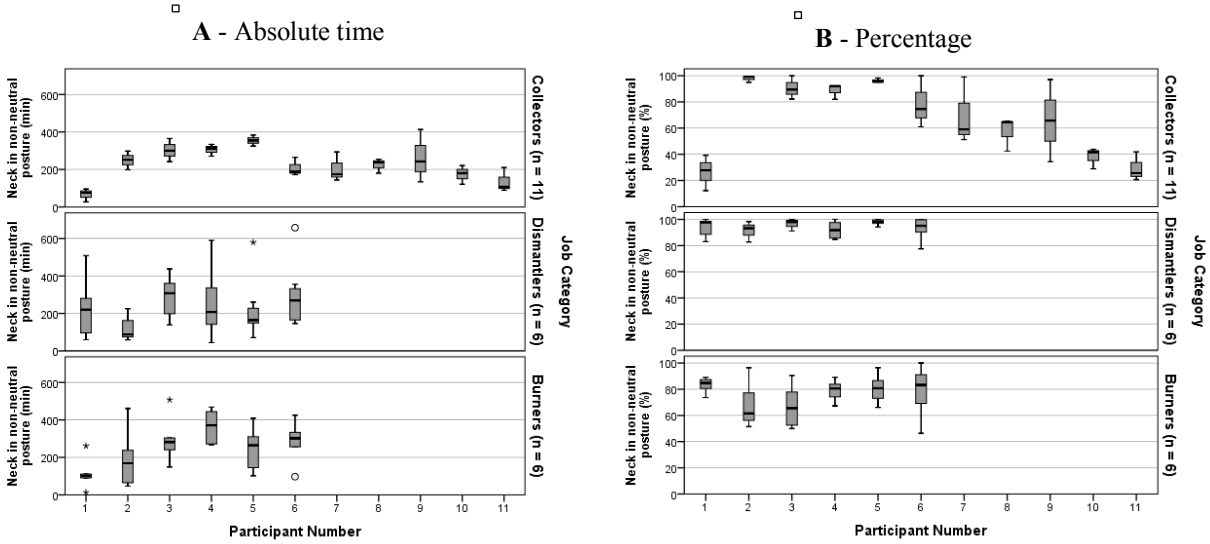
Appendix 7.1: Active work time spent in (A) ordinary walking and (B) walking while pulling/pushing a cart among collectors (n = 11), dismantlers (n = 6), and burners (n = 6)



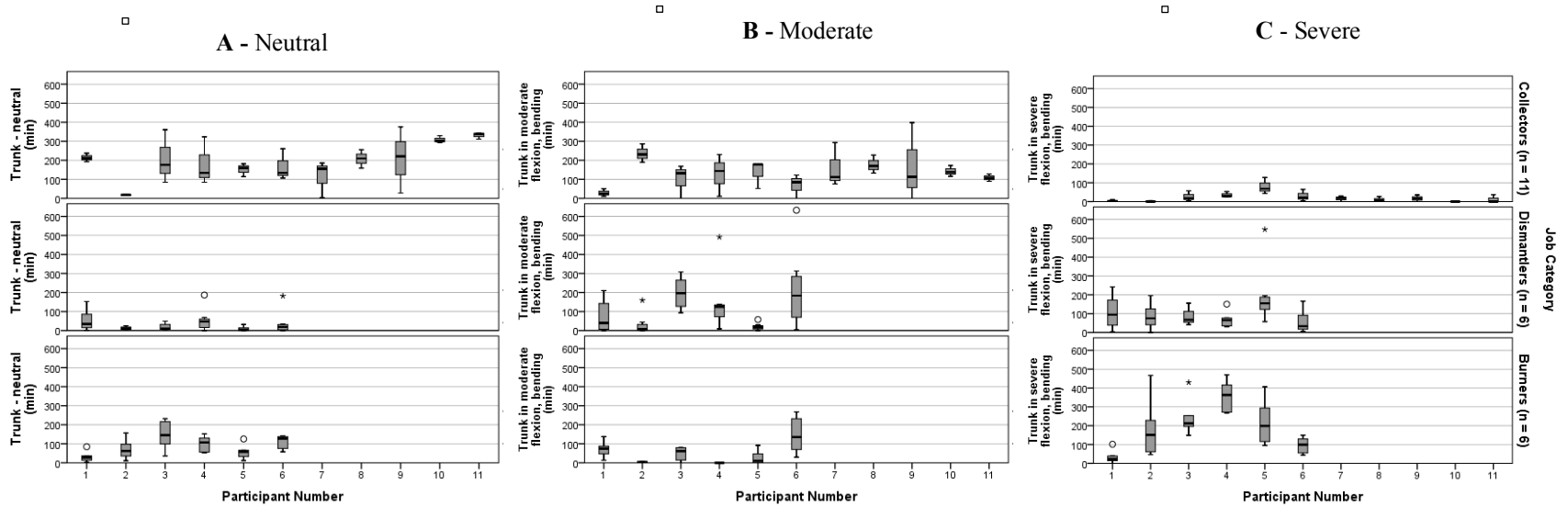
Appendix 7.2: Active work time and percentage of total active work time spent in neutral standing by collectors (n = 11), dismantlers (n = 6), and burners (n = 6)



