TIRED OF SOCIO-ECONOMIC STRESS:
SOCIO-DEMOGRAPHIC CONTRIBUTORS TO FATIGUE OF MINE WORKERS IN SOUTH AFRICA

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Declaration

I, Jodi Lyndall Pelders, declare that this thesis is my own work. This thesis is being submitted for the Degree of Doctor of Philosophy (Public Health) at the University of the Witwatersrand, Johannesburg. The thesis has not been submitted before for any degree or examination at any other university.

Signature: ....

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Publications arising from this research

Journal articles

Pelders, J. and Nelson, G. (2019). Living conditions of mine workers from eight mines in South Africa. *Development Southern Africa, 36*(3): 265-282. https://doi.org/10.1080/0376835X.2018.1456909.

Pelders, J. and Nelson, G. (2019). Socio-demographic contributors to health and safety of mine workers in South Africa. *Work*, *64*: 67-76. https://doi.3233/WOR-192969.

Pelders, J. and Nelson, G. (2019). Contributors to fatigue at a platinum smelter in South Africa. *The Journal of the Southern African Institute of Mining and Metallurgy, 119:* 313-319. http://dx.doi.org/10.17159/2411-9717/2019/v119n3a11.

Pelders, J. and Nelson, G. (2019). Contributors to fatigue of mine workers in the South African gold and platinum sector. *Safety and Health at Work, 10*: 188-195. https://doi.org/10.1016/j.shaw.2018.12.002.

Research reports

Hodgskiss, J., Letsoalo, S., April, Y. and Schutte, S. (2015). *Health and Safety Impacts of Socioeconomic Conditions and Other Matters Relating to Living Conditions in the South African Mining Industry.* Project number: SIM 13-09-01. Mine Health and Safety Council, Johannesburg.

Hodgskiss, J., Letsoalo, S. and Schutte, S. (2016). *Fatigue Detection in the South African Mining Industry.* Human Factors Group, CSIR Implementation Unit, Johannesburg.

Pelders (Hodgskiss), J. (2018). *Contributors to Fatigue of Mine Workers at Gold and Platinum Operations in South Africa.* Draft Report. Human Factors Group, CSIR Implementation Unit, Johannesburg.

Conference proceeding

Pelders, J., Nelson, G. and Magweregwede, F. (2019). Shift cycles and fatigue in the South African mining industry. *Mine Health and Safety Conference 2019.* The Southern African Institute for Mining and Metallurgy. Johannesburg. pp. 81 – 88*.*

Presentations

Pelders, J. (2017). Health and safety impacts of socioeconomic and living conditions in the South African mining industry. *Culture Transformation Advisory Committee (CTAC) Workshop.* Mine Health and Safety Council, Johannesburg. 31 July 2017 *(oral presentation)*.

Pelders (Hodgskiss), J. (2017). Contributors to fatigue at four gold mines in South Africa. *Research Day 2017 – Public Health for Sustainable Development in Africa.* Wits School of Public Health, University of the Witwatersrand, Johannesburg. 27 November 2017 *(oral presentation)*.

Pelders, J. and Nelson, G. (2018). Contributors to stress of mine workers in South Africa. *6th CSIR Emerging Researchers' Symposium.* The Council for Scientific and Industrial Research (CSIR), Pretoria. 28-29 June 2018 *(poster presentation).*

Pelders, J. and Nelson, G. (2018). Socio-demographic contributors to fatigue of mine workers in South Africa. *Wits Integrated Mine Health and Safety Research Group – Postgraduate Research Seminar.* University of the Witwatersrand, Johannesburg. 21 August 2018 *(oral presentation)*.

Pelders, J. and Nelson, G. (2018). Contributors to fatigue of mine workers in South Africa. *9th Wits Cross Faculty Postgraduate Symposium.* University of the Witwatersrand, Johannesburg. 29-30 October 2018 *(flash presentation – oral and poster).*

Pelders, J., Nelson, G. and Magweregwede, F. (2019). Shift cycles and fatigue in the South African mining industry. *Mine Health and Safety Conference 2019.* The Southern African Institute for Mining and Metallurgy, Johannesburg. 31 October – 1 November 2019 *(oral presentation).*

Preface

This PhD has been a journey. I have been a researcher in the mining industry in South Africa for more than eight years, and most of my work has involved human factors-related research relating to health and safety. I have gained a deeper understanding of the complexity of challenges in this domain, the sensitivity of research findings, the various stakeholders involved, and the difficulties and time involved in addressing issues. My research interests lie in improving the quality of life of the workforce and community through the assessment of factors ranging from health, housing and socio-economic characteristics, to work-related matters. I chose this topic for my PhD as a result of the challenges that are faced by mine workers in South Africa, in the hope that the results can help to improve the mining industry and the lives of each person affected by mining. The South African mining industry faces sustainability issues, which, in turn, affect the workers and mining communities. Workers are pressured to work harder in hazardous conditions, while relatively low wages and poor living conditions commonly still prevail; this affects them physically and mentally. The aim of this thesis was to assess the myriad of factors that lead to fatigue of workers in the South African minerals industry. This fatigue compromises safety, and also affects health, wellness and productivity. I hope that this work is a step in the right direction, and sheds some light on the path for positive changes.

This thesis is dedicated to those who have lost their lives in the South African mining industry, either at or outside of work, and to their families and friends.

Abstract

Mine workers face hazards both within and outside of the workplace. Challenges with socio-economic and living conditions prevail in the South African mining industry, and are linked to worker health and wellbeing. Meanwhile, fatigue is an occupational health and safety risk, which can result from hard physical or mental work, health and psychosocial factors, or inadequate sleep. However, there is a lack of research that has assessed the association between demographic and socio-economic characteristics and fatigue. The aim of this research was therefore to fill this gap, and assess socio-demographic contributors to fatigue of mine workers in South Africa. Findings of the research can be used to identify interventions to improve health, safety and productivity in the industry.

The research was cross-sectional and employed mixed methods. Data collection took place at 12 mines and one smelter from 2014 to 2017. Qualitative data were gathered through interviews and focus group discussions, with a total of 395 participants, including those in management, labour representatives, and workers. Quantitative data were gathered from questionnaires completed by 1 515 workers. The qualitative data were analysed using thematic analysis. The quantitative data were analysed using descriptive and inferential statistics, including Chi-square tests and binomial logistic regression. Methodological triangulation was used to combine and verify the results from the different sources.

The results of the study are contained in four papers published in scientific journals, in fulfilment of the study objectives. The first paper details the living conditions of workers from eight mines in South Africa. The second paper examines associations between socio-demographic factors and health and safety of mine workers. The third paper assesses contributors to fatigue of workers at a platinum smelter. The final paper looks at associations between socio-demographic characteristics and fatigue in the South African gold and platinum sectors. Fatigue was found to be associated with various demographic characteristics, socio-economic and living conditions, and lifestyle, health, safety and wellness factors. In particular, higher levels of fatigue were associated with younger age, higher levels of education, increased commuting times, indebtedness, a lack of exercise, poor nutrition, increased alcohol use, and inadequate sleep. Fatigue was also positively associated with higher levels of stress, poorer health, increased use of sick leave, reduced job satisfaction, and poor quality of life. Multi-stakeholder partnerships, improved employee wellness programmes, enhanced workplace culture, monitoring and evaluation, and further research, are recommended.

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Supervisors made it possible for me to complete my PhD. Prof Gill Nelson was an incredible lead supervisor. I am thankful for her meticulous guidance and input into each task and deliverable, for her responsiveness, and the motivation she provided. Mr Schu Schutte and Dr Sizwe Phakathi were co-supervisors, and I appreciate their expertise and knowledge in the field of research. Mr Schutte originally enabled me to pursue this research, and I value his kindness and involvement. I also acknowledge Dr Phakathi for his input, particularly in facilitating the research conducted for the MHSC, and for his insight and enthusiasm.

A number of others have supported this research, although I only mention a few. I would like to acknowledge staff at the Wits School of Public Health, including Prof Kathleen Kahn and Dr Jude Igumbor, for coordinating the PhD programme, and Mr Paul Bahloko for the administrative support provided. The PhD programme was useful and enjoyable. I also received valuable advice from numerous individuals associated with the school, including Prof Laeticia Rispel, and fellow PhD candidates such as Nancy Coulson, Dr Leane Ramsoomar and Sara Nieuwoudt. Furthermore, I relied on training and direction from statistical experts, including Dr Innocent Maposa, from the Faculty of Health Sciences. I also value the kind and helpful advice and input from the assessors of my Interim Seminar, namely Prof Mark Collinson and Dr Sophi Kisting.

I would like to acknowledge my colleagues from the CSIR, including Ms Sophi Hlatshwayo (Letsoalo) and Ms Siphe Ngobese for their roles as research assistants, and Dr Yazini April from the Human Sciences Research Council (HSRC), who was involved as a technical expect for the MHSC project. I appreciate the significant role they played in translating information and interacting with the study participants, and their involvement in data gathering and capturing. Ms Rosemary Wolson and Ms Priya Kalicharan from the CSIR provided valued assistance and guidance relating to intellectual property and legal matters. I also appreciate the support received from CSIR management throughout the process.

The research could not have taken place without the involvement of each of the study participants. I appreciate each of the participating mining companies for granting permission for me to conduct the work, and would like to thank the numerous individuals that facilitated data collection. I am grateful to each of the participants for giving of their time and sharing their input during the fieldwork. This research was conducted for the participants, in the hope that the findings will result in improvements to the quality of life of individuals associated with the South African mining industry.

I appreciate my family and friends, who have been by my side as I have progressed with this PhD. I would like to thank my parents, Dot and Dave Hodgskiss, for always encouraging me to pursue my interests, and for supporting me and my education. I value the role and example set by each of my siblings – Tammy, Callen, Brin, and their partners Jerome, Karen and Claire. Significantly, I also thank my husband, Martin, for his patience, kindness and encouragement throughout the PhD process.

Finally, I am most grateful to the Lord for guiding my steps, and for providing me with the perseverance to continue despite the obstacles faced along the way.

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Definitions

Fatigue	A state of impaired mental and/or physical performance and lowered alertness arising as a result of or a combination of hard physical and mental work, health and psychosocial factors or inadequate restorative sleep
Job satisfaction	Perceptions or attitudes that people have toward their work
Living conditions	State of the environment in which an individual resides
Mine workers	Unskilled, semi-skilled, or skilled labourers working in production at mines, rather than those working in management positions
Quality of life	The standard of health, comfort, and happiness experienced by an individual or group
Socio-demographics	Demographic and/or socio-economic characteristics
Socio-economics	Social and economic factors
Stress	An imbalance between the demands placed on an individual and the resources that the person has for coping with these demands

Abbreviations and acronyms

AMCU	Association of Mineworkers and Construction Union
BBBEE	Broad-Based Black Economic Empowerment
BMI	Body Mass Index
COMSA	Chamber of Mines of South Africa
COP	Code of Practice
CSIR	Council for Scientific and Industrial Research
DMR	Department of Mineral Resources
DOL	Department of Labour
EEG	Electroencephalography
EMG	Electromyography
EOG	Electrooculography
HIV/AIDS	Human Immunodeficiency Virus and Acquired Immune Deficiency Syndrome
KSS	Karolinska Sleepiness Scale
LOA	Living-Out Allowance
MHSC	Mine Health and Safety Council
MPRDA	Mineral and Petroleum Resources Development Act
NGO	Non-Governmental Organisation
NUM	National Union of Mineworkers
PPE	Personal Protective Equipment
PVT	Psychomotor Vigilance Test
RDP	Reconstruction and Development Programme
SES	Socio-Economic Status
SAIMM	Southern African Institute of Mining and Metallurgy
SAMI	South African Mining Industry
SLP	Social and Labour Plan
TB	Tuberculosis
UASA	United Association of South Africa (formerly named)
YREF	Young Researchers' Establishment Fund

Chapter 1: Introduction

The focus of this research is on socio-demographic contributors to fatigue of mine workers in South Africa. This chapter provides an overview of the work contained in this thesis. Firstly, a brief background on the topic is provided. Following this, the aims and objectives are discussed. Finally, a description of structure of the thesis is outlined. This thesis comprises four scientific articles that were published in fulfilment of the research objectives, and an integrating narrative. Further detail on the context and background to this work is provided in the following chapter, which comprises a review of literature on the topic.

1.1. Background

Fatigue is an occupational health and safety risk, especially in hazardous industries such as mining (Hoefel *et al.*, 2013; Schutte, 2010; South Africa, 2014). Fatigue can result in accidents, injuries, fatalities, and long-term health problems (Halvani *et al.*, 2009b; Horberry *et al.*, 2013; Jing-Gang and Lei, 2013; Schutte, 2010; Shaw, 2003; South Africa, 2014; Williamson *et al.*, 2011). Fatigue is a complex and multi-faceted concept (Araújo *et al.*, 2016; Di Milia *et al.*, 2011; Shen *et al.*, 2006). The definition of fatigue used in this research is: "a state of impaired mental and/or physical performance and lowered alertness arising as a result of or a combination of hard physical and mental work, health and psychosocial factors or inadequate restorative sleep" (Schutte, 2010, p. 53). Fatigue differs from many workplace hazards as it is not only affected by work-related factors (Gander *et al.*, 2011; Schutte, 2010; Shaw, 2003; South Africa, 2014). Fatigue can be caused by a number of factors such as high mental and/or physical demands, shift schedules, work conditions, commuting times, sleep, health problems, psychological issues, and lifestyle factors (ACARP, 2002; Åkerstedt *et al.*, 2014; Di Milia *et al.*, 2011; Horrey *et al.*, 2011; Hossain *et al.*, 2003; NSW, 2009; Schutte, 2010; Schutte and Maldonado, 2003; Shaw, 2003; South Africa, 2014; Williamson *et al.*, 2011).

Mine workers in South Africa face numerous hazards both within and outside the workplace. In addition to health and safety risks, mine workers have challenges relating to poor socio-economic and living conditions. This study took place against the backdrop of industrial action and labour unrest in the South African mining industry (SAMI), and in the context of unemployment, poor service delivery, socio-economic inequalities, and dissatisfaction with wages and living conditions in mining communities (Benya, 2015; Chinguno, 2013b; Twala, 2012). Notably, 44 people, of which 34 were mine workers, were killed during protest action at a platinum mine in Marikana on 16 August 2012 (Chinguno, 2013a, 2013b; Leon, 2012; Twala, 2012). Historically substandard housing and living conditions have had adverse effects on the health, productivity and wellbeing of mine workers (South Africa, 2009b). Major health challenges in South Africa are HIV/AIDs and tuberculosis (TB), non-communicable diseases, poverty-related illnesses, and violence and injuries (Coovadia *et al.*, 2009; Pillay-van Wyk *et al.*, 2016); all of which also affect mine workers. In addition to fatigue, occupational health and safety hazards in mining include, but are not limited to, excessive noise, dust, heat, humidity, and physical job demands, along with traumatic injuries, pulmonary diseases (Amponsah-Tawiah *et al.*, 2013, 2014; Donoghue, 2004; Horberry *et al.*, 2013).

Socio-demographic factors can potentially impact levels of fatigue and its consequences, but there is a lack of research about the interaction between socio-demographic factors and fatigue. In this study, the term socio-demographic, as used in a number of previous studies, refers to a range of factors, including demographic characteristics and socio-economic factors (d'Errico and Costa, 2011; Fischer *et al.*, 2006; Kaida and Kaida, 2017; Koukouli *et al.*, 2002). More specifically, socio-demographic factors were considered to incorporate demographic characteristics, work-related factors, socio-economic and living conditions, and lifestyle-related factors, while being related to psychosocial characteristics. Research on determinants of fatigue has generally focussed on sleep and work time factors, while there is a lack of research particularly about psychosocial aspects, individual differences, and lifestyle factors (Dohrmann and Leppin, 2017). Di Milia *et al.* (2011) noted that they were not aware of any study that has comprehensively examined the effect of a large number of demographic factors on fatigue simultaneously. Furthermore, demographic variables are commonly treated as confounders in analyses of association, rather than independent variables, and the effect of demographic variables, other than age and sex, is largely unknown (Di Milia *et al.*, 2011; Horrey *et al.*, 2011). Further studies to assess a larger range of demographic variables as independent factors to gain a better understanding of fatigue, its risk factors, and mechanisms have been recommended (Horrey *et al.*, 2011; Noy *et al.*, 2011).

1.2. Aim and objectives

The aim of this study was to assess socio-demographic contributors to fatigue of mine workers in South Africa. The research hypothesis was that socio-demographic factors are associated with fatigue of mine workers in South Africa. The findings from this research will contribute to filling knowledge gaps relating to fatigue, and could also be used by mining companies to better manage fatigue, and improve worker health, safety and productivity.

The objectives of the study were:

1. To describe the living conditions of mine workers at eight mines in South Africa;
2. To determine associations between demographic, work, living conditions, lifestyle, and psychosocial variables, with health, safety and wellbeing of workers at these eight mines;
3. To assess contributors to fatigue of workers at a platinum smelter in South Africa; and
4. To assess contributors to fatigue of mine workers in the South African gold and platinum sectors.

The objectives were aligned to the aim of the study. The first two objectives contributed to understanding the context of the study, including socio-demographic characteristics of mine workers in South Africa, and issues relating to health, safety, wellness and fatigue at eight mine sites. Following this, fatigue, and factors associated with fatigue, were studied in further detail at selected sites in the gold and platinum sector (Objectives 3 and 4). More specifically, the first objective was to describe the living conditions of mine workers and provide context in terms of the socio-demographic characteristics of mine workers in South Africa. The second objective focused broadly on health, safety and wellness of mine workers from eight mines (from five different sectors), for which fatigue was one of the factors that was contextualised in this domain. The third objective assessed fatigue of workers in a platinum smelter. These findings could be compared to those obtained at mine sites. The final objective was to conduct an in-depth assessment of fatigue at five sites; the platinum and gold sectors were identified for further analysis, as both socio-demographic and fatigue challenges were prevalent in these sectors. In addition to demographic, socio-economic, living condition and lifestyle characteristics, work-related factors were studied within these objectives as, while these were not the focus of the study, these are important contributors to fatigue of mine workers. The original PhD title and objectives prelisted the research proposal were modified slightly as the study progressed; a description of these modifications is provided in Appendix J.

The outcomes of the four objectives are presented and discussed in respective papers that have been published in peer-reviewed journals, as summarised in Table 1.1. These scientific papers were drafted in fulfilment of the study objectives for the purposes of this thesis.

Table 1.1: Scientific papers based on study objectives

Objective	Paper title	Authors	Journal	Status
1	Living conditions of mine workers from eight mines in South Africa	Pelders, J. Nelson, G.	*Development Southern Africa*	Published online – 10 April 2018; and in print – 2019
2	Socio-demographic contributors to health and safety of mine workers in South Africa	Pelders, J. Nelson, G.	*Work*: *A Journal of Prevention, Assessment, and Rehabilitation*	Published online – 14 August 2019; and in print – 2019
3	Contributors to fatigue at a platinum smelter in South Africa	Pelders, J. Nelson, G.	*The Journal of the Southern African Institute of Mining and Metallurgy (SAIMM)*	Published in print – 2019
4	Contributors to fatigue of mine workers in the South African gold and platinum sector	Pelders, J. Nelson, G.	*Safety and Health at Work*	Published online – 17 December 2018; and in print – 2019

1.3. Overview of the thesis

This thesis is written in an 'integrated' format, and comprises the four scientific papers that were written in fulfilment of the study objectives, preceded by an integrating narrative. The integrating narrative synthesises and discusses the papers, and includes a literature review, the methods of the study, summary of results, and discussion of the findings, followed by the conclusion and recommendations of the research. The papers are attached as Appendices (Appendix A to D). Further outputs from the study are included in Appendices E to I.

1.4. Conclusion of the chapter

The need for further research relating to socio-demographic contributors to fatigue has been identified. The intention of this research was to bridge research gaps relating to fatigue and to make recommendations towards addressing related challenges in the SAMI. The objectives of the research were fulfilled by the drafting and publication of four original scientific articles relating to the research aim. This thesis comprises the four articles, preceded by an integrating narrative to provide further information relating to the background, methods, results, discussion, and conclusions and recommendations arising from the research. The following chapter is the review of literature, which provides an overview of the study context and the area of research. A background to the SAMI is provided, followed by a description of fatigue and its causes and effects.

Chapter 2: Literature review

This chapter details findings from local and international literature that relate to socio-demographic contributors to fatigue of mine workers in South Africa. The first section of the literature review illustrates the context of the research – namely, the SAMI. This section describes both socio-demographic and occupational health and safety elements, which include fatigue concerns. In the next section, definitions of fatigue are examined, following which the numerous potential causes and effects of fatigue are explored. During the review of literature, it became evident that numerous factors could be both causes and consequences of fatigue; these are discussed concurrently. The measurement and management of fatigue is discussed, which lead to the following chapter, which describes the methods employed for this research. A conceptual framework for the research was compiled based on findings from the literature review and an understanding of associations between the studied variables. This framework provides a visual representation of the factors studied in this research and the numerous linkages between them.

2.1. The South African mining industry

Mining plays a significant role in South Africa's economy (Minerals Council South Africa, 2018a). It is estimated that almost 500 000 people were directly employed, and 4.5 million dependents supported, in the SAMI in 2017 (Minerals Council South Africa, 2018a). However, a number of factors challenge the sustainability of the industry, including rising costs, low productivity levels, occupational health and safety concerns, and environmental and social issues (Coulson *et al.*, 2017; Deloitte, 2014; Gumede, 2018; Kinnear and Ogden, 2014; Singh, 2017).

2.1.1. The history of the SAMI

Most South African mining towns maintain poor social and economic conditions, such as poverty, bad housing and infrastructure, unemployment, poor health, prostitution, and a high influx of single migrant labourers, as a consequence of the historical practices of the SAMI (Cronjé and Chenga, 2009). In the colonial and apartheid eras, migrant labourers were employed in the SAMI as it required cheap labour to maintain profitability, and African men left their families in rural parts of South and southern Africa to travel to mining centres and live in single-sex compounds while working at the mines (Bezuidenhout and Buhlungu, 2010). These black workers were banned from, among other things, obtaining skilled jobs and permanently settling in mining towns (Cronjé and Chenga, 2009). Although many mine workers still live in mine hostels while their families reside elsewhere, predominantly in rural settings, there has been a shift to the creation of family housing for mine workers (Marais and Cloete, 2013; Marais and Venter, 2006).

2.1.2. Living conditions in the SAMI

The housing and living conditions for many workers in the SAMI are historically substandard, and have had adverse effects on worker health, productivity and social well-being (South Africa, 2009b). The workforce was predominantly housed in high density, single-sex mining compounds or 'hostels' from the late 1800s (Marais and Nel, 2016; Marais and Venter, 2006; South Africa, 2009b). Mining compounds were considered inhumane and were highly regimented; workers were restricted in terms of where they could work, where they could go, the modes of transport they could use, and the conditions in which husbands and wives could interact (Bezuidenhout and Buhlungu, 2010; SACN, 2017). The situation began to change in the 1970s, with the building of less militaristic compounds, and the provision of family accommodation for mine workers; in response to resistance from mine workers, mining companies formally abandoned the preference for compound accommodation in 1986 (Bezuidenhout and Buhlungu, 2010; Mariais and Venter, 2006). Subsequently, along with political transformation and the attainment of democracy, a new housing policy was implemented in South Africa in 1994, which focuses on ownership for the poor (Chinguno, 2013b; Cloete *et al.*, 2009; Marais and Venter, 2006).