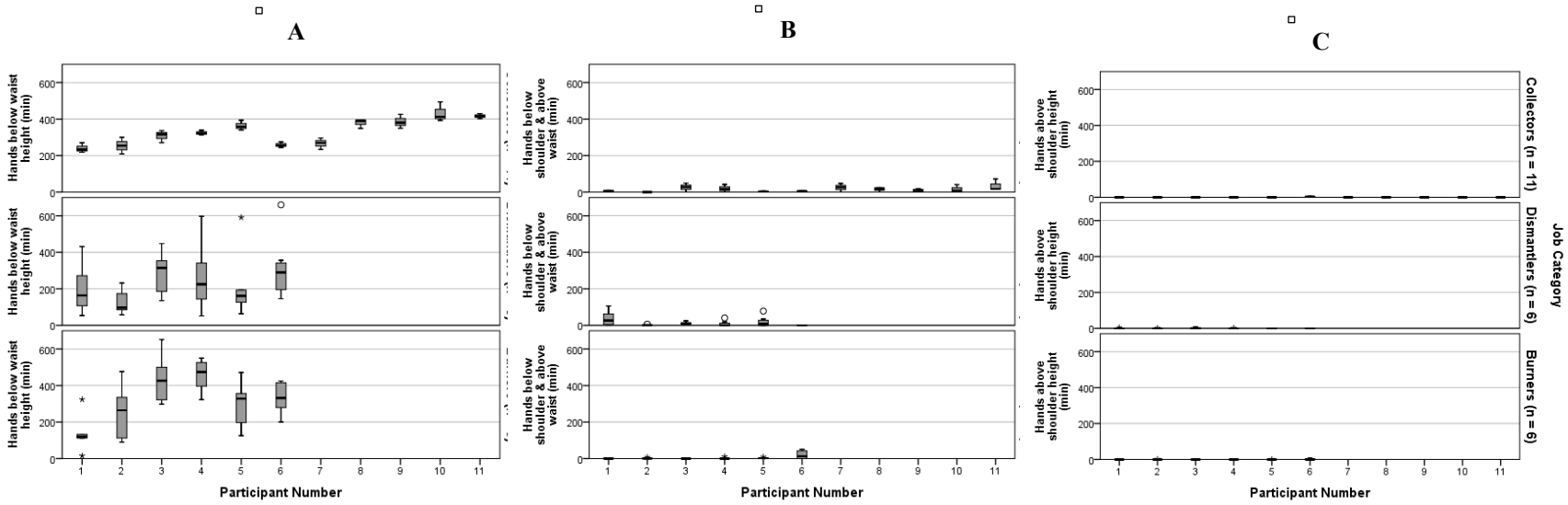
Appendix 7.3: Active work time spent in (A) sitting with the hips and knees < 90 deg. (B) sitting with the hips and knees at about 90 deg. (C) sitting with the hips and knees >90 deg. for collectors (n = 11), dismantlers (n = 6) and burners (n = 6)



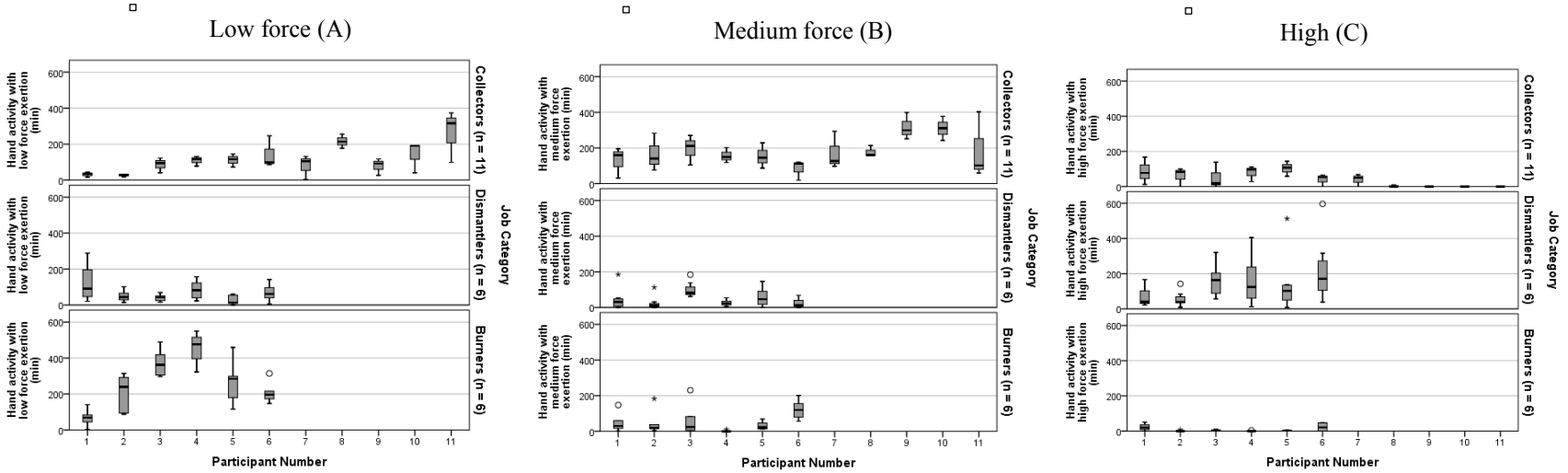
Appendix 7.4: Active work time and percentage of total active work time spent in non-neutral neck postures by collectors (n = 11), dismantlers (n = 6), and burners (n = 6)