Currently, mine workers have several choices of where to live, both in and around mining communities (Bezuidenhout and Buhlungu, 2010). Mine workers also now have more flexibility to travel, with access to a range of transport options, including minibus taxis and personal cars, as alternatives to trains and company buses (Bezuidenhout and Buhlungu, 2010). Available housing, in addition to conventional compounds located near mine shafts, includes converted compounds and married quarters, family units, villages near mines, flats rented from companies, mine workers' own houses in new suburbs, Reconstruction and Development Programme (RDP, government sponsored) houses, township houses, informal settlements, and 'backrooms' (Bezuidenhout and Buhlungu, 2010; Chinguno, 2013b; Marais and Nel, 2016). Mining companies also commonly offer 'living-out allowances' (LOAs) to employees to subsidize accommodation if workers do not reside in mine accommodation. However, the LOA has had unintended negative social consequences, as it was not necessarily used towards food and accommodation (Chamber of Mines of South Africa (COMSA), 2017). The LOA is linked to an increase in informal settlements, as some employees live in minimal accommodation in informal settlements around the mines, in order to save some of the LOA to send to their rural families (Bezuidenhout and Buhlungu, 2010; COMSA, 2017; The Bench Marks Foundation, 2012).

Lewis (2003) reported the proportion of mines in South Africa with various types of worker accommodation and the proportions of mine labour staying in these accommodation types at the time (see Table 2.1). The most common arrangements were single-sex hostels and LOAs, in which 46% and 31% of the workforce resided, respectively. Hostel room occupancy rates were also assessed. Of the single-sex hostel dwellers, the majority (65%) were accommodated in rooms with seven to eight occupants, while 16% were accommodated in rooms with five to six occupants, and 18% with four or fewer occupants (Lewis, 2003).

Table 2.1: Proportions of labour living in different types of accommodation (adapted from Lewis, 2003)

Accommodation type	Mines reporting use of this accommodation (%)	Mine labour (including contractors) staying in this accommodation (%)
Living-out allowance from mining company	73	31
Single-sex hostel	66	46
Family hostel	45	6
Single flats on mine	21	2
Bond rate subsidy from mining company	8	<1
Bond repayment subsidy from mining company	7	<1
Housing capital subsidy from mining company	1	1
None of the above	0	13

Findings from a worker perception survey by Lewis (2003) indicated that employees were generally moving away from mine accommodation to off-mine dwellings. Of those who stayed in off-mine accommodation, 41% lived in backyard shacks, backyard brick buildings, or free-standing (informal) shacks, while 50% lived in houses or brick structures on their own stands. The remaining 9% stayed in local authority houses, self-built housing on local authority land, flats, or rooms in houses. Around a quarter of the workers reported that their housing impacted negatively on their safety at work, with off-mine residents (34% with LOAs and 30% participating in home ownership schemes) reporting this more frequently (Lewis, 2003). In terms of transport, around 85% had access to taxis and 66% to buses nearby their dwellings, while around 20% had motor vehicles available to them at their dwellings. Those who received LOAs had poorer access to buses and taxis than those with other accommodation arrangements (Lewis, 2003).

In the study by Lewis (2003), it was evident that lower housing standards were more likely to be experienced by off-mine dwellers, especially those who received LOAs, and by lower category employees with lower incomes and educational levels. Problems with housing quality experienced by off-mine dwellers included the quality of building materials, which affected waterproofing and security; basic bulk services (water, electricity, and sewerage); violence and insecurity in the informal dwellings; access to, and quality of, health services and transport; and the perceived permanence of the housing. For the hostel dwellers the deficits were mainly overcrowding; a lack of sleep, rest and privacy; violence and insecurity; and poor access to schools for their children.

In another study conducted in the SAMI, about half of the participating mine workers regarded their areas of origin as their permanent homes, and sent around 33% of their incomes to their families that still lived there (Marais and Venter, 2006). The participating mine workers were asked to rate their levels of satisfaction with their current housing situations; 67% said they were unhappy, 15% were satisfied, and 19% were happy. The majority (70%) of the on-mine residents were unhappy, compared to 48% of the off-mine residents. The main reasons for the unhappiness of on-mine residents were a lack of privacy (33%); not living with family (21%); and a poor living environment (10%). The main reasons for off-mine residents' unhappiness were that they wanted to own a house (23%); sub-standard facilities (19%); and a lack of privacy (11%). Additionally, 82% of on-mine residents and 67% of off-mine residents said that they would like to change their housing situations. While mine workers expressed a high level of dissatisfaction with the compound system, a large proportion reported that they would like to continue to stay in this accommodation (20%); many were not able to afford any form of family housing. At the same time, many mine workers who did not reside in the vicinity of the mine often did not live under adequate conditions. Of the off-mine residents, 73% lived in rented accommodation, and 37% in informal housing. It was also noted that the provision of a housing allowance and the enablement of mine workers to find their own housing had played a role in increasing the number of informal houses in the surrounding areas. The majority of the workers (89%) said that they would prefer to own housing units (Marais and Venter, 2006).

In a later study in the SAMI, 80% of the hostel dwellers indicated that they had a home elsewhere, and most did not want to live in the mining area permanently (Cloete *et al.*, 2009). Of the hostel-dwellers, 63% were generally satisfied or happy with the accommodation; the main reason for this was the close proximity to the workplace. Overcrowding was the main cause of dissatisfaction with the hostel system (Cloete *et al.*, 2009).

A number of challenges have been documented relating to mining communities in the SAMI. Mining communities in South Africa are often isolated, originally rural, have high illiteracy rates, and are largely dependent on mining companies for their livelihoods and development (Cronjé and Chenga, 2009). Lim *et al.* (2011) estimated that each mine worker financially supported seven to 10 dependants. Community dependence on a single sector is associated with economic vulnerability (SACN, 2017). Furthermore, Cronjé and Chenga (2009) explained that local communities may not be able to effectively respond to mine development, occupational skills requirements, and the change from an agricultural to a cash-dependant society; this has resulted in companies recruiting labour from outside of the communities. Mining developments have resulted in an influx of people into surrounding communities, and a lack of service delivery by local governments and suboptimal upliftment projects have resulted in community expectations not being met (PriceWaterHouseCoopers, 2012). Infrastructure development concerns, such as limitations of water, electricity and transport, have been documented (PriceWaterHouseCoopers, 2012). Furthermore, local communities are often exposed to environmental hazards from mine operation waste (Cronjé and Chenga, 2009). Additional negative impacts of mining include environmental degradation, reduced employment in agriculture, chemical spills, water contamination, dust pollution, damaged buildings, and illness (Amponsah-Tawiah *et al.*, 2014). The effects of mine downscaling and closure also have significant social and economic consequences to mining settlements (Marais, 2013; Marais and Cloete, 2013; Marais and Nel, 2016).

2.1.3. Social impacts of mining

It is evident that, despite the great value derived from mining in South Africa, mining can have harmful social, economic and environmental impacts on local communities (The Bench Marks Foundation, 2012). Mining companies are under increased pressure to focus on sustainable development, which can be categorised into the environmental, economic and social dimensions (Cronjé and Chenga, 2009; Fauconnier, 2004). Fauconnier (2004) reported on the way in which the mining industry was dealing with social issues. Examples of interventions were increasing wages, continuously improving accommodation options, expanding healthcare facilities, boosting retirement funding, enhancing skills development, and contributing to rural development (Fauconnier, 2004). Mines are expected to support infrastructure and poverty eradication projects in the area of the mine and in major labour-sending areas (Cronjé and Chenga, 2009). Cronjé and Chenga (2009) reported that housing was a major priority of mines, and partnerships with mining companies, national and local governments, non-governmental organisations (NGOs), traditional leaders, and communities, are necessary to resolve housing issues. Additionally, in response to the

HIV/AIDS crisis, education campaigns, provision of antiretroviral treatment, and strengthened partnerships have been introduced (Fauconnier, 2004). Broad-based black economic empowerment (BBBEE) was implemented to ensure that race was no longer a factor in sharing South Africa's mineral wealth (Fauconnier, 2004). Additionally, mines are required to ensure that a higher percentage of historically disadvantaged South Africans are employed in management positions, and that there is a minimum of 10% participation of women in mining (Cronjé and Chenga, 2009).

Regulatory policies have been implemented to ensure corporate social responsibility in the SAMI. Related legislation, regulations and guidelines include the Constitution of the Republic of South Africa, Act No. 108 of 1996 (South Africa, 1996a), the National Housing Act, Act No. 107 of 1997 (South Africa, 1997a), the Employment Equity Act, Act No. 55 of 1998 (South Africa, 1998), the Mine Health and Safety Act (MHSA), Act No. 29 of 1996, and its amendment (South Africa, 1996b, 2008a), the Mineral and Petroleum Resources Development Act (MPRDA), Act No. 18 of 2002, and its amendment (South Africa, 2002b, 2008b), Broad-Based Socio-Economic Empowerment Charter of the South African Mining Industry (the Mining Charter), and its amendment (South Africa, 2002a, 2010a), the Housing and Living Conditions Standard for the Minerals Industry (South Africa, 2009a), and SLP Guidelines (South Africa, 2010b, 2010c).

The South African Constitution was established to restore and uphold equality and human dignity in South Africa (South Africa, 1996a). The Bill of Rights in the Constitution relates to, among other matters, the environment, property, housing, healthcare, food, water, and social security. The National Housing Act refers to housing development priorities for the poor, consultation with stakeholders, and socially and economically sustainable housing developments and communities with safe and healthy living conditions (South Africa, 1997a). The Employment Equity Act was enacted to promote equality and eliminate unfair discrimination in employment (South Africa, 1998). The MHSA and its amendment provide for the protection of the health and safety of employees and other people at mines, and also provide regulations about standards of housing and nutrition for employees accommodated at mines (South Africa, 1996b, 2008a).

The MPRDA and its amendment required the development of a housing and living conditions standard for the minerals industry, a code of good practice for the minerals industry, and a broad-based socio-economic empowerment charter (South Africa, 2002b, 2008b). The objectives of these are to redress historical, social and economic inequalities, and to set relevant frameworks, targets and timetables. A further objective of the MPRDA is to increase opportunities for historically disadvantaged groups, including women, to enter into and benefit from the minerals sector.

The Housing and Living Conditions Standard for the Minerals Industry provides guidelines to foster suitable housing, healthcare services, and sufficient food and water for mine workers (South Africa, 2009a). Strategies to improve the housing and living conditions of mine workers include the upgrading of hostels to decent single accommodation apartments, the conversion of hostels to family housing, and the promotion of home ownership amongst mine workers. In the Codes of Good Practice for the South African Minerals Industry indicators for mine community and rural development, as well as general principles for measuring housing and living conditions, are provided (South Africa, 2009b).

The Mining Charter was developed to help redress issues relating to inequality and to assist in the empowerment of historically disadvantaged South Africans in the mining industry (South Africa, 2002a). In the Charter, specific reference is made to mine community and rural development, and to housing and living conditions. The amendment to the Charter specifically committed mining companies to implement measures to improve the standards of housing and living conditions for mine workers as follows: “Convert or upgrade hostels into family units by 2014; attain the occupancy rate of one person per room by 2014; and facilitate home ownership options for all mine employees in consultation with organised labour by 2014” (South Africa, 2010a, p. 4). The Mining Charter further required mining companies to ensure a baseline of 10% of women participating in the SAMI by 2009.

The MPRDA requires mining companies to submit Social and Labour Plans (SLPs) to the Department of Mineral Resources (DMR) for the granting of mining or production rights (South Africa, 2010b, 2010c). The SLP requires the development and implementation of various programmes that aim to promote employment and improvement of the social and economic welfare of all South Africans, and ensure economic growth and socio-economic development. These programmes include the Human Resources Development Programme, Mine Community Development Plan, Housing and Living Conditions Plan, Employment Equity Plan, and processes to save jobs and manage downscaling and/or closure (South Africa, 2010b, 2010c).

There have, however, been difficulties with the application of the legislation and regulations in the SAMI. For example, a lack of compliance with SLPs. and difficulties in agreeing on projects with local communities, municipalities, other regulators, and other mines in the area are reported challenges (PriceWaterHouseCoopers, 2012). Additionally, changes in housing policies and labour regimes in the mining industry have resulted in informal settlement development and urban sprawl (SACN, 2017). Changes in housing policies, along with dismantling of high density accommodation in hostels, and the conversion into single or family accommodation units, have resulted in large numbers of mine workers having to seek housing elsewhere (SACN, 2017). Changes in labour regimes include a move towards shift work and longer shifts, and outsourcing of contract workers (SACN, 2017). Furthermore, it has been argued that mine housing is unsustainable owing to the limited life of mines, while home ownership and mortgage bonds could also be a problem as a result of unstable labour markets (Cloete *et al.*, 2009). Home ownership might not be appropriate as the need for housing in mining areas might be temporary, and the locations might not be economically viable for the residents in the long-term (Ntema *et al.*, 2017). A further consideration is that many mine workers do not want to move their families to mine areas, but would rather invest in housing in the labour-sending areas, where they would retire (Cloete *et al.*, 2009).

Stakeholders, including government, mining companies, organised labour, and mining communities or civil society, need to cooperate to create sustainable mining development outcomes (Hamann, 2010; Phakathi, 2014). The importance of private-public, local, and multi-stakeholder partnerships, transparent and participatory planning and decision-making, long-term strategy and vision, structures to address issues, and strategies and knowledge-based interventions to mitigate the effects of mine closures and assist communities to become sustainable, have been highlighted (Cronjé and Chenga, 2009; Littlewood, 2014; Marais, 2013). Furthermore, heightened levels of industrial action indicate the need for mining companies to have direct channels of communication with workers (PriceWaterHouseCoopers, 2012).

2.1.4. Women in mining

The mining industry is historically male-dominated, and women were legally prohibited from being employed in underground operations in South Africa until the 1990s (Benya, 2016; van Aardt *et al.*, 2008; Zungu, 2012). As a result of changes in legislation, increasing numbers of women are entering the SAMI. Females represented 6% of mining employees in 2009, 10.5% in 2014, and 12% in 2017 (COMSA, 2018; South Africa, 2015a). However, women in mining could face increased risk of injury and ill-health, and threats to reproductive health, personal safety and security, and work-life balance (AngloAmerican, 2012; Hermanus, 2007). Females could face different health and safety needs than males as a result of different anatomical and physiological compositions (Zungu, 2012). As women generally have lower physical work capacities and strength than men, women would have to work closer to their physical work capacities than men to attain the same levels of productivity, which could lead to a higher risk of fatigue, accidents and injuries than for men performing the same work (Dlamini, 2016; van Aardt *et al.*, 2008). Additionally, women are often required to use work equipment, machinery, tools, and personal protective equipment (PPE) that is designed for men, which could contribute to increased risks of accidents and/or musculoskeletal disorders (Hermanus, 2007; Hodgskiss *et al.*, 2017; van Aardt *et al.*, 2008; Zungu, 2012; Zungu, 2013).

2.1.5. Health and safety

This section describes health and safety matters in South Africa and in the mining industry locally and internationally. The history of South Africa has had a substantial effect on its peoples' health, and on health policy and services (Coovadia *et al.*, 2009). This history incorporates colonial subjugation, apartheid dispossession and the post-apartheid period, in which racial and gender discrimination, the migrant labour system, high levels of poverty and unemployment, and income inequalities were (and still are) evident (Coovadia *et al.*, 2009; Pillay-van Wyk *et al.*, 2016). Health system challenges include those posed by communicable and non-communicable diseases, which have been accelerated by the HIV/AIDS epidemic. South Africa is faced with a quadruple burden of disease, namely the epidemics of poverty-related illnesses, non-communicable diseases, HIV/AIDS, and violence and injuries (Coovadia *et al.*, 2009; Pillay-van Wyk *et al.*, 2016). Leading causes of death in South Africa for 2012 are listed in Table 2.2.

Table 2.2: Top 10 single causes of death in South Africa in 2012 (adapted from SAMRC, 2012)

Disease, injury or condition	Persons (%)
HIV/AIDS	29.1
Cerebrovascular disease	7.5
Lower respiratory infections	4.9
Ischaemic heart disease	4.7
Tuberculosis	4.5
Diabetes mellitus	3.6
Hypertensive heart disease	3.5
Interpersonal violence	3.5
Road injuries	3.3
Diarrhoeal diseases	3.1

The prevalence of HIV/AIDS has been a particular concern in the SAMI, and the pandemic in South Africa has been attributed to the migrant labour system (Bezuidenhout and Buhlungu, 2010; Fauconnier, 2004). Dias *et al.* (2006) investigated the impact of HIV/AIDS on occupational health and safety in the SAMI and reported that the harsh working environment in mines could hasten the progression of HIV/AIDS, particularly if poor nutrition and living conditions were present. A study on gold miners showed that HIV positivity was, additionally, associated with an increase in work-related injury rates (Lim *et al.*, 2011). Furthermore, the prevalence of HIV/AIDS increases the risk of silicosis (Donoghue, 2004). Silicosis and HIV pose an interactive risk for the development of TB, which is a significant contributor to occupational disease in the mining industry (Dias *et al.*, 2006; Hermanus, 2007). International and regional efforts have focussed on controlling the triple epidemics of silicosis, TB and HIV infection of migrant mine workers in South Africa, who are from rural areas of South Africa and surrounding countries (Ehrlich *et al.*, 2018).

Both HIV/AIDs and TB are significant health risks in the SAMI, as they are linked to living and working conditions, including migrant labour, single-six hostels and dense living arrangements, and closed ventilation in underground workplaces (Hermanus, 2007). The incidence of TB in South Africa increased from 305 per 100 000 in 1993 to 948 per 100 000 in 2007 (Stuckler *et al.*, 2011). Stuckler *et al.* (2011) noted that this incidence is largely attributable to HIV infection, but that TB transmission is also related to factors such as late diagnosis, incomplete treatment, migration, and low socio-economic status (SES). Mine workers have a particularly high risk of contracting TB, and mine workers in sub-Saharan Africa have a higher incidence of TB than any other working population in the world (Stuckler *et al.*, 2011). Many mine workers are migrants, and migrancy is linked to TB risk factors, including HIV, healthcare disruptions and low SES (Stuckler *et al.*, 2011). Mine workers in some areas have access to extensive tertiary-care health facilities during employment periods; however, primary-care facilities near mines and in the rural areas to which workers return between periods of work are often sparse. Stuckler *et al.* (2011) further noted that health care facilities may be inaccessible to contract workers. Sex work is also common around single-sex hostels at mines, which increases the risk of HIV and, hence, TB (Stuckler *et al.*, 2011). It has been estimated that mine workers were three to four times more likely to be infected with HIV than non-mine workers (Stuckler *et al.*, 2011).

Lim *et al.* (2011) analysed death-related data in South African platinum mine workers from 1992 to 2008. Mortality due to HIV/AIDS was the most common cause of death in the study cohort (44%), followed by deaths from unnatural causes (27%) which comprised road traffic accidents (38%), homicides (30%), occupational injuries (17%), suicides (8%) and other accidents (6%). The rate of unnatural death in the cohort was more than triple the worldwide average for males in 2004, but lower than the average for the South African population in 2000. While the rates of homicides, suicides and accidents were lower than those in the South African population, rates were significantly higher for occupational fatalities and road traffic accidents. Alcohol misuse, excessive speeding, driver fatigue, mechanical failures and inadequate facilities for pedestrians were causes of traffic accident deaths. However, the rates of road traffic accidents decreased over the study period, perhaps because mine workers and their families were more likely to live closer to the mine with time, and therefore spend less time travelling home on non-work days, or because of an increase in car ownership. Violence in South Africa is related to social and structural factors such as poverty, unemployment, inequity, racial and political conflict, social dynamics, lack of firearm control, and high levels of drug and alcohol use (Lim *et al.*, 2011).

Health issues in mining communities include family stress, violence towards women, and addiction problems (Shandro *et al.*, 2011). Health issues have also been associated with the mining boom-bust cycle (i.e. mining initiation and production to mine closure), as during booming mine activities, increases in pregnancies, sexually transmitted infections, and mining injuries were reported, while during bust times, mental health issues such as depression and anxiety were prevalent (Shandro *et al.*, 2011). D’Souza *et al.* (2013) studied factors associated with health-related quality of life among women in mining communities. They reported that people living in mining communities may be exposed to health problems that are related to contamination of air, water, food, soil and river beds with toxic chemical and metallic discharges. At the same time, those employed in mines are exposed to risks of occupational illnesses, which result from exposure to toxic and hazardous substances, poor safety, and a lack of control over the work that is performed. D’Souza *et al.*’s study revealed that those in a mining community reported more eye, upper respiratory, lower respiratory and psychosomatic illnesses than those in an agricultural community (54%, 30%, 49% and 52%, versus 43%, 24%, 20% and 35%, respectively), as well as higher levels of domestic violence. Other reported hazards in mining communities included unemployment, criminal and violent behaviour, alcoholism, drug addiction, gambling, and infidelity, which have further resulted in increased risks of HIV/AIDS and other sexually transmitted diseases (D’Souza *et al.*, 2013). Those in socially and economically disadvantaged and stressed communities of developing countries are reportedly at a heightened risk of health problems (D’Souza *et al.*, 2013).

Mining is globally recognised as a highly dangerous and hazardous sector, as reflected in the high prevalence of accidents, injuries, occupational diseases and fatalities (Amponsah-Tawiah *et al.*, 2013; Chen and Zorigt, 2013; Kramer *et al.*, 2017; Nowrouzi-Kia *et al.*, 2018; Saleh and Cummings, 2011; Sanmiquel *et al.*, 2014). Mine workers' health and safety is affected by various physical, psychosocial, chemical and mechanical risks (Amponsah-Tawiah *et al.*, 2013, 2014). Identified hazards include excessive noise, poor lighting, high dust levels, chemicals, mine gases, fires, heat, humidity, whole-body and hand-arm vibration, restricted spaces, physical work demands, and shift work (Amponsah-Tawiah *et al.*, 2013, 2014; Donoghue, 2004; Hermanus, 2007; Horberry *et al.*, 2013; Nowrouzi-Kia *et al.*, 2018). Resulting challenges faced by mine workers include traumatic injuries, cumulative trauma injuries, pulmonary diseases, silicosis, asbestosis, mesothelioma, lung cancer, heat stress, noise-induced hearing loss, fatigue, and impaired performance (Amponsah-Tawiah *et al.*, 2013; Donoghue, 2004; Kramer *et al.*, 2017). Accidents can result from rock falls, fires, explosions, flooding, mobile equipment incidents, faulty machinery, slips and falls, falls from height, entrapment, and electrocution (Amponsah-Tawiah *et al.*, 2013; Kramer *et al.*, 2017; Nowrouzi-Kia *et al.*, 2018).

Mining injuries are common, have significant socio-economic consequences and impacts on worker health, and are characterised by personal, workplace, and health system factors (Bhattacherjee *et al.*, 2007; Ghosh *et al.*, 2014; Nowrouzi-Kia *et al.*, 2018). Factors associated with occupational injuries identified in previous research include older age, lower education and occupational class, exercise level, health status, marital status, smoking, family conflicts, emotional instability, stressful life events, daily hassles, a lack of social support, a lack of safety management teams, job stress, job tasks, poor work conditions, poor work environments (e.g. underground mining), job training and work experience (Bhattacherjee *et al.*, 2007; d'Errico *et al.*, 2007; Ghosh *et al.*, 2004; Nowrouzi-Kia *et al.*, 2018). Bhattacherjee *et al.* (2007) recommended that preventative measures should reduce the job tasks, help workers to improve their living conditions, and increase worker awareness of the risks associated with these factors.

Psychosocial hazards are associated with compromised workplace safety outcomes, while poor working conditions associated with mining also affect workers' psychological and physical health (Abbe *et al.*, 2011; Amponsah-Tawiah *et al.*, 2013, 2014; Chen and Zorigt, 2013). Psychosocial hazards at work are related to job content, job control, workload, workplace, environment, equipment, work schedule, organisational culture, stakeholder pressure, investment, policies or regulations, management and supervisor support, interpersonal relationships at work, responsibility for the safety of others, job certainty, training, safety climate, career development, job security, and the home-work interface (Abbe *et al.*, 2011; Amponsah-Tawiah *et al.*, 2013; Chen and Zorigt, 2013). Other psychosocial hazards include drug and alcohol abuse, stress resulting from fatalities and traumatic injuries or accidents, and post-traumatic stress disorders (Donoghue, 2004). Remote locations are common in mining, and separation of mine employees from their families and communities during work periods could also result in psychosocial stress (Donoghue, 2004).