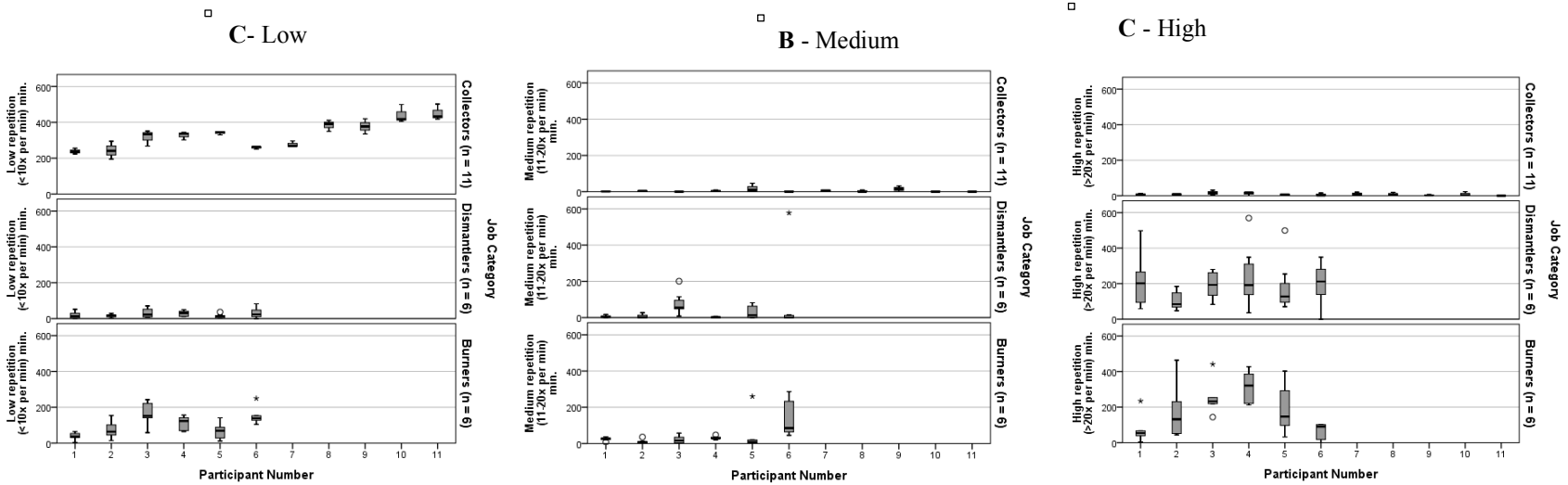
Appendix 7.5: Active work time spent in (A) Neutral (B) Moderate (C) severe trunk flexion or lateral bending by collectors (n = 11), dismantlers (n = 6), and burners (n = 6)



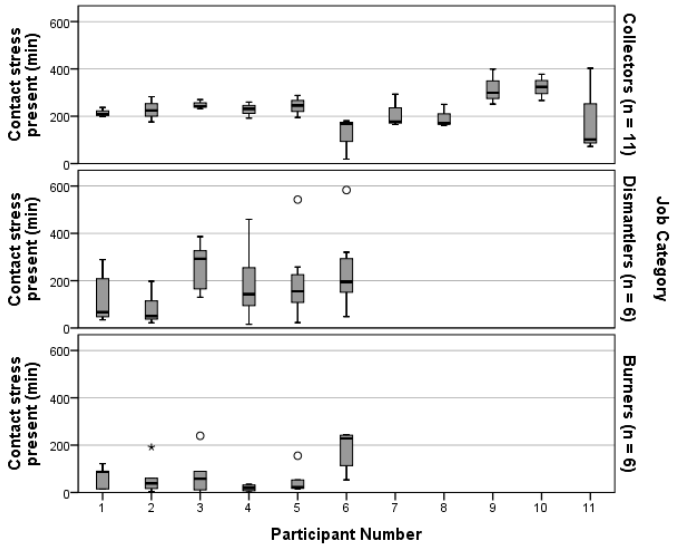
Appendix 7.6: Active work time spent by collectors (n = 11), dismantlers (n = 6), and burners (n = 6) in working with the hands (A) below waist, (B) between waist and shoulder, and (C) above shoulder heights



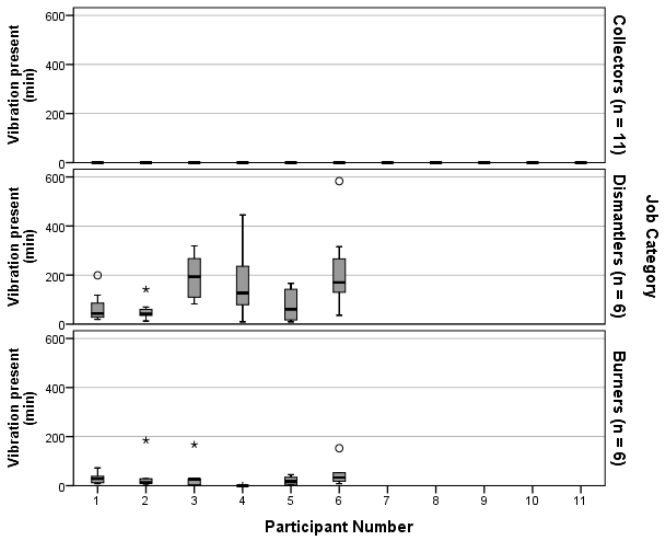
Appendix 7.7: Active work time spent by collectors (n = 11), dismantlers (n = 6), and burners (n = 6) in (A, D) low, (B, E) medium, and (C, F) high force exertion and repetition.