Sick leave frequency and duration are also related to working conditions, job contents, working relations, and work circumstances (Beemsterboer *et al.*, 2009; d'Errico and Costa, 2011). Sick leave is further associated with health status, motivation, and individual and lifestyle characteristics including age, gender, marital status, level of education, SES, level of satisfaction with private circumstances, alcohol consumption, and smoking (Beemsterboer *et al.*, 2009; d'Errico and Costa, 2011). Improved health and safety performance can lead to improved productivity and employee morale, and reduced absenteeism (Chen and Zorigt, 2013).

2.1.6. Fatigue in the mining industry

Fatigue is a significant health and safety concern, as it increases the risk of accidents, injuries and death, and reduces productivity (Halvani *et al.*, 2009b; Schutte, 2010; South Africa, 2014; Williamson *et al.*, 2011). Many incidents and near misses in the mining industry involve sleepiness and fatigue (Jing-Gang and Lei, 2013; Vieira and Barros, 2011). Fatigue reduces alertness, attention, work efficiency and quality, judgement, and ability to avoid danger, and is seen to inadvertently produce unsafe behaviour (Halvani *et al.*, 2009b; Jing-Gang and Lei, 2013). The following section discusses the concept of fatigue, after which numerous potential causes and consequences of this phenomenon are examined.

2.2. Fatigue, sleepiness, and sleep

2.2.1. Defining fatigue and sleepiness

Fatigue is difficult to define, as it is a complex and multi-dimensional phenomenon (Aghdam *et al.*, 2019; Araújo *et al.*, 2016; Di Milia *et al.*, 2011; Shen *et al.*, 2006). Definitions include:

- "An overwhelming sense of tiredness, lack of energy and a feeling of exhaustion, associated with impaired physical and/or cognitive functioning" (Shen *et al.*, 2006, p. 70);
- "The inability to function at the desired level due to incomplete recovery from the demands of prior work and other waking activities" (Gander *et al.*, 2011, p. 574);
- "An alteration which occurs in the psychophysiological control mechanism that regulates task behaviour, as a result of considerable previous mental and physical considerable efforts which have become onerous to such extent that the individual is no longer capable to effectively meet the necessities that the job requires of his or her mental functioning" (Halvani *et al.*, 2009a, p. 19);
- "A subjective lack of physical and mental energy that interferes with usual activities" (Boosman *et al.*, 2011, p. 690); and
- "A biological drive for recuperative rest" (Williamson *et al.*, 2011, p. 498).

The definition of fatigue used in this research is "a state of impaired mental and/or physical performance and lowered alertness arising as a result of or a combination of hard physical and mental work, health and psychosocial factors or inadequate restorative sleep" (Schutte, 2010, p. 53). This definition of fatigue was chosen as it reflects the reduced levels of functioning noted in numerous definitions of fatigue, and incorporates both physiological and cognitive or psychological components, while also considering a range of potential causes of fatigue. These causes are not limited to prior activity or sleep, and were incorporated to preclude other potential causes of impaired performance. For this research, fatigue was understood to be analogous to tiredness or feelings of exhaustion, to share symptoms with sleepiness, to potentially be caused by sleep deprivation or stress, and to be present in conditions such as burnout.

Fatigue is a highly prevalent phenomenon that is associated with physical and psychosocial morbidity, is often a main healthcare complaint, and has been a debilitating or even life-threatening force in working populations (Abu-Mourad *et al.*, 2010; Shen *et al.,* 2006). The consequences of fatigue can be short-term, mainly relating to poor safety outcomes, or long-term, relating to reduced physical and/or psychological health, and include tiredness in everyday activities, muscular weariness, and reduced coordination and alertness (Dawson *et al.*, 2011; Shaw, 2003). Prevalence rates of fatigue of 18% to 24% have been reported in the general populations of the US, UK and Norway, and around 20% of the total working population worldwide is reportedly fatigued (Di Milia *et al.*, 2011; Shen *et al.*, 2006). Mine workers in a South Africa have been reported to experience, on average, 22% of the listed symptoms of fatigue (Edwards *et al.*, 2011).

Fatigue may be acute or chronic, physiological or psychological, and central or peripheral (Shen *et al.*, 2006). Acute fatigue can occur when there is inadequate recovery from a single work period, while cumulative (or chronic) fatigue occurs when recovery from acute fatigue is insufficient over time (Gander *et al.*, 2011). Acute fatigue may be classified as mental or physical (Brake and Bates, 2001). Physical fatigue follows physical exertion and is characterised by reduced force-producing capacity, while mental fatigue is characterised by reduced motivation, efficiency, and alertness during or following task performance (Davy, 2018). Flechtner and Bottomley (2003), similarly, noted that subjective fatigue has at least three aspects, namely physical, emotional and cognitive. Jing-Gang and Lei (2013) indicated that fatigue among mine workers may be physiological (as a result of the manual operations), psychological (because of the poor working environment, monotonous work, and mental or emotional burdens), or pathological (because of disease). However, fatigue needs to be distinguished from symptoms of depression, such as low self-esteem, sadness, despair and hopelessness (Shen *et al.*, 2006).

Fatigue and subjective sleepiness distinct phenomena, but they are associated; the terms are often used interchangeably or are combined under the word ‘tired’ (Åkerstedt *et al.*, 2014; Dawson and Fletcher, 2001; Hossain *et al.*, 2003; Shen *et al.*, 2006). Sleepiness can be defined as ‘sleep propensity’, or a person’s tendency to fall asleep (Shen *et al.*, 2006). There may be considerable overlap between sleepiness and fatigue, and they may produce similar test results (Hossain *et al.*, 2003). Subjective sleepiness may be associated with impaired cognitive and psychomotor performance, mood, motivation, autonomic and other physiological changes, and the perceived need for sleep (Shen *et al.*, 2006). Meanwhile, fatigue has generally been related to poor sleep quality, reduced sleep duration, and sleep-onset latency (i.e. the time taken to fall asleep) (Åkerstedt *et al.*, 2014; Dawson and Fletcher, 2001; Shaw, 2003).

Fatigue and/or sleepiness can result from a lack of adequate restorative sleep caused by the cumulative effects of chronic and acute sleep deprivation, a misalignment of a person's sleep-wake schedule and circadian rhythm or time of day, and an increased number of waking hours before the start of work (Åkerstedt *et al.*, 2008; Fletcher and Dawson, 2001; Hossain *et al.*, 2003). Sleep deprivation may be cumulative, which refers to partial sleep deprivations over consecutive days, or continuous, when one stays awake for a single, extended period (Dawson *et al.*, 2011; Fletcher and Dawson, 2001). Numerous occupational, physiological and psychosocial factors influence the amount of sleep received, such as the length of work and rest periods, the timing of rest periods relative to the circadian cycle, and the use of non-work time (Ferguson *et al.*, 2010). In terms of circadian rhythm effects, sleep occurring when an individual is biologically driven to be awake, as is commonly the case for shift workers, tends to be shorter and of poorer quality (Fletcher and Dawson, 2001).

2.2.2. Sleep and circadian rhythms

Sleep is regulated by the interaction of homeostatic and circadian processes that determine sleep-wake cycles (Alhola and Polo-Kantola, 2007). The homeostatic process depends on prior sleep received and time awake (Åkerstedt *et al.*, 2008; Alhola and Polo-Kantola, 2007). Meanwhile, the circadian process refers to the effect of an endogenous circadian pacemaker (Åkerstedt *et al.*, 2008; Alhola and Polo-Kantola, 2007). The circadian rhythm can be defined as "the internal cycle of roughly 24 hours that regulates the physiological and behavioural activities of all living organisms – also referred to as 'the body clock" (South Africa, 2014, p. 3). Body temperature, heart rate, and blood pressure, for example, are higher during daylight hours, and are associated with increased alertness and performance; body temperature, heart rate and cortisol decrease in the evening, and are associated with sleep (Caldwell *et al.*, 2008; Schutte, 2010).

Sleep loss, such as that due to sleep deprivation and chronic sleep restriction, impairs health, safety, productivity, and quality of life (Alhola and Polo-Kantola, 2007; Belenky *et al.*, 2003). Total and partial sleep deprivation result in impaired cognitive performance, including attention, working memory, long-memory, and decision-making (Alhola and Polo-Kantola, 2007). Sleep deprivation also results in lapses, response slowing, fluctuations in alertness and effort or motivation, and poorer moods (Alhola and Polo-Kantola, 2007; Franzen *et al.*, 2009; Kalmbach *et al.*, 2018). Reduced sleep can increase cardiovascular disease risk, and lead to hypertension, diabetes, obesity, cognitive dysfunctions, and lower learning abilities (Pfeifer, 2017). Sleep and labour productivity are associated, as workers who had shorter sleep than usual have been found to have poorer performance, especially when performing repetitive tasks (Szalontai, 2006). It is argued that sleep is necessary for efficiency and utility, and to maximise productivity and income (Szalontai, 2006).

Psychomotor performance of participants who were awake for 28 hours has been shown to be similar to that of those with moderate alcohol intoxication (Araújo *et al.*, 2016). Performance lapses have been recorded following cumulative wakefulness in excess of 16 hours (van Dongen *et al.*, 2003). Sleep deprivation studies have also indicated peak levels of fatigue, sleepiness, cognitive errors, and slowed reaction times in morning hours, ranging from 02h00 to 12h00, as a result of sleep deprivation and circadian rhythmicity (Lombard and Hodgskiss, 2014; Roca *et al.*, 2012; van Dongen and Dinges, 2000; Wesensten *et al.*, 2004). These times are the few hours following the circadian minimum core body temperature (van Dongen and Dinges, 2000). Figure 2.1 illustrates the interaction between measures of sleepiness and body temperature throughout the 24-hour cycle. Lowest levels of alertness tend to occur around 04:00 to 05:00 (Åkerstedt *et al.*, 2008).

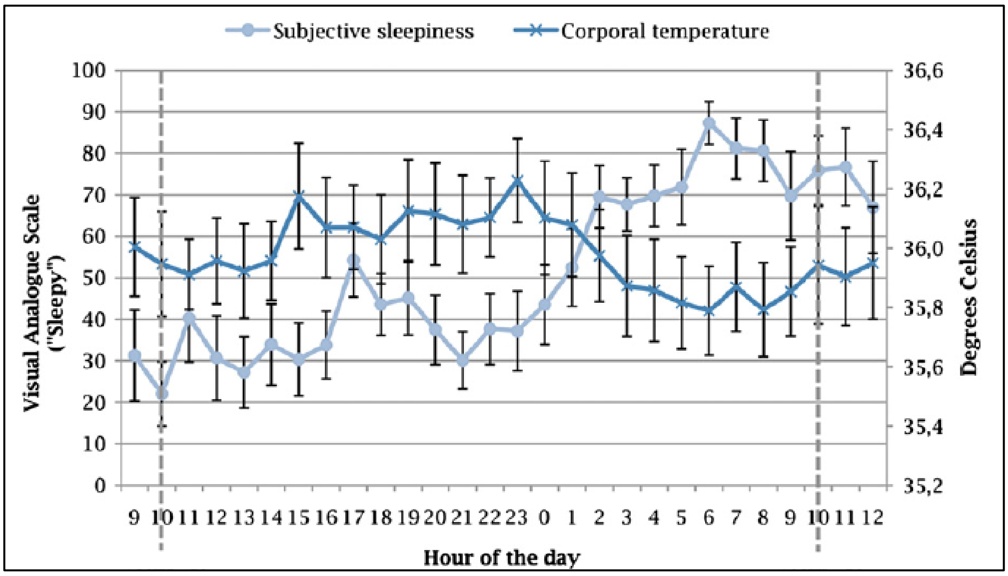

Figure 2.1: Subjective sleepiness and body temperature during a sleep deprivation study (Roca *et al.*, 2012, p. 174).

Individuals differ in terms of sleep length, timing and structure, and some people are more vulnerable to sleep loss than others (Alhola and Polo-Kantola, 2007). Genetic factors are significant determinants of individual sleep requirements, and individual traits could also affect the ability to tolerate sleep deprivation (Alhola and Polo-Kantola. 2007; Rae *et al.*, 2016). Di Milia *et al.* (2011) asserted that different people display tendencies towards morningness or eveningness, and that this is largely genetically determined, although it can be influenced by societal, family and various environmental factors. Personality could also affect these characteristics as, for example, extraversion has been associated with eveningness (Baehr *et al.*, 2000). Morning-types have earlier sleep schedules and earlier circadian temperature phases than evening-types (AngloAmerican, 2005; Baehr *et al.*, 2000). Baehr *et al.* (2000) found that minimum core temperatures of morning-types, neither-types (neutral), and evening-types occurred at 03:50, 05:02, and 06:01, respectively. Morningness and eveningness affect the times of day when loss of alertness occurs (Di Milia *et al.*, 2011). These tendencies also affect sleep durations and efficiency when forced to conform activities to work schedules that may not align to the natural sleep pattern (Di Milia *et al.*, 2011). Evening- or neutral- types could be better suited to shift work or permanent night work than morning-types (AngloAmerican, 2005).

Guidelines recommend that children of 6 to 13 years obtain 9 to 11 hours of sleep, teenagers (14 to 17 years) 8 to 10 hours, and adults (18 to 64 years) 7 to 9 hours of sleep per night (Rae *et al.*, 2016). Objective data gathered from 2010 to 2015 suggested that the majority of the 6 052 participants did not follow the current sleep guidelines; total sleep time ranged from 5.8 to 7.8 hours per night (Rae *et al.*, 2016). Mean hours of sleep reported in a nation-wide study in Germany was 6.8 hours during the work week, and 8.0 hours during the weekend (Pfeifer, 2017). Similarly, Szalontai (2006) reported that habitual sleep received by Western adults is considered to be 7.5 hours. However, in a South African time use survey, the average time spent on sleep and sleep-related activities, was 573 minutes (9.6 hours) per day (Szalontai, 2006).

2.3. Causes and consequences of fatigue

Fatigue can result from both work- and non-work-related factors (South Africa, 2014; Schutte, 2010; Shaw, 2003; Theron and van Heerden, 2011). Many demographic, personality and workplace factors affect levels of fatigue and its consequences (Horrey *et al.*, 2011). Total worker fatigue is the result of a combination of fatigue related to work-time arrangements, work and environmental factors, and personal factors; work performed interacts with factors such as work schedules and personal characteristics in fatigue outcomes (Di Milia *et al.*, 2011; Schutte, 2010). Work-related factors include roster design, task-related factors, and the work environment (ACARP, 2002; Shaw, 2003). Non-work related causes include health (e.g. sleep disorders, medical and psychiatric illnesses), medications, lifestyle, poor nutrition, a lack of exercise, sleep disruption, stress, alcohol or drug abuse, a lack of awareness (e.g. of risks or requirements), culture, social and domestic activities, and environmental factors such as accommodation and community factors

(ACARP, 2002; Hossain *et al.*, 2003; Schutte, 2010; Shaw, 2003; South Africa, 2014). Employee demographics, cultural obligations, personal lifestyle choices, in addition to work factors, can all influence sleep and waking behaviour (Dawson *et al.*, 2011).

In this section, specific factors that could be associated with fatigue are explored in more detail. These factors range from demographic and socio-economic characteristics, housing conditions, lifestyle, and work, to health, safety and psychosocial influences and outcomes. Figure 2.2 illustrates potential variables linked to fatigue.

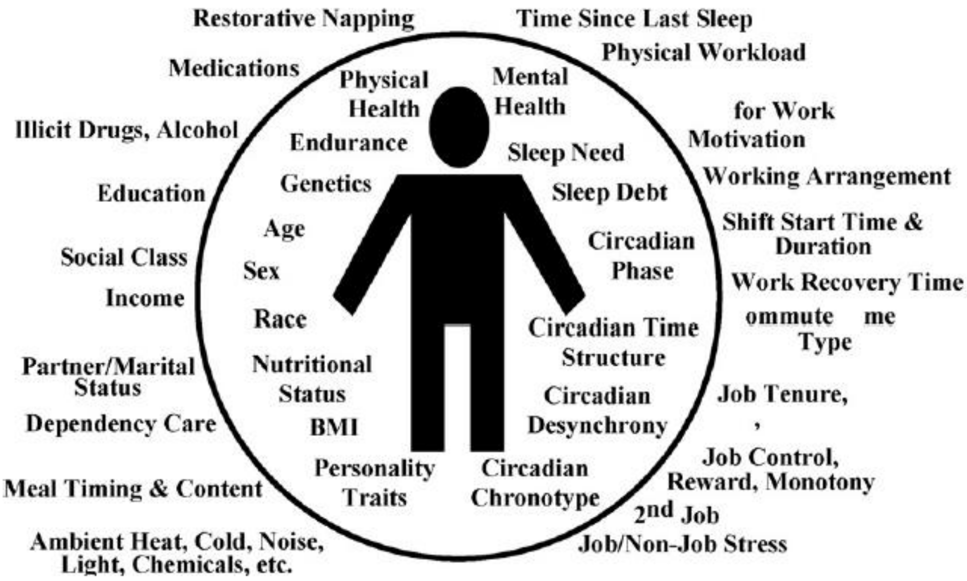

Figure 2.2: Range of potential endogenous and exogenous variables that may be linked with fatigue (Di Milia *et al.*, 2011, p. 517)

2.3.1. Demographic characteristics

As will be discussed further in this section, fatigue has been associated with age, gender, marital status, ethnic identification, SES, and work status in working populations (Halvani *et al.*, 2009a). However, a better understanding of how individual differences impact fatigue is needed, in order to best predict fatigue, understand safety outcomes, and assess various fatigue countermeasures (Horrey *et al.*, 2011). The interaction of demographic factors with fatigue, aside from age and sex, is a generally neglected area of study (Di Milia *et al.*, 2011). When these variables have been assessed, they are usually considered as covariates or confounders (Di Milia *et al.*, 2011). Additionally, demographic issues have been highlighted in future directions for fatigue research (Noy *et al.*, 2011).

2.3.1.1. Age

Mixed results on the association between age and fatigue have been reported. A number of studies have reported increased risk of fatigue with increasing age (Flechtner and Bottomley, 2003; Härmä *et al.*, 2018). Aging causes a decrease in physical and mental abilities, beginning at around 45 to 50 years, which could lead to increased risk of occupational injuries, and deterioration in performance as a result of worsened eyesight, slower perception and response times, and reduced muscle strength (Amponsah-Tawiah *et al.*, 2014; Di Milia *et al.*, 2011). Additionally, aging changes the structure of sleep, with shorter sleep durations and worsened sleep quality (Alhola and Polo-Kantola, 2007; Araújo *et al.*, 2016; Di Milia *et al.*, 2011; Rae *et al.,* 2016). Average sleep times have been found to decrease by over 30 minutes with age (Szalontai, 2006). There is also an increased tendency towards morningness, reduced tolerance to shift work and extended shifts (≥12 hours), and more difficulty in adjustment of circadian rhythms due to changes in the sleep-wake cycle, with increased age (AngloAmerican, 2005; Araújo *et al.*, 2016; Baehr *et al.*, 2000; Di Milia *et al.*, 2011). Younger workers are generally considered to be more adaptable to shift work or permanent night work (AngloAmerican, 2005). The association between age and fatigue is reportedly strongest in blue-collar workers with low job autonomy (Di Milia *et al.*, 2011).

Conversely, several other studies found that increased fatigue was associated with younger individuals (Åkerstedt *et al.*, 2014; Halvani *et al.*, 2009a; Park *et al.*, 2001; Winwood *et al.,* 2006). Alhola and Polo-Kantola (2007) reported that cognitive performance during prolonged wakefulness was sustained better in older than in younger individuals, suggesting better tolerance for sleep deprivation in older people. Older workers have also been shown to be more realistic in their expectations about the effect of fatigue on performance (AngloAmerican, 2005). Younger workers have reported lower levels of well-being than older workers, and their lack of experience or knowledge could result them in being more likely to engage in risk-taking behaviours (Amponsah-Tawiah *et al.*, 2014; Chau *et al.*, 2008). Younger participants are also usually more chronically sleep deprived, because of factors such as raising children, studying and/or building careers (Alhola and Polo-Kantola, 2007). Age-related lifestyle differences may be associated with fatigue-related accident risk (Di Milia *et al.*, 2011). As such, it appears that older individuals might be more susceptible to fatigue due to changes in sleep structure, while fatigue might be a risk to younger individuals because of lifestyle factors and risk-taking behaviours.

2.3.1.2. Sex

Fatigue has often been reported to be more prevalent in females than males, including female mine workers in South Africa (Abu-Mourad *et al.*, 2010; Åkerstedt *et al.*, 2014; Di Milia *et al.*, 2011; Edwards *et al.*, 2011; Flechtner and Bottomley, 2003). Working women have tended to have shorter sleep duration estimates than men, and age-dependent sleep disruptions and fatigue have been reported to be more evident in women, prominently in the pre- and peri-menopausal phases (Di Milia *et al.*, 2011). Differences in sleep structure between men and women are reported, with women of all ages reporting more sleeping problems than men (Alhola and Polo-Kantola, 2007). It also appears that women tend to have more morning characteristics than men (Baehr *et al.*, 2000). However, other studies have shown that women sleep more than men (e.g. Kalmbach *et al.*, 2018; Rae *et al.*, 2016; Szalontai, 2006). Rae *et al.* (2016) reported that females tend to sleep for longer, but suffer more from a lack of sleep than males. Social or physiological factors could result in sex differences in sleep deprivation (Alhola and Polo-Kantola, 2007). Females have also been found to experience more stress resulting from greater domestic responsibilities, and appear to be at a higher risk of fatigue than males, especially when night shifts are worked (Di Milia *et al.*, 2011). In general, it appears that women experience more fatigue than men, although mixed findings of differences in sleep required and received by males and females are reported.

2.3.1.3. Marital status, partnership, and family composition

Marital status or partnership, and having dependants or children in the household, have been associated with fatigue. Being partnered appears to mitigate fatigue, and non-married individuals have been reported to be more likely to be fatigued than those who are married (Di Milia *et al.*, 2011; Halvani *et al.*, 2009a; Winwood *et al.*, 2006). Marital status and household composition could reflect level of social support (Koukouli *et al.*, 2002). Others have reported that being married reduces sleep time, and has been identified as a predictor of sleep disturbances (Smagula *et al.*, 2016; Szalontai, 2006). Marital quality was also associated with sleep disturbances (Smagula *et al.*, 2016; Yang *et al.*, 2013). Meanwhile, sleep time has been found to be reduced in those with dependants or children (Szalontai, 2006). Male night shift workers without children have been found to have longer sleep times on work days, and reduced risk for fatigue during night work, than those with children (Araújo *et al.*, 2016). Szalontai (2006) reported that having a young child in the household reduced average daily sleep time by over 12 minutes; this effect was larger for women than for men. Fatigue could therefore be higher in those with young children, but be mitigated by having a partner or high levels of social support. However, it is expected that there would be differences in individual circumstances and experiences that would affect these associations.

2.3.1.4. Race and ethnicity

Sleep duration has been associated with race, with white males and females receiving more sleep and having less sleep variability and lower levels of fatigue, than their black counterparts (Di Milia *et al.*, 2011). However, Szalontai (2007) reported highest average sleep times for black females (almost 10 hours per day), and lowest for white males (slightly over 8 hours per day) in South Africa. Racism, perceived racial discrimination and self-stereotyping can also potentially affect health and sleep (Williams *et al.*, 2010). Rae *et al.* (2016) highlighted the need to understand and account for ethnic differences in sleep requirements and beliefs, as a result of recorded ethnic differences in sleep obtained. Migration history and status could also affect sleep and fatigue, as a result of the association with health, which may be due to variations in SES, stressors and strains associated with migration and adaptation, healthcare, segregation, as well as social and psychological resources (Williams *et al.,* 2010). It is evident that mixed findings are reported relating to the association between race or ethnicity and fatigue, while these findings could be mediated by socio-economic and psychosocial factors.