Appendix 7.8: Active work time spent by collectors (n = 11), dismantlers (n = 6), and burners (n = 6) in (A) low (B) medium, and (C) high hand repetitive movements

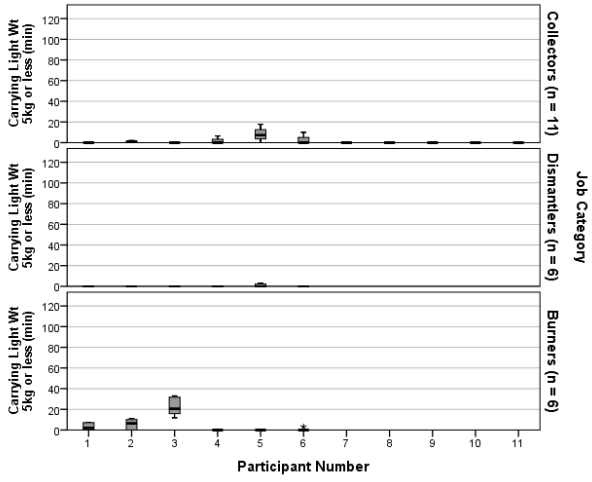


Appendix 7.9: Active work time collectors (n = 11), dismantlers (n = 6), and burners (n = 6) were exposed to contact stress.

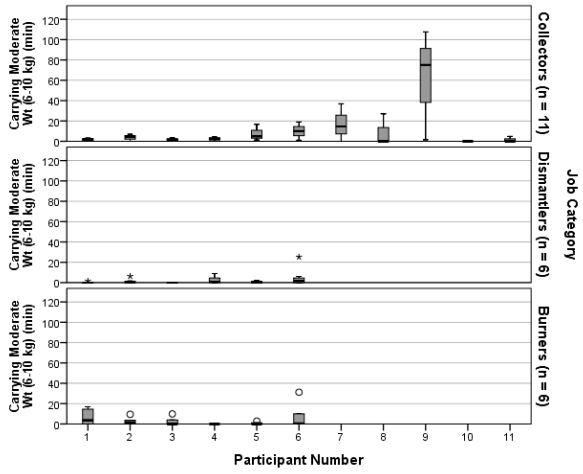


Appendix 7.10: Active work time collectors (n = 11), dismantlers (n = 6), and burners (n = 6) were exposed to vibration.

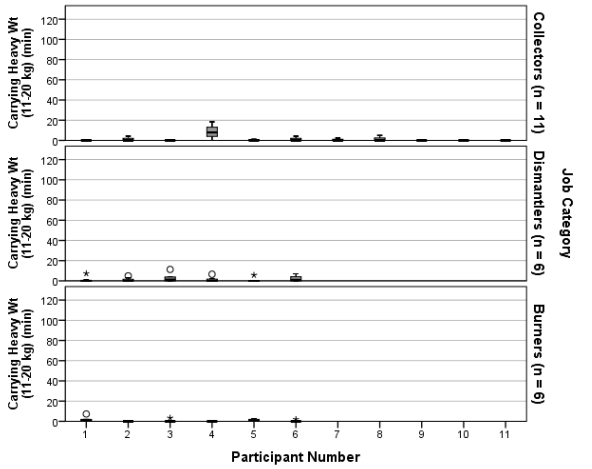
A – light weight



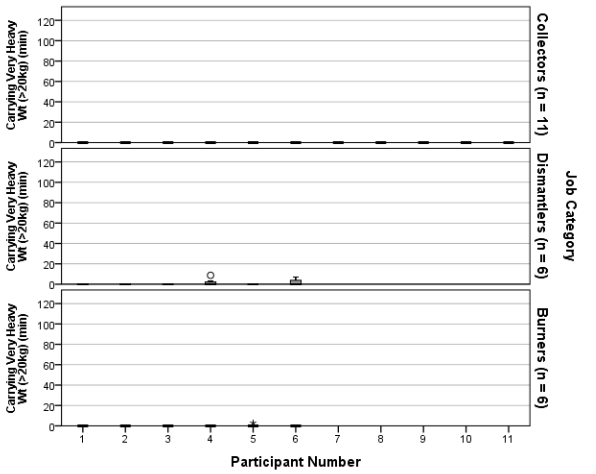
B – moderate weight



C – heavy weight



D – very heavy weight



Appendix 7.11: Active time spent in carrying (A) light, (B) moderate, (C) heavy, (D) very heavy weight by collectors (n = 11), dismantlers (n = 6), and burners (n = 6)

APPENDIX 8

Publication from objective 1 (Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63(1), 938–942.)