2.3.2. Socio-economic status

Socio-economic status reflects inequalities in access to and distribution of resources, and the most common indicators are education, occupational status, and income (American Psychological Association (APA), 2013a, 2013b; d'Errico *et al.*, 2007; Di Milia *et al.*, 2011). Indicators of SES are also associated with race (APA, 2013b; Williams *et al.*, 2010). Further indicators of socio-economic position include wealth, household conditions, partners' socio-economic position, and area-level measures (Galobardes *et al.*, 2006a, 2006b).

Low SES has been associated with reduced opportunity for adequate sleep, and with environmental conditions that impair sleep quality, such as crowded, unsafe, noisy or uncomfortably hot or cold houses (van Cauter and Spiegel, 1999). Van Cauter and Spiegel (1999) hypothesised that impaired sleep mediates the relationship between SES and health. They found that sleep loss resulted in decreased glucose tolerance, elevated evening cortisol levels, and increased sympathetic activity, which may lead to the development of chronic conditions, such as hypertension, diabetes and obesity, which are more common in low SES groups. Psychosocial burdens associated with low SES may also mediate the relationship between SES and health (van Cauter and Spiegel, 1999). Low SES is implicated as a risk factor for many problems within communities, including higher psychological distress, reduced quality of life, higher rates of cigarette smoking and heavy drinking, increased likelihood of being sedentary, and higher rates of cardiovascular disease in adults (APA, 2013a). Williams *et al.* (2010) reported that Blacks and low SES individuals experienced more stress than Whites and high SES individuals, and that similar stressors had worse effects on the mental health of socially disadvantaged groups.

On the other hand, Szalontai (2006) reported that workers in South Africa who were more educated and those with higher wages had lower daily sleep times than those who were less educated or had lower wages. Additionally, Szalontai noted that sleep time may vary because of economic incentives that complete for time. These findings are in line with international research that has shown that individuals in countries with higher per capita incomes have lower average daily sleep times than those in countries with lower per capita incomes, including South Africa (Szalontai, 2006). Additionally, the study revealed that people living in rural areas, on average, slept less than those living in formal urban areas. Pfeifer (2017) also reported lower sleep times and higher sleeplessness where there is higher general stress and lower regional unemployment rates, and in more educated people, full-time employed workers, shift-workers, and higher household income classes.

As such, fatigue and sleeplessness could be related to low SES because of poor living or sleeping conditions, psychosocial burdens and lifestyle factors. Meanwhile, those with higher income and education might experience higher levels of fatigue as a result of a lack of time to sleep because of working hours and stress. The three main indicators of SES, namely education income and employment, are separately discussed in more detail below.

2.3.2.1. Education

Mixed findings on the association between education and fatigue are reported, and are subject to confounding by other factors (Di Milia *et al.*, 2011). Halvani *et al.* (2009a) found no link. Others reported higher fatigue, particularly physical fatigue, in uneducated groups (Di Milia *et al.*, 2011). Meanwhile, Szalontai (2006) reported that individuals with matriculation certificates (completed secondary education), on average, slept almost 45 minutes less than those with no education, while those with post-schooling qualifications had a further 29 minute reduction in sleep. These findings are likely related to the relationship between education and wages (Szalontai, 2006). Education may reflect the transition from a person's parents' SES to personal SES, and early life circumstances, such as access to and performance in schooling; education is also a strong determinant of future employment and income (Galobardes *et al.*, 2006a). Therefore, education might reflect life course influences on health and safety (Galobardes *et al.*, 2006a). The number of years of formal education is also differentiated by race (Statistics South Africa, 2011; Williams *et al.*, 2010). The knowledge and skills gained through education may affect cognitive functioning, improve risk perceptions and access to information, increase receptiveness to health education messages, or improve communication with, and access to, appropriate health services (d'Errico *et al.*, 2007; Galobardes *et al.*, 2006a).

2.3.2.2. Income

Income or wealth is the indicator of SES that most directly measures material resources, and can influence a range of material circumstances that have direct implications for health (and, potentially, fatigue) (Galobardes *et al.*, 2006a). High levels of poverty and inequality are evident in South Africa, and income remains highly differentiated by race, with rural poverty rates reportedly higher than in urban areas (Leibbrandt *et al.*, 2010; Statistics South Africa, 2011). Means by which higher incomes can affect health are: 1) access to better quality material resources, such as food and shelter; 2) access to services that may improve health directly (e.g. health services or leisure activities) or indirectly (e.g. education); and 3) improved self-esteem and social standing (Galobardes *et al.*, 2006a). Conversely, income level may also be affected by health status (e.g. not being able to work effectively because of health problems) (Galobardes *et al.*, 2006a). Although income could related to health-related causes of fatigue, Szalontai (2006) reported that an increase in wages led to a decrease in daily sleep time; the predicted difference in daily sleep time was over 50 minutes between those earning the average wage, and those in the highest income group.

2.3.2.3. Employment

Occupation is related to income, intellect and social standing, and can characterise working relations between employers and employees (Galobardes *et al.*, 2006a). Occupation may influence health and safety outcomes as a result of material resources, easier access to better healthcare and education, and through psychosocial processes, such as workplace stress (Galobardes *et al.*, 2006a). Additionally, working conditions can have a direct effect on health and safety, through work-related environmental or task exposures, or occupational hazards (Galobardes *et al.*, 2006a; Williams *et al.*, 2010). Molarius *et al.* (2006) found that employment status, psychosocial working conditions, and satisfaction with work, were associated with self-rated health. d'Errico *et al.* (2007) reported that the occurrence of work-related injuries were higher in those with lower levels of education and lower occupational classes, which could be because those working in higher SES levels were generally employed in less hazardous jobs.

Fatigue risk, more specifically, is inherent in shift work and work that is physically or mentally demanding, repetitive, or requires high levels of vigilance (Schutte, 2010; Winwood *et al.,* 2006). Those in low SES occupations, including those that involve shift work, might have more limited time available to sleep, and fatigue is likely to be related to longer working hours and higher physical workloads (Di Milia *et al.*, 2011; van Cauter and Spiegel, 1999). In a study of workers at an iron ore company in Iran, higher levels of fatigue were reported by those categorised as 'miners', followed by 'mechanics', 'truck drivers', 'white collar workers', 'supervisors', and 'others' (Halvani *et al.*, 2009a). In some studies, white-collar workers were more at risk of fatigue than blue-collar workers, possibly as a result of mental fatigue, which is more common among higher SES employees (Di Milia *et al.*, 2011). Low levels of job control, along with high work demands, have also been implicated in fatigue (Di Milia *et al.*, 2011). The effects of work demands, work conditions, and shift schedules on fatigue are explained in more detail later in this chapter.

2.3.3. Housing conditions

Fatigue or occupational tiredness results from a combination of living and working environment impacts (Jing-Gang and Lei, 2013). Housing conditions that can affect sleep health include noise, lighting, elevated temperatures or excessive cold, and allergens (AngloAmerican, 2005; Sandberg *et al.*, 2014). Crowded housing, poor construction quality and configuration, and a lack of functional windows for ventilation contribute to these causes (Sandberg *et al.*, 2014). In a study of Latino farmworkers, air conditioning (an indicator of housing quality) was associated with better sleep quality, while poor sleep quality was related to increased time taken to fall asleep, the number of night time awakenings, and fewer hours of sleep (Sandberg *et al.*, 2014). In the SAMI, employees living off mines were slightly more likely to report sleep problems than those living on mine property (Lewis, 2003). Around a quarter of the study participants (22%) had an injury on duty during the previous year, and those living on mine property had a greater likelihood of this occurring; possibly due to confounding factors such as level of education and income (Lewis, 2003). Additionally, TB in the household was reported to be more frequent in crowded dwellings (Lewis, 2003).

Housing conditions or characteristics can also be associated with fatigue due to the association with SES and with health (Alnsour and Meaton, 2014; Galobardes *et al.*, 2006a). Lifestyle and psychosocial factors further mediate this risk (Molarius *et al.*, 2006). Housing conditions are shown to reflect quality of life in a community, and are important for the health and welfare of the inhabitants of the community (Alnsour and Meaton, 2014; Burridge and Ormandy, 2007; Statistics South Africa, 2011). Basic living conditions, including access to clean water and sanitation, should be considered a foundation for a healthy workforce (Brunette *et al.*, 2011). A lack of access to amenities such as water or sanitation, for example, could lead to an increased risk of infection and disease (Galobardes *et al.*, 2006a; PricewaterhouseCoopers, 2012). Additionally, domestic crowding has negative consequences such as higher psychological stress, and poor health outcomes through facilitation of the spread of infectious diseases (APA, 2013a; Burridge and Ormandy, 2007; Galobardes *et al.*, 2006a). Matters to be considered for housing to be reasonably fit for habitation, include repair, stability, lighting, ventilation, dampness, water supply, drainage and sanitary conveniences, facilities for storing, preparing and cooking food, and waste water disposal (Burridge and Ormandy, 2007). Health is also impacted by exposure to environmental toxins, poor quality housing, and criminal victimisation or community violence (Williams *et al.*, 2010).

Additionally, precarious employment associated with poor living conditions in developing countries can contribute to occupational stressors faced by workers (Fischer *et al.*, 2006). Meanwhile, segregation, in terms of concentrated poverty, can limit access to quality education, healthcare, employment opportunities, recreation facilities, and the availability of healthy foods; it has also been associated with the use of tobacco and alcohol, higher acute and chronic stressors, and concerns of personal safety (Williams *et al.*, 2010).

As such, poor housing conditions and overcrowding can contribute to poor health and fatigue, while these outcomes are subject to confounding by other factors.

2.3.4. Commuting time

Commuting refers to the regular travel between home and work, and includes day-to-day travel, or long distance commutes at the beginning of work cycles (Caponecchia and Williams, 2018; Shaw, 2003). Excessive commuting times can result in fatigue at work (Shaw, 2003; South Africa, 2014). Increased commuting time adds to the demands of the work day, and reduces the time that is available for personal, recreational, and domestic activities, and recovery sleep (Di Milia *et al.*, 2011; Gander *et al.,* 2011). Commuters, including passengers, are at risk of fatigue from inadequate sleep, especially when working early morning shifts; furthermore, driving after a night shift has been linked with increased occurrence of accidents (Di Milia *et al.*, 2011). Accidents while commuting are also significant causes of work-related fatalities (Caponecchia and Williams, 2018). Historical settlement policies in South Africa resulted in long commuting times of African (Black) workers (Szalontai, 2006).

Pfeifer (2017) noted that the relationship between commuting to work and sleep was a largely neglected area of research. However, Pfeifer showed that workers with further commuting distances slept significantly less per night during the work week, and slightly longer during the weekend, which could be compensation for sleep loss during the work week. On average, every kilometre distance from the place of residence to the workplace was correlated with 0.0035 hours less sleep per night during the work week (Pfeifer, 2017). The effect of increased commuting distance on reduced sleep during the work week was more prominent for full-time than part-time workers (Pfeifer, 2017).

Research has revealed other negative effects of commuting on health, mental well-being and productivity (Pfeifer, 2017; van Ommeren and Gutierrez-i-Puigarnau, 2009). Reasons for reduced productivity with longer commutes include arriving at work late or leaving early, lower effort levels, and increased absenteeism. Absenteeism could result from poor health, possibly due to high levels of stress associated with long commutes, or because of shirking, and the associated benefits of increased leisure time and saving financial costs by not travelling (van Ommeren and Gutierrez-i-Puigarnau, 2009). Van Ommeren and Gutierrez-i-Puigarnau (2009) found that commuting distance was positively and significantly associated with number of days absent. The number of days absent was 12% higher for workers with a one-way commuting distance of 40 km than for those with a commuting distance of 10 km, for example, even after controlling for health indicators (van Ommeren and Gutierrez-i-Puigarnau, 2009).

2.3.5. Lifestyle

Various activities performed outside of work, and other lifestyle factors, including exercise, nutrition, smoking and alcohol use, are potential causes of fatigue (Shaw, 2003). Long work hours, domestic or family responsibilities, social commitments, leisure activities, and personal time compete with rest and recovery and make it difficult to maintain a work-life balance (Caldwell *et al.*, 2008; Dawson and Fletcher, 2001; Ferguson *et al.*, 2010). Leisure activities may affect fatigue and motivation at work (Jing-Gang and Lei, 2013). However, it has been reported that work demands interfere with personal lives more frequently than personal responsibilities interfere with work (Mostert *et al.*, 2011). Second jobs, in which some may be employed during long periods off duty, are a further consideration (Gander *et al.,* 2011; Shaw, 2003). Additionally, long working hours appear to increase the use of unhealthy coping mechanisms, such as smoking and poor diets (Caldwell *et al.*, 2008). Unhealthy lifestyle and living conditions, which are often prevalent in developing countries, can impair health and wellbeing (Fischer *et al.*, 2006). Poor self-rated health is associated with socio-economic and lifestyle factors, and was found to be most common in individuals who had experienced economic hardship, lacked social support, or who were physically inactive, underweight or obese (Molarius *et al.*, 2006).

Physical activity or exercise, which may also include physical labour performed at work, is associated with better sleep quality, improved adaptation to shift work, and reduced fatigue (Caldwell *et al.*, 2008; Lombard, 2009, Sandberg *et al.*, 2014). Further benefits of exercise and physical fitness include improved health, reduced risk of cardiovascular disease and musculoskeletal injuries, decreased muscle tension and stress, improved concentration and performance, and faster recovery between work shifts (AngloAmerican, 2005; Hansen *et al.*, 2016; Lombard, 2009; Theron and van Heerden, 2011). A lack of physical activity and sleep problems can lead to impaired moods and major depression, and might result from shift work and time constraints (Kalmbach *et al.*, 2018; Lombard, 2009).

Health and fatigue are further impacted by nutrition, smoking, and alcohol use. Irregular meal times, a lack of balanced meals or unhealthy diets, and high intakes of carbohydrates, caffeine and alcohol have been associated with poor health related to shift work (AngloAmerican, 2005; Hulsegge *et al.*, 2016). Shift workers have higher risks of metabolic disorders and diseases than those who work during the day, which could be associated with the diet quality or composition and irregular timing of eating, along with factors such as physical inactivity, psychosocial stress, and inadequate sleep (Lowden *et al.*, 2010). Meal timing and content are constrained by workplace task demands, availability of foods and beverages, and by social, domestic, and rest requirements outside of work (Lowden *et al.*, 2010). The use of sugar and caffeine can help to reduce sleepiness and improve alertness; however, heavy food intake can result in increased sleepiness, and the use of caffeine can result in poorer quality sleep (AngloAmerican, 2005; ICAO, 2015; Mathis and Hess, 2009; Theron and van Heerden, 2011). Alcohol use also contributes to sleepiness, and is shown to reduce sleep quality, deteriorate living conditions, cause a number of diseases, and has been associated with increased injury risk (AngloAmerican, 2005; Chau *et al.*, 2008; ICAO, 2015; Theron and van Heerden, 2011). Additionally, smoking has been seen to impair sleep quality, and lead to disease, affected physical functions and psychomotor speed, cognitive impairment, sleep disorders or insomnia, and sick leave (Chau *et al.*, 2008; ICAO, 2015; Theron and van Heerden, 2011). As such, lifestyle factors, including activities performed, recreational exercise, nutrition, alcohol use and smoking can affect sleep and fatigue.

2.3.6. Job demands and working conditions

The type of work performed, the work environment, and shift patterns or long working hours are all causes of fatigue (Amponsah-Tawiah *et al.*, 2014; Chau *et al.*, 2008; Mostert *et al.*, 2011; Shaw, 2003). More specifically, common workplace factors that can result in fatigue include high work demands, high physical workloads, temperature extremes, poor lighting, excessive noise, work stress, poor ergonomic design of workstations and equipment, and work-time arrangements or shift system design (Åkerstedt *et al.*, 2014; AngloAmerican, 2005; Schutte, 2010; South Africa, 2014). Work scheduling factors include early start times, night work, extended or consecutive work periods, insufficient recovery time between duty periods, inconsistent schedules, on-call work, time-zone changes, and unplanned duty extensions (Caldwell *et al.*, 2008). The impacts of shift schedules on fatigue are discussed further in the following section.

Task-related factors associated with fatigue include repetitive or monotonous work, sustained physical and/or mental effort, and complex physical or mental tasks (AngloAmerican, 2005; Jing-Gang and Lei, 2013; Shaw, 2003; South Africa, 2014; Williamson *et al.*, 2011). Task demands incorporate aspects of overload and boredom, where fatigue due to physical overload is a significant factor that leads to accidents, while poor motivation, level of responsibility and work intensity also need to be considered (Davy, 2018; Jing-Gang and Lei, 2013). Inadequate or poorly designed equipment, a lack of maintenance, and poor environmental conditions, such as where there are temperature extremes, noise, poor lighting, dust, vibration, or hazardous substances, also can contribute to fatigue (Jing-Gang and Lei, 2013; Mathis and Hess, 2009; Shaw, 2003; South Africa, 2014). For example, prolonged noise can result in stress, anxiety, irritability and tension which, in turn, increase fatigue and impair work performance (Amponsah-Tawiah *et al.*, 2014). Additionally, physical fatigue is evident in heat exhaustion, which is characterised by symptoms including dehydration, hyperthermia and elevated heart rates; impaired worker performance was reported when the mean heart rate over a shift exceeded 120 beats per minute (Brake and Bates, 2001).

Other work-related factors, such as understaffing, poor work organisation, a lack of supervision and communication, administrative problems, equipment failure, a lack of suitable training, and industrial disputes, may impact levels of fatigue (Fletcher and Dawson, 2001; Jing-Gang and Lei, 2013). Work-related stress is also a risk factor for fatigue (Shaw, 2003). Gander *et al.* (2001, p. 573-574) list a number of organisational factors that could impact on levels of fatigue, including "The cultural, regulatory and enforcement environments; the size of the company; the nature of the business…; the level of commitment to health and safety (the safety culture) in the company; the presence of safety management systems…; the nature and extent of supervision…; remuneration practices…; knowledge about fatigue among staff at all levels in the organisation; and for individual employees, their perceived quality of working and domestic life." Poor working conditions, high pressure at work, a lack of job resources, poor tasks characteristics, a lack of social and technical support, and poor salaries and benefits are linked to employees experiencing higher levels of anxiety, insomnia, physical illness, and feeling exhausted (Oldfield and Mostert, 2007).

2.3.7. Shift schedules

Fatigue management strategies in the mining industry commonly have a major focus on shift schedules (ACARP, 2002; AngloAmerican, 2005; Halvani *et al.*, 2009b; Shaw, 2003; South Africa, 1997c, 2014). Shift work can be defined as "an organisation of work where workers succeed each other at the same workplace while performing similar operations at different times of the day thus allowing longer hours of operation than feasible for a single worker" (South Africa, 2014, p. 4). Shift work refers to various working time arrangements, and includes all working hours outside of normal daytime hours (Dall'Ora *et al.*, 2016). Shift work is a widely used tool for work time organisation as it allows for working hours to extend beyond the usual eight-hour day, and for around-the-clock activities (Costa, 2003). Shift work is required in professions such as social services, healthcare, security, electricity, transport, and production operations, including the mining and smelting industry (Alhola and Polo-Kantola, 2007; Baulk *et al.*, 2009; Costa, 2003). However, shift work is associated with disturbed sleep, sleep loss, fatigue, occupational incidents, and a number of chronic conditions, including cardiovascular disease and type II diabetes, and impaired mental health (Härmä *et al.,* 2018; Kalmbach *et al.*, 2018). Shift work is a primary cause of fatigue and disrupts biological rhythms, sleep and social interaction (AngloAmerican, 2005). It is not considered possible to eliminate fatigue of shift workers, but the fatigue can be mitigated and managed (AngloAmerican, 2005).

It is evident that shift work has negative effects on social and domestic activities, and long-term impacts on physical and psychophysiological health (Baulk *et al.*, 2009). Those who work shifts and/or extended hours are seen to have greater difficulties in maintaining a work-life balance (Ferguson *et al.*, 2010; Greubel *et al.*, 2016). Other factors that need to be considered when assessing the effects of shift work on fatigue are 'moonlighting' or second jobs, the regulation of overtime, and travelling or commuting time (Baulk *et al.*, 2009). Day of the week effects may also be present, such as by increased injury rate occurring on weekends or Mondays, which could result from social or work organisation factors (Di Milia *et al.*, 2011). Furthermore, social conflicts associated with unconventional work schedules may affect sleep and quality of life (Araújo *et al.*, 2016).

Shift workers face an increased risk of fatigue and excessive sleepiness at work, and many occupational health and safety risks associated with shift work have been attributed to sleepiness and fatigue (Araújo *et al.*, 2016; Dawson *et al.*, 2011; Dawson and Fletcher, 2001; Halvani *et al.*, 2009b). Shift workers are vulnerable to increased sleepiness, chronic fatigue, and decreased alertness, which is a risk to their personal safety and that of their co-workers and the general community (Hossain *et al.*, 2003). Shift workers also more likely to get sick, particularly as a result of sleep deprivation and irregular sleep-wake cycles (Araújo *et al.*, 2016). High workloads and shift schedules that are misaligned to circadian rhythms contribute to high rates of sleep deprivation (Kalmbach *et al.*, 2018).

Shift work or night work has negative effects on health, and could aggravate existing health problems such as cardiovascular disease and gastro-intestinal disorders (AngloAmerican, 2005). Long work hours, inadequate sleep, and challenging shift schedules may also have negative impacts on mental health, and shift work may result in severe sleep disorders, chronic fatigue, and chronic anxiety or depression (Halvani *et al.*, 2009b; Kalmbach *et al.*, 2018). AngloAmerican (2005, p. 5) listed problems associated with shift-work fatigue, which included: "Chronic sleep problems (more than 50% of shift workers); gastric ailments (4-5 times increase in occurrence); chronic fatigue (80% of workers); depression and mood swings; increased alcohol and drug abuse; higher incidence of serious accidents; (and) increased incidence of divorce and spouse abuse." Shift schedules have been associated with the use of sick leave, while the association is specific to the shift schedule (d'Errico and Costa, 2011; Merkus *et al.*, 2012).

Work schedules vary according to the shift length, timing of work hours, shift schedule, speed of shift rotation, and the number of off-days (Di Milia *et al.*, 2011). The features of shift work that are considered to contribute to fatigue development and increased accident risk include long shifts, hours on duty, shift type, time of day, the quality of rest breaks, the number of consecutive shifts worked, the interval between shifts, the number of rest days, and the variability of the shifts (Ferguson *et al.*, 2011; Folkard *et al.*, 2007). There is an inverse relationship between shifts, night work, long working hours, and sleep duration and reports of fatigue (Di Milia *et al.*, 2011). Work-related fatigue results from an interaction of time-on-task, working against circadian rhythms, and prior sleep received; long work hours, a lack of time to rest, and poorly designed shift systems are potential problems (AngloAmerican, 2005; Dawson and Fletcher, 2001; Di Milia *et al.*, 2011; Jing-Gang and Lei, 2013). Spencer *et al.* (2006) noted that incident risk appeared higher overnight compared to the day, and that it increased with time on tasks and with the number of consecutive shifts.

Specific work time arrangements that could negatively impact on worker adjustment to shift work, as indicated in South Africa (2014, p. 20), include:

- "A shift roster with an irregular or unpredictable pattern;
- More than four consecutive 12-hour night shifts;
- More than five consecutive 8-hour night shifts;
- Work schedules/rosters that do not allow opportunity for continuous sleep of seven to eight hours in each 24-hour period;
- Excessive regular overtime and on-call work;
- Early morning shift start times (before 06:00);
- Backward rotating rosters (day to night to afternoon);
- Shifts lacking appropriate shift breaks;
- Less than 36 hours off after a period of night shift work; (and)
- 12-hour shifts that involve critical monitoring tasks, heavy physical work, potential exposure to harmful agents/substances."

The effects of schedule features, including shift timing, duration, rest breaks and the number and timing of consecutive shifts worked on fatigue, are detailed further below.

2.3.7.1. Shift timing

The time of day when work takes place can be a cause of fatigue (Shaw, 2003). Work at unusual times is associated with health and safety risks, leading to economic losses as a result of increased sick leave and staff turnover rates (Greubel *et al.*, 2016). As humans are diurnal, the optimal work schedule is one that involves day work, as it would cause little, if any, circadian and social disruptions (Di Milia *et al.*, 2011). Disruption of the circadian rhythm is a major factor contributing to fatigue or sleepiness at work (Schutte, 2010). Shift work, or non-traditional work hours, results in a misalignment of the sleep-wake cycle with circadian rhythms, including core body temperature and melatonin (Baulk *et al.*, 2009; Ferguson *et al.,* 2012; Schutte, 2010). Core temperature rhythms associated with fatigue and alertness are at a minimum between 04h00 and 06h00, with maximums around 12 hours later (Dawson and Fletcher, 2001). Accident risk is seen to correspond with the circadian nadir, between 02h00 and 06h00, or during the night time period (midnight to 07h00), and mid-afternoon 'siesta' time (15h00) (Di Milia *et al.*, 2011; Pack *et al.*, 1995). However, peaks in accident risks have been estimated to occur close to midnight, and peaks in fatigue around five hours later (Spencer *et al.*, 2006).

Shift work, including early morning and night work, results in increased sleepiness and fatigue, is linked to reduced sleep durations, and is commonly associated with cumulative sleep deprivation (Dawson and Fletcher, 2001; Di Milia *et al.*, 2011; Ferguson *et al.*, 2012; Härmä *et al.,* 2018). Sleep before early morning shifts, and after night shifts, is often restricted (Araújo *et al.*, 2016; Härmä *et al.,* 2018; Spencer *et al.*, 2006). Restricted sleep, in turn, increases sleepiness and reduces alertness, impacts neurobehavioral performance, and increases the risk of accidents and incidents (Dawson and Fletcher, 2001). In a study of live-in mining operators, Ferguson *et al.* (2010) found that sleep obtained while on day shifts (6.1±1.0 hours) was significantly longer than on night shifts (5.7±1.5 hours), but significantly shorter than on off days (7.4±1.4 hours). In the absence of domestic, family and social activities, participants still did not receive sufficient sleep; this was attributed to shift length, shift timing, including early shift start times, circadian influences, and personal choices regarding the use of time (Ferguson *et al.*, 2010). Ferguson *et al.* (2010, 2011) reported that more than six hours' time in bed per night is required to maintain performance across consecutive shifts and sleep history was a predictor of fatigue-related performance. They also reported that fatigue was higher at the end of night shifts, compared with the beginning of the shift, or at the start or end of day shifts (Ferguson *et al.*, 2011).

Night shift work, in particular, restricts night time sleep, and increases the need to sleep during the day (Araújo *et al.*, 2016). Furthermore, evening shifts have been associated with increased difficulties falling asleep (Härmä *et al.,* 2018). The circadian drive for wakefulness during the day influences sleep, and the circadian drive for sleep in humans is usually high in the late evening and coincides with a high homeostatic drive after around 16 hours of wakefulness (Ferguson *et al.,* 2012). Night work causes a mismatch between the circadian timing system, and environmental cues (Costa, 2003). Environmental factors, such as temperature, noise and light also mediate daytime sleep quality and quantity (Ferguson *et* *al.*, 2010). Night shift work is associated with higher levels of fatigue, and increased probability of accidents, and fatigue would likely be reduced with reductions in the number of night shifts worked (Baulk *et al.* 2009; Härmä *et al.*, 2018; Winwood *et al.*, 2006).

Circadian adaptation to night shift work is usually not that high (Dawson and Fletcher, 2001). Spencer *et al.* (2006) reported that 7% of permanent night workers showed good adjustment to the night shift and a further 22% showed some level of adjustment, while approximately 70% did not show evidence of a significant adjustment. Spencer *et al.* added that while performance is likely to be better on permanent night shifts rather than on rotating shift systems, social and domestic issues could make it difficult for workers to maintain an orientation to night shifts. Ferguson *et al.* (2012), similarly, found that no significant circadian adaptation took place during day or night shifts and noted that circadian adaptation to shift work was dependant on factors such as light exposure, environmental conditions, shift schedules, and individual characteristics.

2.3.7.2. Shift duration

The length of time spent at work and performing work-related activities is a further potential cause of fatigue (Shaw, 2003). The risk of injuries and accidents is seen to increase following more than eight hours of work in a day (Di Milia *et al.*, 2011; Folkard *et al*., 2007). Spencer *et al.* (2007) reported that 10-hour shifts were associated with a 13% increase in risk and 12-hour shifts with 27.5% increased risk compared to 8-hour shifts. There appears to be very little change in risk levels during shift lengths of between four and eight hours (Folkard *et al*., 2007). Additionally, Baulk *et al.* (2009) found that participants were more fatigued at the end of a shift than they were at the beginning. Lapses in performance are expected following approximately 16 hours of wakefulness (Spencer *et al.*, 2006).

A negative relationship between work time and sleep time has been recorded (Ferguson *et al.*, 2010). Sleep length has been shorter when working shifts than on off days, and greater exhaustion and sleepiness have been evident in those working more hours per week (Di Milia *et al.*, 2011). A one hour increase in daily working time has been found to decrease sleep time by an average of 10 to 13 minutes (Pfeifer, 2017). Previous research has reported that the risk of falling asleep during the shift increased by 17% for each hour in the morning shift, and by 35% for each hour worked during the night shift (Spencer *et al.*, 2006). The effect of commuting time should also be considered in relation to shift lengths (Folkard *et al*., 2007). Long shifts may be preferable to the workforce, as a result of maximising leisure time, and minimising trips to and home from work (Spencer *et al.*, 2006).

Increased overtime hours are also linked with fatigue and decreased job performance and safety outcomes (Dall'Ora *et al.*, 2016; Di Milia *et al.*, 2011). However, overtime work appeared less problematic if voluntary and rewarded, and if sufficient job autonomy was allowed (Di Milia *et al.*, 2011). Long work hours or overtime may result from call-out duties (Shaw, 2003; South Africa, 2014). On-call work arrangements have also been associated with sleep disruption, sleep deprivation, and increased risk of errors (Di Milia *et al.*, 2011).The regulation of overtime is important, as overtime reduces the time for recovery between shifts (AngloAmerican, 2005).

2.3.7.3. Rest breaks

The duration of continuous duty without a break contributes to fatigue, sleepiness and the risk of incidents (Folkard *et al*., 2007; Spencer *et al.*, 2006). Rest breaks can be effective in maintaining performance and attention (Caldwell *et al.*, 2008; ORR, 2012; Spencer *et al.*, 2006). Rest breaks during work are seen to initiate a recovery process, with breaks of 30 minutes considered to reverse the accumulation of fatigue that increases gradually throughout a shift (Folkard *et al.*, 2007). Breaks within shifts should be long enough and frequent enough for workers to be rested, refreshed, and nourished (Shaw, 2003). Breaks are recommended at relatively short intervals to increase alertness, and are considered more effective when combined with food intake and physical activity (AngloAmerican, 2005; Lombard, 2009). Napping can be used as a countermeasure against fatigue, especially during night shift work; however impaired alertness can be expected for up to 15 minutes after awakening (AngloAmerican, 2005; Davy, 2010; ORR, 2012). Fatigue caused by daily work can be reduced by receiving the necessary sleep, breaks and rest (Jing-Gang and Lei, 2013).

2.3.7.4. Consecutive shifts

Sufficient recovery times between shifts are important (Spencer *et al.*, 2006). Breaks between work shifts that are too short, such as less than 10 hours, can result in fatigue (Shaw, 2003). Shaw (2003) provided further guidelines in this regard, including enough time in a break for five hours of uninterrupted sleep in 24 hours (for one night only), enough time in breaks for 12 hours of sleep in 48 hours, and enough time for 50 hours of sleep in seven days. An interval of 16 hours or more between consecutive night shifts has been recommended to obtain adequate sleep (Spencer *et al.*, 2006). Long work hours of work across a shift cycle (e.g. time spent at work exceeding 50 hours in any seven days) are further fatigue-related risk factors (Shaw, 2003). It has been reported that the risk of incidents was approximately doubled in those who worked 65 hours compared to those who worked 40 hours per week (Spencer *et al.*, 2006).

The risk of work incidents increases after successive shifts of all types, but this increase is substantially larger on night than day shifts (Araújo *et al.*, 2016; Spencer *et al.*, 2006). Safety and productivity risks have been shown to be significantly elevated on second, third and fourth consecutive night shifts, compared to the first (Ferguson *et al.,* 2012). As approximately 30% of permanent night workers show some level of adjustment to night shifts, they might be better able to cope with consecutive night shifts than others (Folkard *et al.*, 2007). However, longer recovery times might be required following shifts when the circadian rhythm has been severely disrupted (Spencer *et al.*, 2006). The length of time taken to recover from the sequence of consecutive shifts is related to the extent of the sleep disruption (Spencer *et al.*, 2006). It has been suggested that, under normal circumstances, successive work days should be limited to six, and that a minimum of two successive rest days be provided (Spencer *et al.*, 2006).

There are different opinions about the optimal speed of shift rotation, as some studies support the use of quickly rotating shift systems (e.g. one or two consecutive night shifts) to improve sleep and performance, while others contradict these findings (Härmä *et al.*, 2018). The use of rotating shift systems rather than permanent night shifts has been supported, as rapid shift rotation minimises circadian rhythm disruption, and is considered to improve social contact, alertness and health (AngloAmerican, 2005). However, Kalmbach *et al.* (2018) found that shifts in sleep timing by three or more hours earlier or later, led to shorter sleep durations and worse moods, while advanced shifts led to greater sleep deprivation, than delayed sleep. The use of forward-rotating shifts is generally supported, as this allows sufficient time between shifts for recovery, and to avoid 'quick returns' (i.e. 11 hours or less between shifts) (Härmä *et al.*, 2018; Spencer *et al.*, 2006). Forward rotating schedules have been associated with better sleep quality and less work-family conflict (Spencer *et al.*, 2006). Backward rotations have been associated with more circadian disruption, and quick returns with increased sleepiness and fatigue (Härmä *et al.,* 2018; Spencer *et al.*, 2006).

It is evident that, while shift work is necessary in industries such as mining, it can have negative effects in terms of worker fatigue. Shift schedule features, including timing, duration and the incorporation of rest breaks between and within shifts, should be assessed to minimize potential health and safety risks.

2.3.8. Health

Health and fatigue are associated, as poor health can contribute to fatigue, while fatigue can also contribute to poor health. These associations are discussed in turn in this section, followed by associations between health, sleep and sleep disorders, more specifically, and then general contributors to health of workers. Chronic medical conditions, sleep disorders, disturbed sleep and sleepiness also increase the risk of fatigue-related accidents, incidents, and injuries (Åkerstedt, 2006; Horrey *et al.*, 2011).The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely absence of disease or infirmity" (WHO, 2008, p. 81).

Physical and mental health problems affect sleep health and fatigue (Di Milia *et al.*, 2011; Sandberg *et al.*, 2014). Fatigue is associated with various illnesses and serious diseases, and chronic fatigue has been associated with prolonged medical conditions (Åkerstedt *et al.*, 2014; Halvani *et al.*, 2009a). Illnesses and diseases that can result in fatigue include colds, flu, fever, infection, and anaemia (Åkerstedt *et al.*, 2014; Shen *et al.*, 2006). Fatigue is also present in disorders such as cancer, renal failure, epilepsy, brain-injuries, neuromuscular disease, and multiple sclerosis (Boosman *et al.*, 2011; Shen *et al.*, 2006). Additionally, fatigue was reported in 50% of HIV and HIV/AIDs patients (Shen *et al.*, 2006). Fatigue is also associated with pregnancy, depression, and sleep disorders or disturbances, such as insomnia, sleep apnoea or restless leg syndrome (AngloAmerican, 2005; Boosman *et al.*, 2011; Hossain *et al.*, 2003; Shen *et al.*, 2006; South Africa, 2014). Certain medications also cause fatigue (South Africa, 2014; Theron and van Heerden, 2011). Medical disorders and chronic conditions can also affect sleep quality and quantity (Horrey *et al.*, 2011). In a South African time use survey, health status had a significant influence on sleep patterns, as those who were ill on the day of the survey had an additional 2.5 hours of daily sleep or bed rest (Szalontai, 2006).

Conversely, the accumulation of fatigue may lead to illness, which is a further safety risk (Jing-Gang and Lei, 2013). Fatigue has been associated with poorer subjective health, cardiovascular disease, obesity and diabetes (Åkerstedt *et al.*, 2014; Dawson *et al.*, 2001). Fatigue and circadian rhythm disruptions can cause or exacerbate long-term health issues or medical conditions, such as gastrointestinal disorders or digestive problems, cardiovascular disorders or heart disease, high blood pressure, high blood sugar, high blood cholesterol, respiratory disorders, arthritis, stress and mental disorders, such as anxiety and depression (AngloAmerican, 2005; Schutte, 2010; Shaw, 2003). Fatigue may also affect women's reproductive health and the incidence of pre-term births (Caldwell *et al.*, 2008; Schutte, 2010). Furthermore, fatigue contributes to absenteeism, sick leave and the use of health facilities (Åkerstedt, 2006; Åkerstedt *et al.*, 2014; ter Wolbeek *et al.*, 2007).

Associations between sleep and health are commonly reported. Both reduced and increased sleep durations are predictors of mortality, and higher mortality rates have been reported among people who slept for less than six hours or more than nine hours a night (Åkerstedt, 2006; Rae *et al.*, 2016). Sleep loss has adverse effects on neuro-behavioural performance, metabolic, cardiovascular, immune and endocrine function, obesity, and psychological health (Araújo *et al.*, 2016; Rae *et al.*, 2016; van Cauter and Spiegel, 1999). Poor sleep quality, sleep disorders and disturbed sleep are associated with increased risk of workplace injuries, and numerous mental and physical health problems, including cardiovascular disease, high blood pressure, diabetes, obesity, migraines, lung disorders musculoskeletal pain, depression, anxiety and burnout (Åkerstedt, 2006; Sandberg *et al.,* 2014). Shorter sleep durations have been associated with higher body mass indexes (BMIs) and obesity, which is a key risk factor for cardiovascular disease and diabetes (Rae *et al.*, 2016). Additionally, health risks, including metabolic-type disorders, associated with increased BMIs, cholesterol and triglyceride levels, may arise as a result of consistently working night shifts (Di Milia *et al.*, 2011). Sleep apnoea may also be considered as part of the metabolic syndrome (Åkerstedt, 2006). Conversely, an increased BMI, or obesity, is a risk factor for obstructive sleep apnoea, which reduces sleep quality and increases consequent fatigue (Di Milia *et al.*, 2011; Sandberg *et al.*, 2014).

The health and well-being of workers depends on the interaction of various individual, medical, psychosocial, and job-related factors (Araújo *et al.*, 2016). Saunders *et al.* (2001) identified ten factors as broad determinants of health, namely: 1) physical environment; 2) crime; 3) housing and homelessness; 4) social services; 5) socio-economic environment, including employment; 6) lifestyle; 7) education; 8) leisure and culture; 9) transport; and 10) accidents. Physical, cultural and socio-economic environments can have a major impact on the health of the public, either directly, such as through accidental chemical exposure, or indirectly, by influences on quality of life and well-being (Saunders *et al.*, 2001). Additionally, work ability has been significantly associated with socio-demographic factors, working conditions, and health outcomes (Fischer *et al.*, 2006). These socio-demographic variables included income responsibility, sole breadwinners, raising children, and age; working conditions included thermal discomfort, organisation of the workplace, and verbal abuse, and; health outcomes included high BMI, obesity, sleep problems and fatigue (Fischer *et al.*, 2006). Job demands, job resources, and the work-home interface also have an impact on health (Oldfield and Mostert, 2007). Environmental factors in places where individuals and groups live, learn, work, play and worship can be modified to reduce social disparities in health (Williams *et al.*, 2010).

It is evident that numerous factors can affect the health of workers, and should be considered when assessing or managing fatigue. Medical conditions can contribute to fatigue, while fatigue can also lead to physical and mental health conditions.

2.3.9. Psychosocial factors

Fatigue has been associated with general well-being, and is a common symptom in burnout, depression and insomnia (Åkerstedt *et al.*, 2014; Shen *et al.*, 2006). It is indicated that between 50% and 80% of fatigue cases predominantly result from psychological factors (Theron and van Heerden, 2011). Fatigue has been associated with higher levels of stress, psychosocial distress, posttraumatic stress, tension, anxiety, confusion, and other intense emotional experiences (Åkerstedt, 2006; Åkerstedt *et al.*, 2014; Dawson *et al.*, 2011; Shen *et al.*, 2006). Meanwhile, low levels of emotional functioning, or 'low spirits', have been reported among those with high fatigue scores (Flechtner and Bottomley, 2003). Attitude and motivation are also associated with fatigue (AngloAmerican, 2005). Additionally, fatigue is a cause of job dissatisfaction, could affect psychological aspects of the workforce, and be harmful to business activities (Halvani *et al.*, 2009a). Increased risk of depression has also been associated with long working hours or prior overtime work (Virtanen *et al.*, 2018). Meanwhile, psychological wellbeing could mediate between the work environment and job outcomes (Dall'Ora *et al.*, 2016). In addition, social pressures, family conflicts, and relationship problems may contribute to the experience of fatigue (Fletcher and Dawson, 2001; Jing-Gang and Lei, 2013). Meanwhile, social support and being part of a family potentially improves the work fatigue and recovery balance (Winwood *et al.*, 2006).

Similar to the effects of fatigue, a lack of sleep has adverse effects on subjective moods and emotional reactivity (Paterson *et al.*, 2013; Scott *et al.*, 2006). Excessive daytime sleepiness has been associated with higher depressive symptoms, and sleep disturbances increase the risk of future depression (Åkerstedt, 2006; Sandberg *et al.,* 2014). Sleepiness is also associated with increased anger, confusion, and reduced enthusiasm or motivation (Kaida and Kaida, 2017). Sleep deprivation is reported to deteriorate moods, and affects the ability to regulate emotions (Schwarz *et al.*, 2013). Sleep problems could contribute to aggression and violence, and poor sleep quality and sleep deprivation have been associated with increased frequency and intensity of anger, hostility, aggression, and short-temperedness, and weakened inhibition of aggression and responses to emotional stimuli (Kamphuis *et al.*, 2012). Sleep deprivation was also seen to impair the accurate recognition of facial emotions, slow facial reactions to emotional stimuli, and reduce facial expressiveness (Kamphuis *et al.*, 2012; Minkel *et al.*, 2011; Schwarz *et al.*, 2013). High levels of sleepiness are also associated with increased pessimism, and less engagement in pro-environmental behaviours (Kaida and Kaida, 2017).

Therefore, it is evident that psychological and social problems can result in fatigue. Meanwhile, inadequate sleep and fatigue can result in job dissatisfaction, impaired emotional state and negative behaviour. Quality of life and stress are related to these psychosocial factors, and are discussed below.

2.3.9.1. Quality of life

Fatigue and decreased sleep duration have been associated with impaired quality of life (Abu-Mourad *et al.*, 2010; Araújo *et al.*, 2016; Jokobsson *et al.*, 2004). Quality of life has also been associated with anxiety and depression (Yohannes *et al.*, 2011). Quality of life is a multi-dimensional phenomenon and is considered to encompass numerous aspects including emotional, psychological, physical, cognitive, cultural, interpersonal and social functioning, and spiritual wellbeing (Jokobsson *et al.*, 2004; Locke *et al.*, 2007). Work system elements, the living environment, and economic constraints, and political, economic, and social contexts, are considered to interact and affect a person's quality of life (Brunette *et al.*, 2011). Predictors of quality of life and general well-being among mine workers included mining equipment, ambient conditions, and job demands and control (Amponsah-Tawiah *et al.*, 2014). Considerations of fatigue or health-related issues, and aspects such as economics and living conditions should be made when attempting to improve quality of life, and factors external to the work environment should be considered in addition to job-related factors (Brunette *et al.*, 2011; Jokobsson *et al.*, 2004).

2.3.9.2. Stress

Workplace stress may be defined as "the harmful physical and emotional responses that occur when job requirements do not match the worker's capabilities, resources, and needs" (Park, 2007, p. 5). Strain refers to the negative effects of stressful events, and may be psychological, such as depression or anxiety, or physical and biological, such as disease (Cope, 2003). Stress is recognised, globally, to be a major challenge to individual as well as organisational health (Park, 2007). Stressed workers are more likely to have poor mental and physical health, less motivation, lower productivity, make more errors, be less safe at work, and have more work accidents (Edwards *et al.*, 2011; Hoefel *et al.*, 2013; Park, 2007). Cardiovascular diseases, including high blood pressure, high cholesterol and type II diabetes, as well as musculoskeletal disorders, are commonly associated with stress (APA, 2013c; Fauvel *et al.*, 2001; Kajantie and Phillips, 2006; Maina *et al.*, 2009). High job strain, inferred from a combination of high work demands and low levels of job control, has been associated with increased cardiovascular mortality risk (Kivimäki *et al.*, 2002). Stress is seen to increase costs due to lost productivity, sick pay, health care and litigation (Park, 2007). Mental and psychological problems, such as those experienced in stressful conditions, can result in psychosomatic symptoms, including muscle pain, headaches, depression, tiredness, sleep disturbances, and fatigue (Abu-Mourad *et al.*, 2010).

Positive correlations between fatigue and stress have been reported (AngloAmerican, 2005; Park *et al.*, 2001). Stress is closely related to impaired sleep, and is the primary cause of persistent psychophysiological, or primary, insomnia (Åkerstedt, 2006; Dahlgren *et al.*, 2005). Stress is known to increase physiological and psychological activation in response to increased environmental demands, and people with disturbed sleep display many of the same physiological changes as those under stress, including elevated levels of cortisol, and increased heart rate, body temperature and oxygen consumption (Åkerstedt, 2006). Shortened or disturbed sleep may further exacerbate the effects of stress, such as because of reduced performance capacity and impaired moods associated with fatigue (Åkerstedt, 2006). Increased stress has been associated with increased work hours, shorter total sleep time, and increased fatigue, and highest levels of sleepiness have been found in evenings following work days during high stress periods (Dahlgren *et al.*, 2005). Cumulative job stress could have an effect on fatigue symptoms that does not disappear after a period of rest (Park *et al*., 2001). Furthermore, stress is implicated in burnout, which is characterised by extreme fatigue, along with cognitive impairment, reduced empathy, and impaired sleep quality (Åkerstedt, 2006; Dahlgren *et al.*, 2005).

Stress may be associated with financial difficulties, domestic responsibilities, or be work-related, and stress and disturbed sleep may result from high work strain or job demands, a lack of social support, and negative life events (Åkerstedt, 2006; Shaw, 2003). Work and living conditions can also be linked in terms of the effects on stress and job satisfaction (Brunette *et al.*, 2011). Stress at work can be grouped into five categories, namely stressors intrinsic to the job, role in the organisation, career development, relationships at work, and organisational structure and climate; while extra-organisational stressors include aspects such as family problems, life crises, and economic problems (Brunette *et al.*, 2011). Causes of stress in workers include poor working conditions, job dissatisfaction, heavy workloads, mental demands, lack of control over the work done, lack of rewards or recognition for the work performed, infrequent breaks, long work hours, shift work, tasks which do not use a worker's skill, poor communication in the workplace, poor social relations, gender or sexual harassment, a lack of support from supervisors and co-workers, job insecurity, and rapid changes in the workplace (Amponsah-Tawiah *et al.*, 2014; APA, 2013c; NIOSH, 1999; Shaw, 2003; Theron and van Heerden, 2011).