Processes and challenges associated with informal electronic waste recycling at Agbogbloshie, a suburb of Accra, Ghana

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3. Environmental Health Sciences, School of Public Health, University of Michigan, Ann Arbor, USA.

Abstract: Electronic waste (e-waste) is a worldwide problem in terms of increasing production rate in the global waste stream. Its recycling is known to be associated with adverse health outcomes. The recycling site at Agbogbloshie is a major e-waste recycling hub which presents enormous health threats to the residents in this community as a result of exposure to complex mixtures of chemicals associated with the poor work methods employed. This paper describes the processes involved in e-waste recycling at Agbogbloshie and discusses some of the associated health and psychosocial challenges. Direct field observations and in-depth interviews of eight e-waste workers were conducted from November, 2017 to December, 2017. Results from a thematic analysis of the data gathered; suggest that inappropriate recycling methods, financial constraints, and the high physical demands of e-waste recycling work were associated with adverse musculoskeletal health conditions among the workers. A more systematic ergonomic study is currently being undertaken to quantify the associations between physical work exposures and worker musculoskeletal health among e-waste workers in Agbogbloshie. Further studies that focus on locally adapted ergonomic interventions for effective recycling of e-waste and reducing the health risk to workers are needed.

INTRODUCTION

Technological advancement and high demand for new electronic and electrical equipment have resulted in high turnover and shorter lifespan for these equipment. This phenomenon has presented the world with a huge burden of managing end-of-life electrical products. Tons of e-waste are dumped in developing countries and eventually become a problem to manage (Bakhiyi et al., 2018). A greater part of the challenge in managing e-waste in developing countries is lack of appropriate recycling methods and technology required for efficient extraction of the required constituents from old or discarded electronics, while minimising occupational health risk to e-waste recycling workers (Zhang & Xu, 2016).

In most developing countries, those engaged in recycling activities often belong to vulnerable groups in society (Zhang & Xu, 2016), and their livelihood is fully dependent on earnings from e-waste recycling activities (Amankwaa, 2013). Agbogbloshie is one of the world's largest e-waste recycling sites creating a potential for numerous health challenges. Agbogbloshie has served as a major e-waste hub for over a decade (Davis et al., 2018) with an estimate of over 171,000 tons of e-waste processed annually (Prakash et al., 2010). The fact that rudimentary methods are used for e-waste processing presents occupational health and environmental problems.

This paper aims to describe the processes involved in manual e-waste recycling at Agbogbloshie, and highlights the health and psychosocial challenges associated with this type of work.

METHODS

This study was conducted at the Agbogbloshie e-waste processing site located in the heart of Accra, adjacent to the Agbogbloshie food market, and close to the central business district. The study employed a qualitative approach relying on direct visual observations and interviews. The study was approved by the institutional review board of the University of Ghana, College of Health Sciences.

Eight (8) e-waste workers were engaged in in-depth interviews. Initially, an interview guide was developed through rigorous literature search in addition to field observations at the e-waste site. The interview guide required workers to describe; in detail, the processes and tools used during e-waste recycling. Workers were also asked about the reasons for their choice of the specific e-waste job category they worked in, the health challenges they experience from their work the level of stress or difficulty associated with their work and their ability to cope with these stressors. A series of walk through observations were done to supplement information obtained from the interviews. The interviews lasted between 10 to 15 minutes and were recorded using a Sony™ voice recorder. The audio recordings were transferred onto a computer for transcription and subsequent analysis.

An interpretive analysis approach was used to analyse the data. A reflective cognitive approach was used in explaining the observations made as recommended by Gambo (2017).

RESULTS

Demographics

The study sample comprised eight male e-waste workers with ages ranging from 19 to 34 years and with an average ± SD age of 25.88 ± 5.22 years. Five of the participants had primary education, one had completed junior high school and two had been educated up to senior high school. The number of years they had worked as e-waste workers at Agbogbloshie ranged from 3 years to 10 years with an average of 6.88 ± 3.00 years. Participants worked 3 to 6 days a week depending on the availability of e-waste to recycle.

Description of e-waste recycling processes at Agbogbloshie

Figure 1 is a flowchart summarizing the observed e-waste recycling processes at Agbogbloshie. There are 3 main job categories among e-waste workers at Agbogbloshie, namely, representing the essential activities of collection, dismantling and burning of e-waste and interspersed with other supporting tasks (Acquah et al., 2018, unpublished).