Job stress of mine workers, more specifically, can result from the everyday workload faced in the dangerous mining environment or from an emergency situation or mine disaster (Amponsah-Tawiah *et al.*, 2014). Mining is typically characterised by high job demands, low control, and potential effort-reward imbalances, which are predictors of mental and physical health problems (Amponsah-Tawiah *et al.*, 2014). A lack of control in the workplace has been associated with mental health outcomes such as stress, anxiety, depression, apathy, exhaustion, health behaviours and ill-health consequences (Amponsah-Tawiah *et al.*, 2014). Physical and non-physical stressors also potentially contribute to workplace injuries (Abbe *et al.*, 2011). Shift workers are seen to have higher than normal stress levels; this can result from disrupted social and family lives and difficulties performing duties at home (AngloAmerican, 2005). Higher risk of divorce and suicide is reported for shift workers (AngloAmerican, 2005). The prevalence of workplace stress reported by mine workers in South Africa ranged from 19% to 30% (Edwards *et al.*, 2011). High levels of stress appeared to be more prevalent in underground than surface workers, and night rather than day workers (Edwards *et al.*, 2011). Additionally, the participating mine workers with high levels of job strain, as indicated in the Job Content Questionnaire, tended to report more fatigue symptoms in the Subjective Fatigue Checklist (31% of symptoms, compared to 18%, 22%, and 20% in the low strain, active and passive categories, respectively) (Edwards *et al.*, 2003). Workplace stress in the SAMI has also been found to be associated with occupational category as well as socio-economic position (Hodgskiss and Edwards, 2013). Those in management, engineers, and with higher SES, as indicated by education, race, housing and mode of transport, generally reported higher levels of job demands but also higher levels of job control, than those with poorer SES (Hodgskiss and Edwards, 2013).

In summary, stress and fatigue are linked. Stress and strain can result from work-related or personal factors, and have been shown to result in impaired sleep and fatigue. As such, it is difficult to separate the different components of stress. It also appears that stress and fatigue can result from some of the same causes (e.g. high mental or physical demands), while a number of the consequences are also shared (e.g. poor mental and/or physical health and safety outcomes).

2.3.10. Safety and performance

Fatigue is a significant health and safety concern, and is considered to have an adverse effect on every aspect of human performance (Schutte, 2010). Increased fatigue levels result in reduced performance and productivity in the workplace, and increased risk of accidents and injuries (Hoefel *et al.*, 2013; Schutte, 2010; South Africa, 2014). Fatigue contributes to accidents, injuries and death in various settings, including mining (Halvani *et al.*, 2009b; Schutte, 2010; Theron and van Heerden, 2011; Williamson *et al.*, 2011). Fatigue increases the risk of incidents because it results in a lack of alertness, poorer judgement, and slow reaction times (Shaw, 2003). These incidents have been attributed to attention failures or failure to suppress inappropriate actions (Williamson *et al.*, 2011). People make more errors, and find it more difficult to concentrate and to react when fatigued (Bates, 2009; Jing-Gang and Lei, 2013). Fatigue is correlated with neurobehavioral impairment, and impairment of tests of psychomotor or cognitive performance (Åkerstedt, 2006; Dawson and Fletcher, 2001). Fatigue also to affects a person's ability to accurately assess fitness for work (Balkin *et al.*, 2011). Fatigue and work ability are also associated (Fischer *et al.*, 2006).

Similarly, sleep deprivation results in longer reaction times, difficultly in learning and concentration, impaired memory, decision-making, judgement, and reasoning (Kim *et al.*, 2011; Wlodarczky *et al.*, 2006). Sleep loss is associated with impaired alertness, reaction time, attention, vigilance, problem solving, divergent thinking capacity, creativity, flexibility, inhibition, and increased risk-taking behaviour (Killgore *et al.*, 2006). Sleep deprivation has been seen to impair performance on tasks that require executive cognitive functions, including verbal fluency or speech, response inhibition, innovative and flexible thinking, and emotional control (Dawson *et al.*, 2011; Kim *et al.*, 2011). Sleep debt occurs when people continually get less sleep than necessary, and influences fatigue, health and safety, as it affects cognitive and physical performance, and increases the risk of errors and incidents in the workplace and while travelling (Ferguson *et al.*, 2010; Theron and van Heerden, 2011).

Fatigue and sleep loss affect productivity, health and safety outcomes, as a result of impaired alertness, reaction times, and judgement. As such, it is important to assess and address the causes of fatigue to mitigate these risks. The following sections detail the measurement and management of fatigue in the context of the SAMI.

2.4. Measuring fatigue

There is no gold standard for measuring fatigue, which makes it difficult to control and manage (Aghdam *et al.*, 2019). Fatigue may not be directly measured, but levels of fatigue can be estimated from associated symptoms (Davy, 2018; Dittner *et al.*, 2004; Ngcamu-Tukulula, 2018). Various subjective and objective measures are used to assess sleepiness and fatigue (Di Milia *et al.*, 2011; Shahid *et al.*, 2010). Examples of subjective measurement tools to measure sleepiness and fatigue include:

- The Stanford Sleepiness Scale (Hoddes *et al.*, 1973);
- Epworth Sleepiness Scale (Johns, 1991);
- Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg, 1990);
- Samn-Perelli Fatigue Scale (Samn and Perelli, 1982);
- Pittsburgh Sleep Quality Index (Buysse *et al.*, 1989);
- Subjective Fatigue Questionnaire (Yoshitake, 1971);
- Sleep Wake Activity Inventory (Rosenthal, 1993);
- Brief Fatigue Inventory (Mendoza *et al.*, 1999);
- Fatigue Severity Scale (Krupp *et al.*, 1989);
- Checklist Individual Strength (Vercoulen *et al.*, 1994); and
- The Multidimensional Fatigue Inventory (Smets *et al.*, 1995).

The Profile of Mood States (POMS) questionnaire (McNair *et al.*, 1971; Lorr *et al.*, 2004) also includes a subscale relating to fatigue. Subjective sleepiness can also be measured using visual analogue scales (Brunier and Graydon, 1996; Dittner *et al.*, 2004; van Dongen and Dinges, 2000; Roca *et al.*, 2012). Van Hooff *et al.* (2007) used a single-item measure of fatigue, posing the question, “How fatigued do you currently feel?” with response ratings from 0 (‘not at all’) to 10 (‘extremely’). The Morningness-Eveningness Questionnaire (Horne and Östberg, 1976) was developed to give an indication of a person’s ‘chronotype’ or preferences in sleep timing and the time of day when at highest alertness and functioning, while the Circadian Type Inventory indicated which individuals would readily adjust to shift work (Baehr *et al.*, 2000).

Objective measures of fatigue include performance measures, behavioural observations and physiological responses (Ngcamu-Tukulula, 2018). Fatigue can be assessed by changes in performance on simulated tasks, such as the Psychomotor Vigilance Task (PVT), logical reasoning, and numerical aptitude (Basner *et al.*, 2011; Di Milia *et al.*, 2011). Auditory and visual reaction time tests, such as the PVT, have been widely used in sleep research and to measure vigilant attention (Balkin *et al.*, 2014; Basner *et al.*, 2011; Belenky *et al.*, 2003; Holzer, 2011; van Dongen and Dinges, 2000; Wesensten *et al.*, 2004; Wlodarczky *et al.*, 2006).

Behavioural observations include those of yawning, red or swollen eyes, eye rubbing, fidgeting, frequent blinking, staring blankly, difficulty keeping eyes open, head nodding, inability to follow instructions, taking shortcuts or increased propensity towards risk-taking behaviour, and lateness or absenteeism (Mathis and Hess, 2009; Ngcamu-Tukulula, 2018; ORR, 2012).

Numerous other objective tools for measuring sleepiness and fatigue are used, as noted by various authors (Alhola and Polo-Kantola, 2007; Balkin *et al.*, 2004; Caterpillar, 2008; Egelund, 1982; Gu *et al.*, 2002; Hodgskiss and Lombard, 2013; Kaida *et al.*, 2007; Mathis and Hess, 2009), and include:

- Heart rate variability;
- Skin conductance;
- Electroencephalography (EEG);
- Actigraphy;
- Pupillography;
- Saccade latency (eye-track);
- Face pose tracking;
- Facial expression recognition;
- Critical flicker fusion frequency;
- Sleep latency test; and
- The Maintenance of Wakefulness Test.

Numerous physiological indicators have been used to identify fatigue. When fatigue is referred to as a physical state, it may be inferred by changes in heart rate, blood pressure, hand strength, and actigraphic sleep alterations (Di Milia *et al.*, 2011). Physiological symptoms of fatigue include reduced core body temperature, blood pressure, respiration rate, heart rate, and physical and cognitive functioning (Ngcamu-Tukulula, 2018). Physiological variables, including body temperature, melatonin and cortisol, are seen to reflect the circadian rhythm (Johnson, 1999; Myers and Badia, 1995; Pusnik and Miklavec, 2009). Measures of sleepiness based on physiological changes with sleep loss include pupillometric, oculomotor, eyelid closure, and EEG-based measures, while sleep duration and timing can be measured using wrist actigraphy (Balkin *et al.*, 2004). Three physiological indicators of sleep that constitute polysomnography include EEG, which measures brain waves, electrooculography (EOG), which measures eye movements, and electromyography (EMG), which measures muscle tension (Åkerstedt, 2006; Belenky *et al.*, 2003; Di Milia *et al.*, 2011). Actigraphy allows for portable measurement and recording of movement data over long periods, and provides an objective measure of sleep-wake timing and duration (Balkin *et al.*, 2011).

Oculomotor responses, such as saccadic eye movements, pupil responsivity to light (pupilometry), and percentage eye closure (PERCLOS), have also been used to detect fatigue (Balkin *et al.*, 2011). Pupillography has been used to assess differences in pupil reactivity with sleep deprivation (Franzen *et al.*, 2009). Video-based monitoring systems, that capture aspects such as prolonged eye closure, head nodding, or facial features, have use in workplaces, such as for drivers, to monitor signs of sleepiness (Balkin *et al.*, 2011). Performance measures in the workplace, such as lane tracking or steering performance for drivers, are also used (Balkin *et al.*, 2011; Zhang and Hua, 2015).

Technologies to objectively predict or detect worker fatigue have the potential to complement organisation or regulatory approaches, as they would allow for timely interventions to be applied (Balkin *et al.*, 2011; Schutte, 2010). These include fitness-for-duty technologies, performance-based monitoring technologies, online operator monitoring technologies, and bio-mathematical models of fatigue or alertness (Balkin *et al.*, 2011). Bio-mathematical roster scheduling tools to predict work-related fatigue based on work hours can also help manage fatigue risk (Fatigue Management Solutions, 2014; InterDynamics, 2013). Fatigue detection technologies, such as detection of if a driver is falling asleep, can generate a warning alarm to alert the worker (Zhang and Hua, 2015). Fatigue detection technologies could also assist to ensure the appropriate management of medical causes of fatigue (Balkin *et al.*, 2011).

2.5. Managing fatigue

Appropriate fatigue management is important to mitigate related health and safety risks in industries such as mining, and is subject to legislation and regulations. The MHSA, Act No. 29 of 1996, and the Occupational Health and Safety Act (OHSA), Act No. 85 of 1993, require employers to ensure that the working environment is safe and will not pose a risk to the health and safety of employees (South Africa 1993, 1996b). Both of these Acts specify requirements for employers to conduct risk assessments, implement measures to eliminate or control identified hazards, and train and inform employees about risks and controls (South Africa, 2014). Furthermore, employers must implement a Code of Practice (COP) on any matter that can affect the health and safety of employees or other people that may be directly affected by mine activities, if required by the Chief Inspector of Mines (South Africa, 1996, 2014). The COP for the Arrangement of Working Time provides information and guidelines regarding working time arrangements, and the impacts on employee health, safety and family responsibilities (South Africa, 1997c). The Guideline for a Mandatory COP for Risk-Based Fatigue Management at Mines aims to assist the employer of every mine to prepare a risk-based COP on fatigue management (South Africa, 2014).

Fatigue risk management can be defined as “the planning and control of the working environment, in order to minimise, as far as is reasonably practicable, the adverse effects of fatigue on workforce alertness and performance, in a manner appropriate to the level of risk exposure and the nature of the operation” (Gander *et al.*, 2011, p. 574). Fatigue management could eliminate or reduce the likelihood of fatigue or its causes, and counteract its effects if it does occur (Theron and van Heerden, 2011). Fatigue management is a responsibility shared between the organisation, or employers, and employees, and all stakeholders should participate (Department of Industry and Resources, 2000; South Africa, 2014; Schutte, 2010; Theron and van Heerden, 2011). Responsibility for managing fatigue risks can be identified at the regulatory level, industry or company level, as well as at the level of the individual (Gander *et al.*, 2011). A comprehensive and holistic approach to fatigue management is required and fatigue management programmes should address the unique needs of each operation (Schutte, 2010; Theron and van Heerden, 2011).

Fatigue risk management plans need to consider factors such as the work-time arrangements, the circadian cycle, sleep received, length of time awake, continuous time on task, breaks, and intensity of task demands, in addition to the ergonomic design of workplaces and tasks, environmental conditions, employee fitness for work, management processes for monitoring and controlling worker fatigue, education and information about fatigue, and employee assistance programmes (Department of Industry and Resources, 2000; Gander *et al.*, 2011; Schutte, 2010; South Africa, 1997c). Additionally, an understanding of individual differences in susceptibility to fatigue is important (Caldwell *et al.*, 2008).

Strategies for limiting the likelihood of fatigue involve providing adequate sleep opportunities, which may link with shift scheduling and rostering; confirming adequate sleep is obtained, and ensuring fitness for duty; promoting fatigue knowledge and awareness; detecting and preventing behavioural symptoms of fatigue; detecting fatigue-related errors; investigating fatigue-related incidents and accidents; and keeping records and documentation (Gander *et* *al.*, 2011). Employers should also make arrangements for shift workers to undergo regular medical examinations (South Africa, 1997c).

Further alertness management strategies or controls include aspects such as limiting time spent on tasks, rest breaks, working in cooler areas, higher levels of lighting, not working alone, good supervision, and strategic use of naps, meals and alertness-enhancing compounds such as caffeine (Caldwell *et al.*, 2008; Lowden *et al.*, 2010; HSE, 2006; ORR, 2012; Theron and van Heerden, 2011). Safety critical work should not be planned for when fatigue levels are likely to be high (ORR, 2012; South Africa, 1997c). Mines can also assist employees to maintain good health and to cope with night work, by educating workers about balanced diets, regular exercise and adequate rest, and by providing access to related facilities (Department of Industry and Resources, 2000). Employees' responsibilities include creating conditions conducive for sleep, getting sufficient sleep, drinking enough water, eating well, maintaining physical fitness, and responsible use of substances, including caffeine, alcohol, drugs and medication (Theron and van Heerden, 2011). Employees should also be made aware of procedures to follow when identifying fatigue in themselves or others, and for reporting concerns (ORR, 2012).

Fatigue management plans should be developed in consultative, participatory manner (Shaw, 2003). Some of the steps that can be followed in fatigue management (e.g. Schutte, 2010; Shaw, 2003; South Africa, 2014; Theron and van Heerden, 2011) include:

- Establish an approach to controlling the risk, though consultative forums;
- Secure and maintain senior management commitment;
- Develop and communicate the fatigue policy, programme and process;
- Identify fatigue-related hazards, assess the risk factors, and decide on how to control the risks associated with fatigue, with the involvement of employees;
- Implement the controls using the hierarchy of controls (elimination, substitution, engineering controls, administrative controls, and/or personal protective equipment); and
- Monitor, review and modify the fatigue management plan.

As such, fatigue risks can be assessed by examining the roster design, and task-related, work environment, and non-work-related factors (Shaw, 2003; South Africa, 2014). Information about fatigue-related hazards can be gained from consultations with workers and workplace health and safety representatives or committees, self-reports or complaints from employees, reports from supervisors, incident reports, data from employee assistance programmes, absenteeism data, staff turnover, health data, and environmental monitoring (Shaw, 2003; South Africa, 2014). It is expected that reducing fatigue would not only improve safety and productivity at work, but also overall health and wellbeing outside of the workplace (Gander *et al.*, 2011).

2.6. Conceptual framework of the research

Fatigue is an evident health and safety challenge, and the need for a greater understanding about socio-demographic contributors to fatigue has been identified. A range of related factors was discussed in this review of literature. The context of the study, the SAMI, was firstly discussed, in which it was evident that the industry faces a number of challenges, including those relating to socio-economics, living conditions, and health and safety. Following this, concepts, causes and consequences of fatigue were detailed. Numerous associations between demographic, socio-economic, work, lifestyle, health, safety and wellbeing factors and fatigue were reported.

A conceptual framework for the study was developed, based on the literature reviewed and a theoretical understanding of the associations between numerous variables (Figure 2.3). The framework illustrates the interrelatedness of demographic factors, socio-economic and living conditions, work, and lifestyle, with health, safety and wellness, and fatigue. The variables listed in Figure 2.3 are those that were assessed while undertaking this research.

There are three main categories of variables shown in the conceptual framework, namely: 1) socio-demographic characteristics, 2) health, safety and wellbeing, and 3) fatigue. Fatigue was the outcome variable of this research. Fatigue is associated with health, safety and wellbeing characteristics, which incorporate medical conditions, the use of medication, incidents and accidents at work, sick leave or absenteeism and psychosocial factors such as stress, job satisfaction and quality of life. As evident in the literature review, fatigue can be either a cause or consequence of psychosocial and physical health problems. The final category was socio-demographic characteristics, which have been associated with health, safety and wellness, and fatigue.

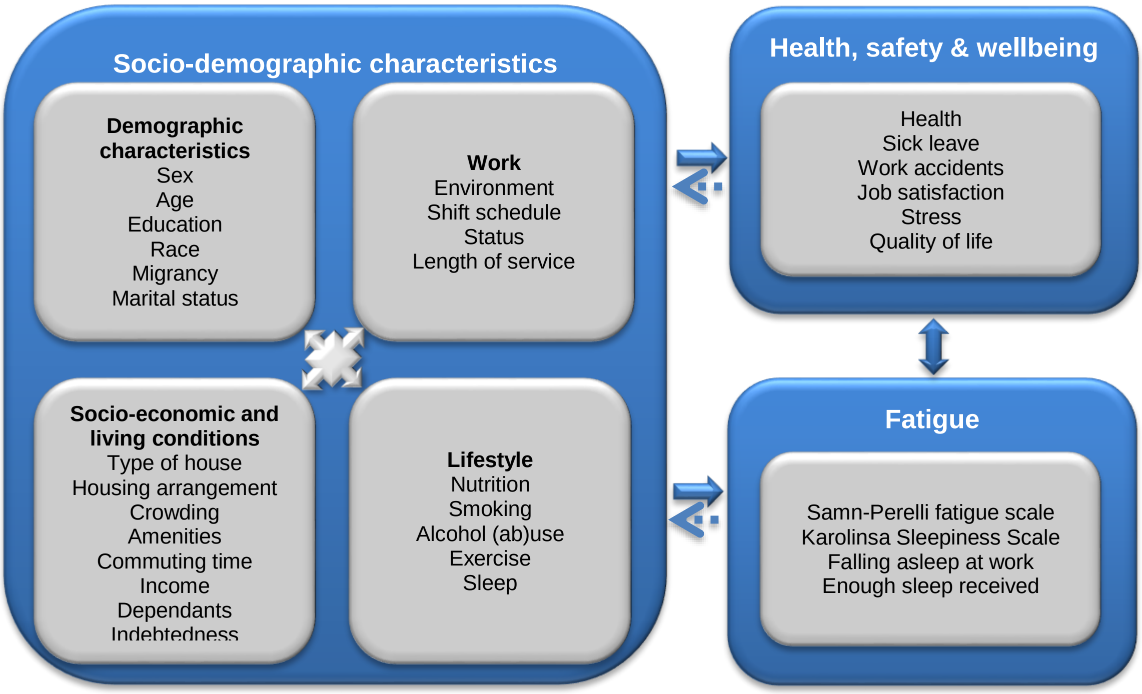

Figure 2.3: The conceptual framework of relationships between socio-demographic characteristics, health-related variables, and fatigue

The socio-demographic characteristics category incorporated variables that were classified as: a) demographic, b) work, c) socio-economic and living condition, and d) lifestyle components. The variables were selected based on factors that have been identified to be associated with fatigue, and also included factors with known importance in the SAMI. The demographic characteristics included age, sex, education, race, migrancy and marital status. Mixed results of the associations of a number of these variables and fatigue have been found in previous research. Work characteristics, such as the work environment and shift schedule arrangements, were included in the study as, although these were not the focus of the work, these factors warrant consideration because of the significant impact that they have on the fatigue of mine workers and because of the relationship with other variables in the framework. Socio-economic and living condition characteristics have also been found to impact on fatigue. A number of these factors, including housing and income-related variables, were listed in the framework. Lifestyle factors are, similarly, shown to be related to other socio-demographic characteristics, health, safety and wellness, and fatigue. The lifestyle factors that were incorporated included nutrition, alcohol use, smoking, recreational exercise and, importantly, sleep obtained.

It is evident that variables in each of these categories are interrelated, and could have cumulative (or confounding) effects in terms of the relationship with fatigue. The associations with fatigue of the variables that were listed in the conceptual framework were discussed in further detail in the literature review. The research tools used to measure fatigue and each of the other variables, are described in the following chapter, which explains the methodology of the research.

2.7. Conclusion of the chapter

Fatigue is a challenge in the SAMI, as it can result in accidents, incidents, and long-term health problems. Along with health and safety concerns, the SAMI faces challenges relating to socio-economic and living conditions, demographics, and sustainability. Fatigue is a complex phenomenon, as it is associated with a range of factors, including work and personal characteristics, and can have both mental or physical, and short- and long-term impacts. However, there is a lack of research about socio-demographic contributors to fatigue. These contributors were, therefore, studied in further detail for this research.

Chapter 3: Methods

This chapter details the methods that were used to assess socio-demographic contributors to fatigue of mine workers in South Africa. A description of the study design, population, sample, tools, procedures, and analyses conducted is provided.

3.1. Study design

This was a mixed methods study, as both quantitative and qualitative approaches were used and integrated (Lederman and Lederman, 2013; Mengshoel, 2012; Molina-Azorin, 2016). Data were gathered from interviews, focus group discussions, and questionnaires. Methodological triangulation was used to provide an in-depth understanding of the topic and to verify the data from different sources (Bekhet and Zauszniewski, 2012). Methodological triangulation involves the use of more than one method simultaneously to study a phenomenon (Bekhet and Zauszniewski, 2012; Heesen *et al.*, 2019). The benefits of methodological triangulation include providing confirmation of findings, more comprehensive data, and increased reliability, validity and understanding of findings (Bekhet and Zauszniewski, 2012; Heesen *et al.*, 2019; Mengshoel, 2012; Molina-Azorin, 2016). The combination of research methods balances the strengths and weaknesses of each research method and enhances the outcome of the study (Bekhet and Zauszniewski, 2012; Heesen *et al.*, 2019; Lederman and Lederman, 2013; Mengshoel, 2012). Challenges associated with the use of mixed methods include the requirement for more time, resources, and a broader skillset than the use of qualitative or quantitative methods alone (Mengshoel, 2012; Molina-Azorin, 2016). Concurrent triangulation design was used, as the quantitative and qualitative approaches were applied simultaneously (Mengshoel, 2012; Molina-Azorin, 2016).

The study design was cross-sectional as data were gathered over relatively short periods of time. Cross-sectional design allows for the analysis of associations between multiple variables and the outcome of interest at a specific time period (Bangdiwala, 2019). However, as discussed further in Chapter 5, a limitation of this research design is that is does not enable the establishment of a causality (Bangdiwala, 2019). The use of mixed methods assisted to enhance this understanding.

Data were collected from three groups from 2014 to 2017, as explained further in this chapter. Similar methods were employed for each of the study groups and, therefore, the methods are jointly discussed. Nevertheless, the differences between groups are indicated.

The methods are also briefly described in the scientific papers (published by peer-reviewed journals) based on the study objectives (Appendices A to D). Papers 1 and 2 were based on the first group of data collected; Paper 3 was based on the second group; and Paper 4 on the third group, as shown in Table 3.1.

Table 3.1: Study groups and data sources related to the study outputs

Study group	Paper	Data source(s)
1	Living conditions of mine workers from eight mines in South Africa (Paper 1) Socio-demographic contributors to health and safety of mine workers in South Africa (Paper 2)	Mine worker questionnaires Interviews and focus group discussions
2	Contributors to fatigue at a platinum smelter in South Africa (Paper 3)	Mine worker questionnaires Interviews and focus group discussions
3	Contributors to fatigue of mine workers in the South African gold and platinum sector (Paper 4)	Mine worker questionnaires Focus group discussions

3.2. Study setting, population and sites

The study setting was the SAMI. There were approximately 1 700 operating mines and quarries in South Africa, and close to half a million people directly employed in this industry at the time of the study (DMR, 2011; Minerals Council South Africa, 2018a). The platinum, gold and coal sectors employ the highest percentages of labour in the industry, but many workers are also employed in the iron ore, diamond, chrome, manganese, copper and other commodities (DMR, 2011; Minerals Council South Africa, 2018a). The target population comprised those working in the SAMI. The number of people employed in the SAMI per commodity in 2015 is shown in Table 3.2, by sex, and employee type. Around 10% of the SAMI workforce was female, in line with the DMR’s target, and 30% were contract workers. The majority worked in underground workplaces (55%), 34% were surface mine workers, 11% worked at opencast operations, and less than 1% at sea (DMR, 2015).

The study sites (12 mines and one platinum smelter) were purposively selected. Most of the sites were selected from the gold and platinum sectors because these sectors employ the most labour. The three groups from which data were collected and the study sites at which they were based are summarised in Table 3.3. One of the sites was common to Groups 1 and 3. It is estimated that the participating mines employed close to 20% of the workforce in the SAMI, based on information received from the Department of Mineral Resources (DMR, 2015) and from the mining companies themselves. The participating sites were located in six of the nine provinces of South Africa (Figure 3.1). These sites reflect the locations of the main mineral deposits in the country. As shown in Table 3.4, the majority of employees in the SAMI were located in the provinces of the North West, Gauteng, Mpumalanga, Free State and Limpopo.

Table 3.2: Number of employees in the SAMI per commodity, by sex and employment type, in 2015 (adapted from DMR, 2015)

Commodity	Sex		Employment type		Total
	Male	Female	Permanent employees	Contractors	
Gold	102 702	12 189	100 824	14 067	114 891
Platinum group metals	168 397	19 681	135 552	52 526	188 078
Diamonds	15 053	2 338	10 472	6 919	17 391
Chrome	15 838	2 704	11 829	6 713	18 542
Iron	18 027	2 734	11 078	9 683	20 761
Manganese	7 741	979	4 361	4 359	8 720
Coal	68 778	8 931	38 506	39 203	77 709
Non-ferrous metals	14 322	2 177	8 248	8 251	16 499
Industrial minerals	11 777	1 539	11 176	2 140	13 316
Other minerals	4 998	824	3 437	2 385	5 822
Total	***427 633***	***54 096***	***335 483***	***146 246***	***481 729***

Table 3.3: Locations and workforce sizes of study groups

Study group	Study site	Site location*	Approximate workforce size	Date of data collection
1	Platinum mine #1	North West[1]	7 200	June - November 2014
	Platinum mine #2	North West[2]	28 400	
	Platinum mine #3	Limpopo[3]	4 200	
	Gold mine #1	Gauteng[4]	12 600	
	Gold mine #2	Free State[5]	3 000	
	Coal mine	Mpumalanga[6]	1 600	
	Diamond mine	Free state[7]	1 000	
	Manganese mine	Northern Cape[8]	3 500	
2	Platinum smelter	Limpopo[9]	300	March 2016
3	Gold mine #1	Gauteng[4]	11 200	March 2017
	Gold mine #3	Free State[10]	8 700	
	Gold mine #4	Mpumalanga[11]	300	
	Gold mine #5	Gauteng[12]	10 600	
	Platinum mine #4	North West[13]	8 900	

*Site locations, indicated in superscript, are shown in Figure 3.1

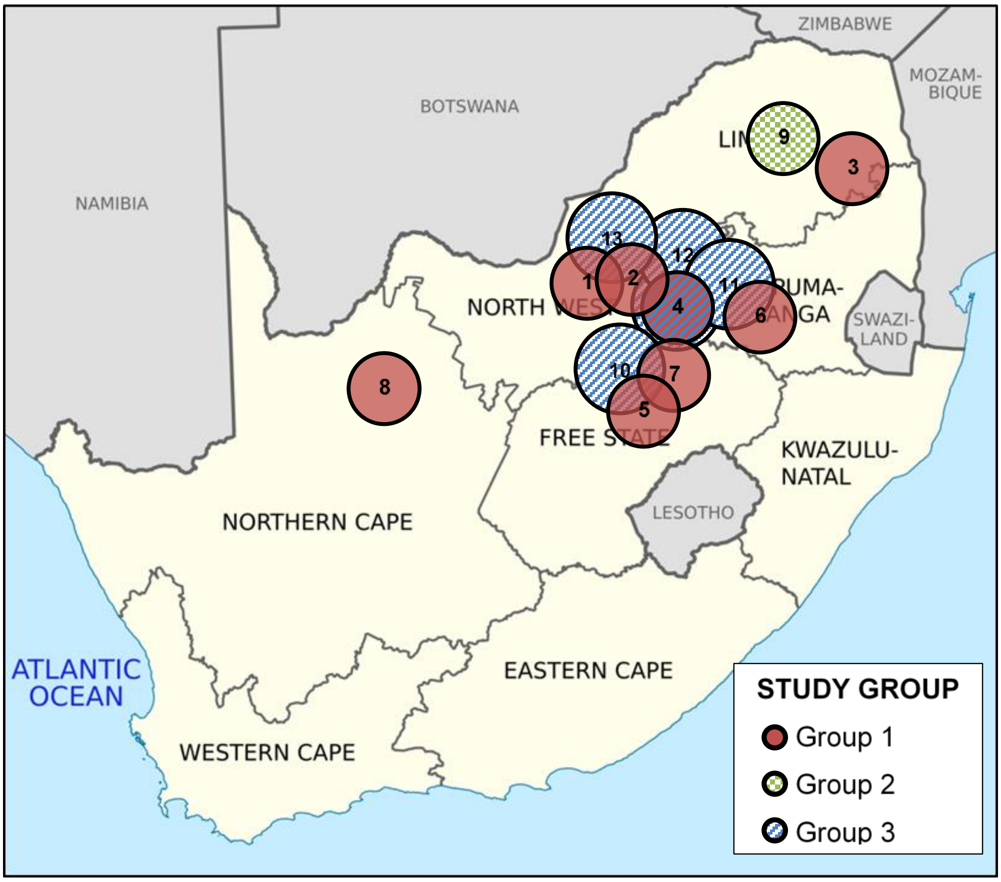

Figure 3.1: Approximate locations of the study sites

Table 3.4: Number of employees in the mining sector per province in 2014 (adapted from Minerals Council South Africa, 2018a)

Province	Number of employees	Percentage of employees (%)
North West	217 187	43.8
Mpumalanga	89 434	18.0
Gauteng	63 632	12.8
Limpopo	53 101	10.7
Free State	43 519	8.8
Northern Cape	16 489	3.3
KwaZulu-Natal	9 234	1.9
Eastern Cape	1 762	0.4
Western Cape	1 582	0.3
Total	***495 940***	***100***

Data were collected from the first group in 2014, as part of a larger study that was commissioned by the Mine Health and Safety Council (MHSC), entitled “Health and safety impacts of socio-economic and other matters relating to living conditions in the SAMI” (project number: SIM 13-09-01). Further funding was received though the mechanism of the Young Researchers’ Establishment Fund (YREF) (project number: YREF 2014 024) of the Council for Scientific and Industrial Research (CSIR). The project was conducted by the

CSIR, under the leadership of the student (Jodi Pelders). Data were collected at eight mines, which included platinum (n=3), gold (n=2), coal (n=1), diamond (n=1) and manganese (n=1) mines. The mines were purposively selected, based on input from professionals with knowledge and understanding of the industry. A range of mining sectors was selected so that the findings from this study would closely represent the SAMI, as a whole. As the platinum and gold sectors employ the most people in the SAMI, more than one of each of these mines was selected. Additionally, mines with varying living conditions for the workers, and mines in different provinces, were chosen. Each of the mines in the first study group was owned by a different company. Data were collected from the second and third groups as part of projects funded by the CSIR. The second group comprised of workers at a platinum smelter, and data collection took place in March 2016. Data were collected from the third group, which included workers at five mines (four gold mines and one platinum mine owned by the same company), in March 2017. One of the gold mines in the third group was also included in the first group.

3.3. Study sample

The study participants comprised individuals in management, labour representatives (unions), and mine workers from each of the sites. Those in management and the labour representatives were purposively selected based on their roles at the sites. Those in management positions included mine managers, and managers or representatives from departments including human resources, employee relations, human capital development, health, safety, wellness, finance, operations, engineering, production, transformation, residence/hostel, community or sustainable development, or the equivalent positions or departments at each site. The labour representatives at the sites comprised individuals who worked full- or part-time for unions, including the National Union of Mineworkers (NUM), Association of Mineworkers and Construction Union (AMCU), United Association of South Africa (UASA), and Solidarity. Labour representatives included shop stewards, chairpersons, secretaries, treasurers, and health and safety representatives.

The mine workers included production and maintenance personnel at the sites, and generally excluded those in management or office-based positions. The workers included males and females of different ages and languages, from a range of working positions. The mine workers were recruited using convenience sampling, as it was not possible to obtain a random sample. Consequently, the findings could be biased, as the participants might have been healthier and less fatigued than those in the entire population. However, it was ensured that the participating mine workers at each site included those with a range of demographic characteristics and job positions such as miners, shift bosses, team leaders, machine operators, development labour, electricians, artisans, assistants and general workers.

The managers, labour representatives and mine workers were all involved in qualitative components of the research, including interviews or focus group discussions. Meanwhile, only mine workers completed questionnaires for the research, from which the quantitative component of the work was based. The data collection tools, procedures and analyses are discussed for each of these components. The data collection tools were developed by the student for use in this study and were reviewed and approved by experts in research and in the mining industry.

Participants were recruited with the assistance of designated officials at each site. The participants were recruited from the locations most appropriate for each study site, in order to avoid disruption of work and production at the sites. In general, data collection with the managers and labour representatives took place in boardrooms or offices. Mine workers were mostly recruited from training centres at the sites, although some were recruited at waiting places inside the workplaces before that start of a work shift. In general, a representative from the site introduced the researchers to the potential participants. The researchers then explained the purpose of the visit, including the aims and procedures, and answered questions. Participants provided signed informed consent prior to participation.

3.4. Interview and focus group discussions

3.4.1. Data collection tools

The interview and focus group discussion guides consisted of open-ended questions for the participants. The questions were customised according to the nature of the discussion (i.e. interview or focus group discussion) and the participants (i.e. managers, labour representatives or workers). For the first group, the discussion guides included semi-structured questions on a range of topics relating to socio-economic and living conditions, and health and safety of the workers, along with how these factors are potentially associated (Appendix K). Subsequently, the discussions for the second and third groups focused on fatigue and potential contributors to fatigue of workers at the study sites (Appendix L). The questions provided guidelines to direct the discussions, although the discussions were also shaped by participant responses, and follow-up questions were asked to gain further understanding about the topic and findings that emerged.

3.4.2. Data collection procedures

Key informant interviews with individuals in management and labour representatives were conducted for the first two groups of data collection, while focus group discussions for individuals in management and labour representatives were conducted for the final study group (see Table 3.1). The interviews took approximately 30 minutes to complete, and the focus group discussions took around one hour each. Focus group discussions were held with approximately two groups of workers from each site, with around eight individuals in each group. These discussions were conducted in a local language readily understood by the participants. In general, the interviews or focus groups with participants in management positions were conducted in English, while those with the labour representatives and mine workers were conducted in English, Zulu or Sotho, or a mix of local languages. English was the official business language at the sites, while Sotho and Zulu or Xhosa account for the predominant language groupings spoken by the participants at home. Voice recordings of the interviews and focus groups were made. In one instance, a labour representative provided consent to participate, but not to have the interview voice-recorded; comprehensive hand-written notes were taken in lieu of a voice-recording.

3.4.3. Data analysis

Thematic analysis was used to analyse the qualitative data. Thematic analysis is a method used to identify, analyse and interpret patterns or themes from qualitative data (Clarke and Braun, 2017; Maguire and Delahunt, 2017; Vaismoradi *et al.*, 2013). Prior to the analysis, the voice-recordings from the interview and focus group discussions were translated, where necessary, and transcribed. During the analysis, data from the discussions were coded and categorised into themes. The interview and focus group questions provided a basic framework for the themes that were covered. However, the themes were identified and refined based on the findings from these discussions. In the analysis process, the transcripts for each participant and group were firstly examined as a whole in order to become familiarised with the content of the discussions. Initial codes were generated based on this process, and the data were then collated into potential themes, after which the themes were reviewed and refined. For this research, the coded data from the transcriptions were copy-and-pasted according to themes for each research group. The data commonly could be coded under more than one theme, and were accordingly categorised. Themes were defined from recurring topics that arose in the discussions, and the data were further categorised into sub-themes. The findings for each theme and sub-theme were then interpreted and documented.

3.5. Worker questionnaires

3.5.1. Data collection tools

The worker questionnaire was designed to gather quantitative information about worker demographic characteristics, living conditions, income, lifestyle, health, wellness and fatigue (Appendix M). It was a forced-choice questionnaire, where the participants were requested to select the most appropriate response to each question. There was also space on the questionnaire for workers to provide open-ended comments. The questionnaire was modified for each study group, according to changes in the focus of the study, while many of the questions remained unchanged. For example, the focus for the first study group was on contributors to health and safety, while the focus for the second and third groups was limited to contributors to fatigue. The questionnaire used for Group 1 comprised 68 questions, Group 2's questionnaire had 75 questions, and there were 50 questions in the questionnaire used for Group 3. This last questionnaire was refined according to results obtained from the previous groups and was shortened to limit disruption to the participants' work as a result of the time taken to complete it.

The questionnaires were designed based on the conceptual framework of the research and on literature on the topic. The questionnaires included questions adapted from previous studies (e.g. Brunette *et al.*, 2011; d'Errico and Costa, 2011; Lewis *et al.*, 2003; Marais and Venter, 2006; Molarius *et al.,* 2006; Schutte and Hodgskiss, 2012; Statistics South Africa, 2011). Demographic data that were gathered included age, sex, race, home language spoken, home province, nationality, marital status and highest level of education attained. Work-related data included job position, work area, job status (i.e. permanent or contract worker), shifts worked and length of service. Socio-economic data included average total income per month after deductions, number of dependents, difficulty paying for needs, and indebtedness. Numerous factors relating to living conditions were considered, including house type, housing arrangement with the mine, housing tenure (e.g. whether the house is owned or rented), area of dwelling, distance from the mine, access to amenities, level of crowding, and whether the dwelling was considered to be a permanent home for the mine worker. Data on commuting times, and modes of transport to get to work were also collected. Questions relating to lifestyle included frequency of recreational exercise, alcohol use, smoking habits, diet, sleep quality and quantity on work days and off days, and sleep disturbances. Health, safety and wellness data were also collected, including self-rated health, the presence of disease, sleep disorder, or work-related injury, the use of medication, sick leave taken in the previous year, involvement in an accident at work in the previous year, levels of satisfaction, stress, quality of life, unintentionally falling asleep at work, and ratings of sleepiness and fatigue.

Single-item measures of self-rated health, stress, job satisfaction, and quality of life were used, in the interests of brevity. Reliable and valid single-item measures are beneficial because of they are short and simple and, as time for completion of the question is short, it minimises disruption of other activities; multiple-item instruments can be lengthy, time-consuming and burdensome to complete, which can result in low completion rates (Locke *et al.*, 2007; Zimmerman *et al.*, 2006). There is evidence that a single item provides a sufficiently accurate measure in some domains, such as for general health status and overall satisfaction at work (Brunette *et al.*, 2011). Self-rated health was measured with a five-point scale, ranging from 'very bad' to 'very good', similar to measures used in previous studies, and is an established predictor of morbidity and mortality (Brunette *et al.*, 2011; Halford *et al.*, 2003; Molarius *et al.,* 2006; Sandberg *et al.*, 2014). Similarly, job satisfaction was measured on a five-point scale, ranging from 'very dissatisfied' to 'very satisfied' (Brunette *et al.*, 2011). Stress was measured on a five-point scale ranging from 'not at all stressed' to 'extremely stressed'. Previous studies have made use of, and validated, single-item measures of stress (APA, 2011; Dahlgren *et al.*, 2005; Elo *et al.*, 2003; Littman *et al.,* 2006). Quality of life was measured on a five-point scale that ranged from 'very poor' to 'very good'. Single-item global quality of life scales have been found to be acceptable, valid and repeatable (Locke *et al.*, 2007; Yohannes *et al.*, 2011; Zimmerman *et al.*, 2006). Likert scales were used for respondents to rate the extent of agreement or disagreement with a statement (Sullivan and Artino, 2013).

Fatigue was indicated using four items, including 1) the Karolinksa Sleepiness Scale (KSS), 2) an adapted version of the Samn-Perelli fatigue scale, 3) having fallen asleep at work in the previous year, and 4) subjectively having received enough sleep. The KSS is a nine-point scale ranging from 'extremely alert' to 'very sleepy, great effort to stay awake'. It is commonly used in sleep and fatigue research, locally and internationally, and has been extensively validated (Dahlgren *et al.*, 2005; Di Milia *et al.*, 2011; Folkard *et al.* 2007; Kaida *et al.*, 2006; Kaida and Kaida, 2017; Lombard, 2009). Similarly, numerous studies have assessed fatigue using the seven-point Samn-Perelli fatigue scale (Folkard *et al.*, 2007; ICAO, 2015; Paterson *et al.*, 2013); the points range from 'fully alert, wide awake' to 'completely exhausted, unable to function effectively'. Flechtner and Bottomley (2003) noted that a good fatigue scale should require minimal input, be valid and reliable, have easily understood items, straightforward scoring and interpretation, and be easily translated and cross-culturally valid. Various studies have validated the use of single-item measures of fatigue (Belenky *et al.*, 2003; Brunier and Graydon, 1996; Dittner *et al.*, 2004; Rhoten, 1982; Strasses *et al.,* 2009; Temel *et al.*, 2006; van Hooff *et al.,* 2007). Although the use of these tools is reported internationally and locally, there is limited research that has reported on the reliability or validity of tools used to identify fatigue in the SAMI, specifically (Bauerle *et al.*, 2018; Maldonado *et al.*, 2004).

The data collection tools were piloted at the first mine where data collection took place. Thereafter, the questions were adjusted, taking into account any identified short-comings. For example, the response rate to questions that required written responses (e.g. for job title) was lower than those that required checkboxes to be ticked; and more responses were omitted in questions that required more than one response. Minor adjustments to the questionnaire were made to avoid questions formatted in this way.

3.5.2. Data collection procedures

Research assistants who were fluent in local languages assisted the workers to complete the questionnaires to eliminate language or literacy barriers. Translations of the questions were available for the research assistants to refer to, to ensure that the questions were interpreted in a standardised way.

3.5.3. Data analysis

The data gathered in this study were captured electronically and then analysed. Questionnaires were excluded if participants completed less than 50% of the questions. Descriptive and inferential statistics on the questionnaire data were performed using STATA 13 software. Most of the quantitative data was categorical; as such, these data were summarised using frequencies and percentages. Chi-square tests and stepwise binary logistic regression were used to assess the associations between the variables. All statistical analyses were performed at a significance level of $\alpha = 0.05$, and an association or difference was deemed significant if $p<0.05$. Statistical guidance was provided by professionals in this field at the onset of the study and throughout the analysis process.

After the qualitative and quantitative data were individually analysed and the results described, the data obtained using the different study tools were triangulated and discussed. This entailed comparing, combining and drawing inferences between the findings (Mengshoel, 2012). The findings from the qualitative data were used to explain findings from the quantitative data, while the qualitative data also provided insight into factors to assess in further detail from the quantitative data.

3.6. Ethical issues

Ethical approval to conduct this study was granted by the CSIR Research Ethics Committee (reference: 85/2013) and the University of the Witwatersrand Human Research Ethics Committee (ethical clearance certificate number: M140444) (Appendices N and O, respectively). All study participants were provided with information about the study aims and procedures, and signed informed consent forms. Participation was voluntary. Research assistants who were fluent in local languages translated information, as and when required. The names of the participating sites, companies, and the participants remain confidential, and will not be made publically available. As focus groups were used, confidentiality could not be assured, as information shared by one individual during the focus group discussion could be shared by another outside of this setting; however, participants were informed of this and were requested to keep the information confidential. For the questionnaires, anonymity was attained, as participants were not required to write their names on the data collection forms. Data were coded and stored using participant numbers. Additionally, information about the names of participating mines and individuals were stored separately from the data. Data were stored securely and were accessible only to the researchers directly involved in the study. Hard copies of data were stored in a secure (locked) office, and electronic data were saved on password-protected computers. Feedback was provided to each of the sites or companies where data collection took place.

3.7. Conclusion of the chapter

This research was cross-sectional and employed mixed methods to assess socio-demographic characteristics, living conditions, health, safety and wellness, and fatigue of mine workers in the SAMI. Data collection took place at 12 mining sites and one platinum smelter in South Africa. Three phases of data collection took place with different study groups, in 2014, 2016 and 2017, respectively. The participants included individuals in mine management, labour representatives, and mine workers. Interviews, focus group discussions, and questionnaires were used to gather data, which were analysed using thematic analysis and descriptive and inferential statistics. The data were triangulated and relationships between the variables were analysed to identify factors that were associated with health, safety, wellness and fatigue. The following chapter describes the findings of the research.

Chapter 4: Results

This chapter describes the results of the research. Four scientific papers were drafted in fulfilment of the study outcomes, and the findings that are presented in the four papers are summarised. The full papers can be found in Appendices A to D. Additional findings, presented in poster and oral presentations at various symposiums, are also briefly described. Following this, the research results were synthesised and described in terms of findings from the qualitative data (i.e. interviews and focus group discussions), and from the quantitative data (i.e. the questionnaires). The combined results are discussed in the following chapter.

4.1. Overview of data collected

Data were collected at 12 mines and one platinum smelter from 2014 to 2017. In total, 71 interviews and 37 focus group discussions were held with 395 participants (including those in management, labour representatives and workers), and questionnaires were completed by 1 515 workers. The numbers of participants per study site and group are indicated in Table 4.1.