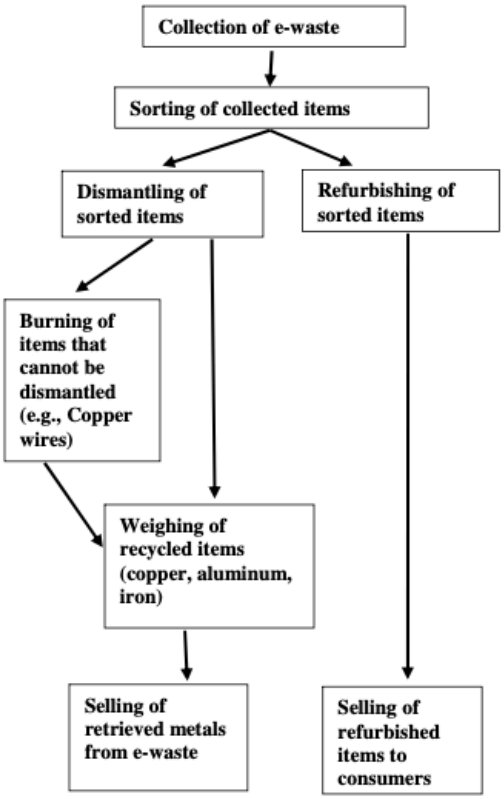

Figure 1: Flowchart showing e-waste recycling processes at Agbogbloshie.

Collection of e-waste could span the entire working shift which is usually from 6am to 5pm. It involves workers travelling to different neighbourhoods in the city and surrounding towns in search of end-of-life electronics. Workers usually walk to these places pulling a collection cart along as shown in Figure 2A. E-waste is sometimes collected for free from small local dumps, or are purchased from owners for a small fee. The collected e-waste is loaded onto a cart and pulled to the dismantling site where it is sold to dismantlers or dismantled by the same collectors. Some collectors who may be fortunate to have motor bikes or bicycles may use these as a means of transportation during the collection process. Occasionally, when collectors gather very large quantities of e-waste that may not fit on their bikes or collection carts, they hire the services of transporters who use tricycles to aid in conveying the items to the e-waste site. These tricycles are commonly known among the workers as "motor king". The transporters (motor king riders) are usually stationed adjacent the main dismantling area close to the main Agbogbloshie street awaiting customers who require their transport services. In addition to e-waste purchased from the neighbouring towns, cargo trucks full of imported e-waste were occasionally seen making their way into the e-waste site. Illegal import of e-waste is a major source of e-waste in Ghana (Balde et al., 2015). The e-waste from these trucks are subsequently sold to e-waste workers for recycling.

E-waste items brought to the dismantling site are sorted initially into two groups as shown in Figure 1. The first involves an attempt to salvage e-waste that could be reused. Electronic items that may not be completely damaged and could be repaired for reuse are sold to a group of workers called repairers whose main interest is to refurbish e-waste and resell them to consumers. The second process of sorting involves collating of items that can be dismantled which are then sold to dismantlers.

Dismantling involves the use of predominantly locally made simple tools such as hammer and chisel and occasionally screw drivers and spanners to break apart e-waste in order to separate the different metals (Figure 2B). The metal constituents are usually copper, iron and aluminium. Items usually dismantled includes, computers, fans, refrigerators, air conditioners, photocopy machines, car engines as well as starters and any other item gathered that is likely to contain some metal constituent. A typical dismantling session lasts between 3 to 4 hours.

Dismantling is usually done employing one of three postures. Smaller electrical gadgets are usually dismantled while sitting and supporting the object being dismantled with the feet as illustrated in Figure 2B. Occasionally, dismantlers may need to stand and bend over to dismantle larger items such as car engine blocks or static condenser components from refrigerators. The third major posture adopted, consists of prolonged upright standing to dismantle very large objects. During the walkthrough observations, some dismantlers were observed dismantling a minibus using this posture. After e-waste items are dismantled, they are then sorted into their respective metallic constituents and items that could not be dismantled are sent for burning to recover the metal constituents (e.g., electric cables) as shown in Figure 2C.

A: Collectors pulling a cart with e-waste

B: Dismantling of e-waste

C: Carrying cables for burning

Figure 2: Picture showing the three main e-waste activities performed at Agbogbloshie.

Burning involves setting up fire to items using foam materials retrieved from spoilt refrigerators. A single burning session of e-waste lasts between 30 to 45 minutes. A long metal rod is used to rotate/flip the burning items to ensure a uniform distribution of the fire and expose the metal. The final metallic end products retrieved from burning and dismantling are then sent for weighing.

Weighing of e-waste involves placing the sorted retrieved metals (e.g., copper, aluminium, iron) onto a weighing scale to determine its resale value. Copper is sold at a higher price than aluminium which is also sold at a higher price than iron. The retrieved metals are often sold to middlemen. These middle men buy processed e-waste from workers in small quantities and gather them into larger piles to be sold at higher rates to industrial companies in Tema, an industrial city in Accra, where these are processed into iron rods, roofing sheets, cooking utensils and gas cookers (Amankwaa, 2013).

Health risks of e-waste recycling in Agbogbloshie

This study investigated health and psychosocial challenges among the 3 main e-waste job categories (Collectors, dismantlers and burners). Participants were interviewed about the health challenges experienced during their work. Symptoms reported included burns and lacerations, musculoskeletal pains, headaches, elevated body temperature and respiratory issues (e.g., coughs). A few sample quotes from participants are provided below.

> *"You see my hand? It is fire that burned it to make it appear this way"* – **23 years old, e-waste burner**

> *"When the smoke is inhaled by you, you will experience coughing at night. And the phlegm produced are blackish in colour just like the colour of the smoke from the burning. When you cough, it will make you feel pain."*- **23 years old, e-waste burner.**

> *"When we go back home and sleep, we realize that your body aches……. your body becomes hot. Then you go and buy 'Kwik Action' and you take it as medication then you sleep…….When it becomes hot, I take Kwik Action to make it cool."* **– 28 years old e-waste burner**.

> *"I get joint pains and headaches from the hot sun"* **29 years e-waste collector.**

Six out of the 8 workers interviewed reported body pains as a frequently experienced health challenge. These workers rely extensively on pain medications in order to cope with the symptoms. This is indicated in some quotes from workers reported below.

> *"You see when it comes and maybe you get some pain killer, maybe it will take a day or two and it will just go"* **– 24-year-old, e-waste dismantler,**

> *"You need to take pain killers before you can sleep"* – **19-year-old, e-waste dismantler.**

Psychosocial challenges

Interviewed workers overwhelmingly considered the work of e-waste recycling to be stressful and difficult to perform. Below are some reports from the workers interviewed:

> *"The job is very difficult to do….. I want to quit it. The last time, I was injured by it and I want to quit"* **23 years old, e-waste burner.**

> *"Every aspect of the work is difficult……It's not good for a human being to do this work."* **30 years old, e-waste burner.**

Interviewed workers complained about the high physical demands of e-waste recycling which makes it a difficult job to cope with. The desire to quit e-waste recycling was obvious among participants. Participants also expressed concerns that,

although their work presented injury risk, a leave of absence from work presented the risk of losing prior customers to other workers. Thus, workers felt the need to push themselves to the limit and work every day despite their injuries.

Workers also complained about the low revenue they earn from e-waste recycling as indicated in the quote below:

> *"I work for long hours and I only earn a little money….when I make enough money, I will quit this job and find a less risky job"* **23 years old, e-waste burner.**

One of the participants reported earning between GH¢20 to GH¢50 Ghana cedis (about $4 to $10) a week. According to the worker this income is inadequate and does not allow saving to generate some capital to change job.

Burning of e-waste usually requires very little or no revenue to operate. Thus, workers who lack the financial resources needed to buy e-waste resort to engaging in e-waste burning. One burner admitted that although high risks are associated with burning of e-waste, he does not have enough money to buy e-waste from collectors to dismantle and as such continues in his current job until he can raise enough money to find another job.

> *"I don't have a job and I don't have money to buy from the others to dismantle. That's why I am doing this work little by little."* **23 years old, e-waste burner.**

For this worker, since, burning of e-waste does not really require purchasing of items, it was much easier to cope with. Thus, he waits for his other colleagues to dismantle their purchased good and then help them recover metals via burning at a fee from items such as copper wires that cannot be dismantled.

The e-waste job category an e-waste worker was enrolled into was largely influenced by the person who initially introduced them to e-waste recycling and provided the initial financial support to work with. Thus, workers were compelled to continue work in the same e-waste job category as their financiers.

DISCUSSION

The present study qualitatively described the processes involved in e-waste recycling at Agbogbloshie, Accra, Ghana, as well as explored the health and psychosocial challenges encountered by workers. Basic collecting, dismantling and open-air burning are used to retrieve essential metals from e-waste during the recycling process. The e-waste recycling process relies on the use of simple manual tools such as hand-pulled collection carts; hammers, chisels, spanners and screw drivers for dismantling as well as the use of long metal rods or pipes for rotating, flipping and moving items burnt during recycling. Whiles it seems cost effective, these tools are inefficient and subject workers to high risks of musculoskeletal injury.

Laceration injuries were common among e-waste workers. Earlier studies conducted at Agbogbloshie, have reported a 96.2% prevalence of lacerations among e-waste workers (Adusei et al., 2015, unpublished) which is exceptionally high. Similarly, burn injuries were a common challenge reported among burners. The lack of appropriate personal protective equipment (PPE) usage during burning may be a significant contributing factor to the occurrence of these injuries. Burners at Agbogbloshie usually wear boots to protect their feet and long clothes to cover their limbs and torso. That notwithstanding, the clothes worn were regular clothes and not fire retardant. Workers hands and faces are usually left exposed and were the common sites of burn injuries. A burner narrated an account of how his younger brother sustained serious injuries to the face during e-waste burning. Other workers had various scars on their hands to show for the numerous instances of burns they had experienced. Injuries sustained during e-waste recycling may be devastating, disabling, and life threatening.

The use of gloves, nose masks and other PPE was not a common practice. According to the participants, PPE was occasionally provided by donor groups in limited supply. However, when the PPEs were worn out, workers were unable to replace these on their own and so their use was discontinued.

In addition to burns and injuries, participants reported episodes of coughs and chest pain from coughing. The exposure of e-waste workers to high volumes of smoke from the burning process poses a great risk to the respiratory system and health of these workers. Amankwaa (2013), reported high acute respiratory infections among e-waste workers in Agbogbloshie. Other global studies have shown significant relationships between e-waste recycling and adverse respiratory health outcomes (Zheng et al., 2013). The use of face masks could have been a first line attempt to reducing respiratory exposures by e-waste workers. This was, however, not the practice at Agbogbloshie.

Participants in this present study reported body pain after the workday. E-waste recycling at Agbogbloshie entails multiple instances of lifting, bending and twisting as well as assuming non-neutral postures for prolonged periods. These activities are suspected to cause musculoskeletal pain (Wai et al., 2010) and disorders (Chaffin et al., 2006). Unpublished results from a study by the Global Environmental and Occupational Health (GEOHealth) research group of the University of Ghana (GEOHealth, 2019) showed a 90% prevalence of work-related musculoskeletal disorders among e-waste workers.

In an attempt to manage the pain experienced by workers during e-waste recycling, e-waste workers at Agbogbloshie resort to self-medication and excessive reliance on pain medication. The over-dependence and inevitable abuse of these medications is a worrying health concern. Recent media reports in Ghana indicated a surge in tramadol abuse (GhanaWeb, 2018) and this was particularly evident during our field observations. Workers were seen mixing tramadol with energy drinks and consumed the mixture during work. Workers interviewed in this study indicated that, it helps them to work for longer periods without experiencing body pain or fatigue. The self-medication habits as well as the possible abuse of tramadol may result in long term health consequences. Immediate measures to address this problem could save workers from expected adverse effects.

High level of stress as well as excessive physical demand were a concern to participants. Participants complained about the difficult nature of their job and consistently expressed great dissatisfaction with their jobs. Although e-waste recycling provides some form of livelihood, little income is earned by workers despite the excessive physical demands of the job. Psychosocial risk factors such as high job demands and low job satisfaction have been shown to increase the level of stress of workers and subsequently increasing their chances of experiencing musculoskeletal disorders (Bongers et al., 1993; Netherlands Organisation for Applied Scientific Research, 2017). Hence, it is suspected that, some of the psychosocial challenges experienced by e-waste workers at Agbogbloshie may have a bearing on the musculoskeletal symptoms experienced by these workers and could require further investigation.

Despite these obvious challenges associated with e-waste recycling at Agbogbloshie, the lack of the needed financial, social and governmental support required to address the increasing problem of e-waste recycling, compels these workers to continue in this hazardous trade.

CONCLUSIONS AND RECOMMENDATIONS

The methods used in recycling of e-waste at Agbogbloshie in Accra, Ghana are rudimentary and manual. These occupational exposures have undesirable health implications for workers. Although workers are unsatisfied with their working conditions and income earned, finding alternate jobs is challenging.

An ergonomic study is underway to quantify the associations between physical work exposures and worker musculoskeletal health among e-waste workers in Agbogbloshie (Acquah et al., 2018, unpublished). The purpose of this study is to identify and reduce the adverse effects of e-waste recycling by improving procedures used in recycling as well as educating workers on observing health and safety protocols. Further research is needed to identify locally adapted ergonomic interventions for effective recycling of e-waste and reducing the health risks to workers.

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APPENDIX 9

Conference abstract publication and poster presentation from objective 3

(*Environmental Epidemiology: October 2019 - Volume 3 - Issue - p 2-3.*)
http://doi.org/10.1097/01.EE9.0000605616.87684.ec

Prevalence of work-related musculoskeletal disorders among electronic waste workers at Agbogbloshie in Accra, Ghana

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CONCLUSION:
Electronic waste workers in Agbogbloshie have an alarmingly high prevalence of work-related musculoskeletal disorders. Contextually and locally adopted ergonomic interventions could help reduce this prevalence.

Background:

Informal and physically demanding techniques are used to recycle electronic waste (e-waste) at Agbogbloshie, Accra, Ghana, one of the largest e-waste recycling sites in the world. The work conditions are expected to promote the development of musculoskeletal disorders (MSDs).

Methods:

The Cornell Musculoskeletal Discomfort Questionnaire was used to obtain information on the occurrence of MSDs in 11 specific body regions from 163 e-waste workers grouped in 3 categories: collectors, dismantlers, burners.

Results:

Table 1 – Proportions of work-related MSDs in the 6 body regions with the highest prevalence

Body Region	Frequency (n=163)	Percentage
Neck	40	24.5
Shoulder	61	37.4
Upper Arm	49	30.1
Lower Back	106	65.0
Knee	64	39.3
Lower Leg	44	27.0

***overall prevalence of MSDs 90%**

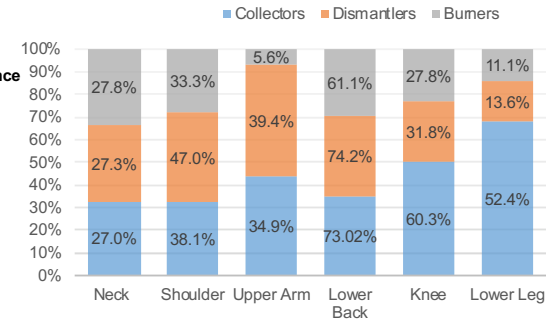

Figure 1: Proportion of e-waste workers by job category with MSDs in the 6 body regions with the highest prevalence

***E-waste job category was significantly associated with the frequency (p = 0.032) and severity (p = 0.005) of MSDs.**

Discussion:

- E-waste recycling activities at Agbogbloshie were associated with a high prevalence of MSDs, and varied by body region and job category.
- Collectors were more likely to develop knee and lower leg MSDs (due to long walks) while shoulder and upper arm MSDs were common among dismantlers (due to upper extremity repetitive and forceful exertions).

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