Table 4.1: Number of study participants per site and group for each data source

Study group	Site	Interviews and focus group discussions			Questionnaires
		Management	Labour representatives	Workers	Workers
1	Platinum mine #1	8	2	17	114
	Platinum mine #2	7	1	16	100
	Platinum mine #3	8	2	9	111
	Gold mine #1	13	8	16	182
	Gold mine #2	5	2	17	79
	Coal mine	7	2	18	91
	Diamond mine	7	1	8	110
	Manganese mine	15	1	19	88
	Sub-total	*67*	*18*	*120*	*875*
2	Platinum smelter	7	1	24	76
	Sub-total	*7*	*1*	*24*	*76*
3	Gold mine #1	21	4	16	181
	Gold mine #3	1	4	16	87
	Gold mine #4	8	2	16	37
	Gold mine #5	3	10	19	127
	Platinum mine #4	14	3	17	132
	Sub-total	*48*	*23*	*83*	*564*
Total		***125***	***43***	***227***	***1 515***

For the first group of participants, 64 interviews and 14 focus group discussions were held, and questionnaires were completed by 875 mine workers from eight mines. Five to eight interviews with individuals in mine management, and at least one with labour representatives, took place at each mine. Most of the interviews were conducted in one-on-one sessions. In some cases, two or more individuals were interviewed together, such as when this was recommended or requested by mine personnel to avoid duplication of responses, increase discussion, and allow for responses to questions of different topics, if a particular participant was not aware of certain matters. The second group comprised those at a platinum smelter; seven interviews were held with individuals in management and labour representation, two focus group discussions were held with workers, and 76 workers completed questionnaires. For the third group, 21 focus group discussions were held, and 564 questionnaires were completed by mine workers; in general, one focus group discussion was held with management, one with labour representatives, and two with workers at each mine. The mean number of participants in the focus group discussions for all the study groups was 9 (±4).

4.2. Summary of papers

4.2.1. Paper 1: "Living conditions of mine workers from eight mines in South Africa"

Paper 1 provided an understanding of the context and background to the entire PhD research. This paper was published in *Development Southern Africa*, and is attached in Appendix A. The aim of this part of the research study was to describe the living conditions of mine workers in South Africa at the time of data collection, and compare the results with those from the SAMI in the previous decade. Data were obtained from Group 1: 64 interviews and 14 focus group discussions with a total of 205 individuals in mine management, labour representatives, and mine workers; and 875 questionnaires completed by mine workers. The conclusion was that, while many changes have taken place to improve living conditions in the SAMI, challenges remain.

4.2.2. Paper 2: "Socio-demographic contributors to health and safety of mine workers in South Africa"

The second paper has been published in *Work: A Journal of Prevention, Assessment, and Rehabilitation.* This paper can be seen in Appendix B. The aim of the study was to assess associations between worker demographics, work factors, socio-economic and living conditions, lifestyle, and quality of life, with health and safety issues. The study sample is that same as for Paper 1 (i.e. Group 1), but different aspects of the research were investigated, presented and discussed. In summary, numerous socio-demographic variables – such as age, length of service, race, nationality, education, mining sector, work status, income, housing, domestic crowding, sleep, exercise, alcohol use, and perceived quality of life – were associated with disease, sick leave, fatigue, work accidents and job satisfaction of the mine workers.

4.2.3. Paper 3: "Contributors to fatigue at a platinum smelter in South Africa"

The third paper was published in *The Journal of the Southern African Institute of Mining and Metallurgy (SAIMM)* in the March 2019 edition (Appendix C). The aim of the study was to assess relationships between demographic, work, socio-economic, living condition and lifestyle factors, and fatigue at a platinum smelter in South Africa. Data collected from Group 2 were analysed. It was evident that both work and non-work factors contributed to fatigue of workers at the smelter, and should be addressed in fatigue management plans.

4.2.4. Paper 4: "Contributors to fatigue of mine workers in the South African gold and platinum sector"

For the final paper, contributors to fatigue of mine workers from four gold mines and one platinum mine in South Africa were assessed (Appendix D). This paper was published in *Safety and Health at Work.* The study participants represented Group 3. The findings showed that fatigue was attributed to numerous factors relating to work, demographic and socio-economic factors, living conditions, lifestyle, health and wellness. Factors associated with greater fatigue included younger age, indebtedness, a lack of exercise, poor nutrition, usually obtaining less than six hours of daily sleep, sleep problems, and higher alcohol use, in addition to poor health, higher use of sick leave, lower job satisfaction, and higher levels of stress.

4.3. Summaries of additional outputs

4.3.1. Presentation 1: "Contributors to fatigue at four gold mines in South Africa"

The PhD work was presented, orally, at the Wits School of Public Health Research Day in November 2017. The abstract is shown in Appendix E. As the title suggests, the presentation described fatigue and contributors to fatigue at four gold mines in the country. The work related to Group 3, but data obtained from the platinum mine were not included in the analysis for this presentation. Numerous contributors to fatigue were identified, including work-related contributors, demographic characteristics, lifestyle factors, health and wellbeing. Work-related contributors included long working hours, inadequate staffing levels, the harsh work environment, physical job demands, and the workplace culture. Higher levels of fatigue were significantly associated with being local, younger age, shorter lengths of service, higher levels of education, less sleep and worse quality sleep, poorer nutrition and self-reported health, lower levels of job satisfaction, and higher levels of stress.

4.3.2. Presentation 2: "Contributors to stress of mine workers in South Africa"

A poster was presented at the CSIR Emerging Researchers' Symposium in June 2018, and was related to stress of mine workers in South Africa (Appendix F). This topic was chosen because, during the course of the research, stress was identified as a key challenge that affects mine workers and contributes to fatigue in the SAMI. Data from Group 3 were analysed. Findings were that more than a third of the participants (36%) usually experienced moderate to extreme levels of stress. Results from the Chi-square analysis showed that stress was positively associated with higher levels of education, driving private vehicles, paying for housing, debt, higher alcohol use, sleep problems, unintentionally falling asleep at work, higher levels of sick leave, and lower job satisfaction and quality of life.

4.3.3. Presentation 3: "Contributors to fatigue of mine workers in South Africa"

A summary of research findings relating to fatigue of the final study group (Group 3) were presented at the 9th Wits Cross Faculty Postgraduate Symposium in October 2018, in the form of a poster (Appendix G) and a flash presentation. Over a quarter of the participants (28%) were classified as fatigued. As with the other papers and presentations, fatigue was attributed to a range of factors. Improved fatigue management that holistically considers the numerous factors that have an impact on fatigue, was recommended to improve health, safety and sustainability in the SAMI.

4.3.4. Presentation 4: "Socio-demographic contributors to fatigue of mine workers in South Africa"

Findings from the PhD research were also presented at the Wits Integrated Mine Health and Safety Research Group symposium in August 2018. Socio-demographic contributors to fatigue of mine workers in South Africa were assessed. The abstract is attached (Appendix H). The data gathered from all three research groups were combined, and the relationships between the numerous independent variables and fatigue were analysed. Variables relating to demographic and socio-economic characteristics, work, living conditions and lifestyle, were associated with fatigue. Fatigue was also associated with increased sick leave, more accidents at work in the previous year, reduced job satisfaction, and poorer quality of life.

4.3.5. Presentation 5: "Shift cycles and fatigue in the South African mining industry"

A paper was presented at the International Mine Health and Safety Conference organised by the SAIMM on 1 November 2019. The paper is attached in Appendix I. The paper summarises findings of the PhD, and introduces research that is underway to develop a framework to optimise shift schedules in the SAMI. It is evident that findings from the PhD should be considered when developing this framework, as factors that affect the fatigue of mine workers (including lifestyle factors and commuting times) impact occupational health and safety in relation to shift schedules.

4.4. Synthesis of findings

4.4.1. Results from interviews and focus group discussions

This section synthesises and summarises results obtained from qualitative data collected from the interviews and focus group discussions. As described in the papers, it was evident that fatigue affected all categories of workers and was associated with increased safety risks, a lack of concentration and motivation, and reduced productivity. Fatigue was a particular concern with hazardous work environments and occupations associated with mining, because of the risk of injuries, fatalities and damage to equipment. The participants attributed fatigue to a range of factors, including work-, demographic-, socio-economic and living condition-, lifestyle-, health- and wellness-related factors.

Numerous work-related factors were perceived to contribute to fatigue. These factors included those relating to work scheduling, job demands, working conditions, work resources and infrastructure. Long working hours were considered a major cause of fatigue, and included 12-hour shifts, extended working hours to complete work targets and receive bonus pay, and overtime work. Overtime work included that conducted on off days, or by those who were on standby and responded to calls to attend to breakdowns outside of regular working hours. Participants commented:

"Especially on the mining side – the guys are working long hours to achieve their target. For them to get a good bonus, they have to work like up until 8 or 9 pm on a daily basis…The hours are killing the people, honestly";

"You also get fatigue from long hours per day, but you can get fatigue working normal hours but never having an off Saturday or off Sunday because you work overtime on those days"; and

"If you work too much overtime, your body becomes exhausted and you end up making mistakes".

The shift configurations could also contribute to fatigue, as early morning shifts, difficulties adjusting to night shift work or rotating shifts, and social conflicts when working on weekends were mentioned. Participants commented, for example:

"I think it [fatigue] might be a challenge to the guys who work night shift, because the body naturally is designed to sleep at night"; and

"…it's difficult to manage sleep patterns when you cycle [shifts]".

Job characteristics that were considered to lead to fatigue included high workloads, physically demanding work, repetitive or monotonous work, work that requires high levels of concentration, workplace culture and high levels of production pressure. With regard to workplace culture, a participant commented:

"People know that if I refuse a lawful instruction I might be dismissed. They are being bullied, that they go and operate this thing whether they are tired nor not,,, It's more about production than individuals".

The harsh working conditions associated with mining, which included hot and humid conditions, and long travelling distances underground were also noted to lead to fatigue. Participants commented:

"The distance that we walk to our working areas is too long. We get tired before we can even start working";

"The heat is killing us. It makes us to always be tired"; and

"It's very hot and at the time we've never had enough time to rest. So obviously when it's too hot, you get asleep easily. So it's a problem…to you and the people that you work with, because you can cause accidents."

Fatigue was also considered to result from a lack of human resources, as this contributed to increased workloads, extended working hours, excessive overtime, and difficulties in taking leave to recover when no one was available to replace the workers. This lack of resources could result from short-staffing or lean staffing levels, and be exacerbated by absenteeism. Participants commented:

> *"The other problem has to do with shortage of staff. You find that you are alone and expected to do different tasks. By the time you knock off you are very tired";*
> *"The more people book off sick, then one person has to do three jobs"; and*
> *"They must provide enough labour if they want to control fatigue".*

Equipment, services, and infrastructure breakdowns or constraints in the mines also contributed to fatigue. A participant commented:

> *"You find out for the task to be carried out, the material that you need, you have to struggle to get what you want. You get told about the budget… They want call budget or no budget. You must make a plan, which results in fatigue and injuries and so forth."*

Aging infrastructure, overcrowding or delays of the conveyances ('cages') and a lack of other transport for workers underground were also mentioned to contribute to extended working hours.

Demographic characteristics that were discussed in relation to fatigue included sex, age, education, migrancy, and work status. With regard to sex, increasing numbers of women are entering the mining industry. Women could be less able to complete the physical demands of the work; it was noted that this could result in higher strain in the women, while it could also lead to increased fatigue of the men in the team, as the men assisted the women to complete the work tasks. Women were not allowed to work underground when pregnant or breastfeeding, and this could also contribute to fatigue of the work team as no one replaced their positions while they were away. Examples of comments made by female participants, in relation to work performance and traditional social expectations on women, were:

> *"…really it's impossible to work the same as the men. You can try, but you can't perform like they are doing"; and*

"You go back home, you still have to cook, you have to look after the children, you have to look after your husband. He's also coming from underground, but he won't understand when you say, 'No, I'm tired'".

In relation to age, the older workers were perceived to work harder, be more skilled, and be more willing and able to cope with the job demands than the younger workers. A participant commented that:

"…nowadays these people are getting weak. They are not like the old guys".

The younger workers tended to be more educated than the older workers, and also included a higher percentage of local workers. Fatigue was generally not considered to differ between local and migrant workers. However, migrant workers could face increased risks as a result of travelling long distances from rural homes or because of social or financial stress resulting from living apart from families. A participant commented:

"I know of some guys here, when they are off they travel to their home places, and when they have to come back to work they leave (either) the same day and go straight to work. That could be very tiring".

Similarly, fatigue of contract workers and permanent employees was generally not perceived to differ. However, it was noted that the working conditions and pay of contract workers was usually worse than that of permanent employees, which could contribute to socio-economic causes of fatigue.

Socio-economic challenges were evident amongst many of the mine workers and were discussed in the context of fatigue. Financial stress was a cause of sleeplessness, distraction, and extra hours worked for bonus and/or overtime pay. Participants commented:

"We end up not sleeping well worrying about debts that we have";
"Debts also contribute to fatigue…you end up not sleeping, and stressing"; and
"People want money, so even if they are fatigued they would still work in order to get extra money".

Poor living conditions, such as those experienced in informal settlements, and a lack of basic amenities, were also associated with poor health and fatigue. Noise, exposure to the elements, and sharing of rooms, especially when working night shifts, were all considered to result in disturbed sleep. Participants mentioned:

> *"Some of us, we prefer to rent shacks to that we can save on the living out allowance that we get"; and*
> *"…where we are renting you find that there's a lot of shacks…and when a person is sleeping next door you can hear everything that is happening and that makes you not to sleep well – leading to fatigue".*

Additionally, transport difficulties and long commuting times reduced the time available for workers to sleep and rest. Many workers had to wake up very early before work, and returned home late, and participants commented, for example:

> *"As mine workers, yes, we do get tired. One of the reasons is we wake up too early, and have to travel about 10 to 30 km to work. Some of us have to wake up at two in the morning so that you can be able to reach work in time…"; and*
> *"Fatigue is a challenge, as a result of the travelling distances to the mine, along with shift configurations".*

Lifestyle factors were associated with health and fatigue, and included factors relating to social and domestic activities, nutrition, recreational exercise, alcohol use, and sleep. Inadequate time available to attend to responsibilities and rest outside of work was a concern. A related comment was:

> *"The mind gets tired because life is not about working in the mine only. When you get home, the kids also need attention, assistance with homework, you need to do the house chores. So we are forever tired."*

Examples of activities performed outside of work included cooking, cleaning, looking after young children, shopping, going to the bank, studying, and social or religious activities. Workers also commented that they did not have enough time or energy to exercise or eat properly, which could further contribute to fatigue as a result of poor health and low energy levels. Participants mentioned that alcohol and substance abuse was a problem, and this was attributed to a lack of alternate recreation facilities and stress.

The timing, quality and quantity of food eaten were all concerns relating to fatigue. Furthermore, participants noted that it was difficult to eat underground, as a result of a lack of breaks and the dusty conditions underground. A participant mentioned:

> *"…but the ones who are working underground, they don't have time to eat, because we don't have lunches or tea time".*

In the mines where illegal mining was a concern, the amount of food and drink allowed underground was rationed, and some complained that this amount was not sufficient to provide enough energy throughout the shift.

Fatigue was associated with health, safety and wellness. Poor health and the use of certain medications were reported causes of fatigue. Health challenges that were noted included HIV/AIDS, TB and other respiratory diseases, and non-communicable diseases, such as high blood pressure and diabetes. These diseases were related to lifestyle, socio-economic and living conditions, and occupational factors. A lack of sleep could also lead to poor health. Fatigue was further associated with absenteeism or the potential abuse of sick leave, and poor performance at work. Stress or psychological problems were also associated with health and fatigue. Participants commented:

> *"There are always complaints that we are always absent from work, but they can't realise that we are fatigued"; and*
> *"If you are stressed too much you can't sleep. That's where fatigue kicks in."*

Fatigue was primarily a safety concern, as it was noted to result in incidents and accidents at work. For example, a participant commented:

> *"If we are fatigued mentally and physically that's when a lot of accidents occur".*

Further detail about the findings from the three study groups were detailed in the PhD papers and the project reports. Similarities and differences in the results between the study groups were not examined in depth for the purposes of this research. However, a notable finding was that the SES of workers at the platinum smelter (Group 2) were perceived to be better than workers from the mines (particularly those in the gold and platinum sector) and, therefore, matters relating to finance, housing and nutrition were not highly prevalent fatigue concerns in this group.

4.4.2. Results from questionnaires

The combined quantitative data obtained from the questionnaires completed by mine workers are provided in this section. Results for each study group individually were reported in the PhD papers, while basic comparisons are noted in this section. For the purposes of the current analysis, the quantitative data from variables that were common to Groups 1, 2, and 3 were coded into the same categories, to allow for comparison. Characteristics of the participants from each group, and combined, are shown in Tables 4.2 to 4.6. Only data that were common to all groups are shown in these tables; some of the data may differ slightly from that reported in the relevant papers as a result of differences in coding and, for example, the removal of the category 'other', which changes the denominators. The mean response rate per question was 97% (±1%), ranging from 94% to 99%, for the combined analysis. In total, 46% of the participants worked at gold mines, 30% at platinum mines and 5% at the platinum smelter, while 7%, 6%, and 6% worked at diamond, coal, and manganese mines, respectively.

Table 4.2: Demographic characteristics

Variable	Category	Group 1		Group 2		Group 3		All data	
		n	%	n	%	n	%	n	%
Sex	Male	746	89	52	68	483	87	1281	87
	Female	96	11	24	32	74	13	194	13
Age (years)	<30	218	26	10	14	97	18	325	22
	30-39	370	44	42	58	227	42	639	44
	40-49	174	20	17	23	145	27	336	23
	≥50	88	10	4	5	76	14	168	11
Race	Black	793	92	67	88	529	95	1389	93
	Other	68	8	9	12	28	5	105	7
Marital status	Married	459	54	39	51	313	56	811	55
	Not married	396	46	37	49	242	44	675	45
Province of origin	Same as mine province	426	50	61	80	164	29	651	43
	Different to mine province	434	50	15	20	398	71	847	57
Country of origin	South Africa	762	89	76	100	442	79	1280	86
	Other	98	11	0	0	118	21	216	14
Education	≤Grade 7	143	17	1	1	179	32	323	22
	Grade 8-11	199	24	5	7	165	30	369	25
	Grade 12	334	40	29	38	148	27	511	35
	>Grade 12	158	19	41	54	59	11	258	18

Table 4.3: Work-related characteristics

Variable	Category	Group 1		Group 2		Group 3		All data	
		n	%	n	%	n	%	n	%
Work area	Surface	182	21	76	100	75	14	333	22
	Underground	693	79	0	0	478	86	1171	78
Night shifts	Yes	388	46	50	67	199	36	637	43
	No	461	54	24	32	350	64	835	57
Work status	Permanent	705	82	64	84	428	78	1197	81
	Contract	154	18	12	16	119	22	285	19
Length of service (years)	<5	423	49	15	20	257	46	695	46
	5-9	232	27	32	42	157	28	421	28
	≥10	207	24	29	38	147	26	383	26

As shown in Table 4.2, the majority of the participants were male (87%) and two thirds (66%) were 30 to 49 years old. Most (93%) were Black, and 86% were local to the country, while 43% were originally from the same province in which the mine was located. The language spoken by the participants is linked to race, but was not included as a variable in the statistical analyses, because of the numerous categories. Recorded home languages spoken by the participants were Southern Sotho (Sesotho) (22%), Setswana (18%), isiXhosa (17%), isiZulu (11%), Northern Sotho (Sepedi) (10%), Xitsonga (10%), Afrikaans (6%), siSwati (2%), English (2%), Tshivenda (1%), isiNdebele (1%), and 'other' (1%). Over half (53%) had completed secondary education (Grade 12). Most (78%) worked underground, 43% worked night shifts, 81% were permanent employees, and 74% had been working for the respective mine for less than 10 years (Table 4.3).

Details of living conditions and income are shown in Table 4.4. Over half of the participants (55%) received LOAs, and 51% rented their dwellings. Most (94%) had access to electricity, 74% had flush toilets, and only 57% had piped water in their homes. Over a third (37%) shared a room with two or more other people. Most (71%) lived 30 km or less from the mine, and 61% took less than 30 minutes to commute to or from work. Almost half (45%) considered the dwelling near the mine to be their permanent home. Most (74%) reported earning less than R 10 000 (~700 USD) per month, and 59% had more than four people depending on this income. Over half (54%) often or always found it difficult to afford necessities, and 61% owed money to someone.

Lifestyle, health, safety and wellness characteristics are shown in Tables 4.5 and 4.6. Around half (46%) did not participate in recreational exercise outside of work, 24% smoked, and 54% drank alcohol. The majority (72%) rated their health as good, although 23% took some form of medication. Most (71%) had taken less than five days of sick leave in the previous 12 months, and 10% had been involved in a work accident in the previous year. Around half (53%) were satisfied with their jobs, and 47% rated their quality of life as good. In terms of sleep, 48% reported to usually receive less than six hours of sleep before a work shift, 18% had sleep problems, and 39% thought they did not receive sufficient sleep. Of the participants, 16% reported usually feeling very tired at work, and 30% had fallen asleep at work in the previous year.

Table 4.4: Socio-economic and living condition characteristics

Variable	Category	Group 1		Group 2		Group 3		All data	
		n	%	n	%	n	%	n	%
Housing arrangement	Living-out allowance	400	48	28	39	370	67	798	55
	Mine accommodation	152	18	5	7	125	23	282	19
	None	205	25	25	35	37	7	267	18
	Other (e.g. housing subsidy)	77	9	13	18	23	4	113	8
Housing type	Formal brick dwelling	317	39	32	44	191	35	540	37
	Flat/townhouse/cottage	100	12	17	23	61	11	178	12
	Hostel/mine residence	126	15	1	1	81	15	208	14
	Shack/informal dwelling	116	14	1	1	115	21	232	16
	Backroom	161	20	22	30	101	18	284	20
Housing tenure	Owned and paid off	173	21	6	8	125	23	304	21
	Owned but not yet paid off	95	12	26	36	61	11	182	13
	Rented	425	51	35	48	275	51	735	51
	Occupied rent-free	133	16	5	7	78	14	216	15
Housing area	Informal settlement	72	9	1	1	64	12	137	9
	Mine (smelter) property	206	25	8	11	132	24	346	24
	Suburban area	120	14	34	45	81	15	235	16
	Township	263	31	20	27	191	35	474	33
	Rural area	178	21	12	16	73	13	263	18
Distance from mine	<10 km	306	36	3	4	235	42	544	37
	10-29 km	226	27	53	70	225	40	504	34
	≥30 km	310	37	20	26	96	17	426	29
Level of crowding	1-2 people	585	68	59	79	282	51	926	63
	>2 people	271	32	16	21	268	49	555	37
Electricity	Yes	817	94	73	97	519	93	1409	94
	No	56	6	2	3	37	7	95	6
Piped water in dwelling	Yes	315	37	62	86	466	83	843	57
	No	530	63	10	14	94	17	634	43
Flush toilet	Yes	580	67	67	89	465	83	1112	74
	No	288	33	8	11	96	17	392	26
Trust community	Yes	454	53	45	59	253	46	752	51
	Sometimes	198	23	21	28	188	34	407	27
	No	197	23	10	13	115	21	322	22
Transport type	Bus	187	22	0	0	142	26	329	23
	Taxi	179	21	5	7	110	20	294	20
	Staff transport	168	20	4	5	93	17	265	18
	Private vehicle	184	22	67	88	139	26	390	27
	Walk	119	14	0	0	61	11	180	12
Commuting time	<15 minutes	157	18	10	13	123	22	290	19
	15-<30 minutes	324	38	54	71	252	45	630	42
	30-<60 minutes	290	34	11	14	140	25	441	29
	>1 hour	90	10	1	1	49	9	140	9
Permanent home	No	495	59	35	46	279	50	809	55
	Yes	345	41	41	54	274	50	660	45
Income	≤R5000	247	29	4	5	138	25	389	26
	R5001-R7500	256	30	2	3	224	40	482	32
	R7501-R10000	139	16	4	5	92	16	235	16
	>R10000	212	25	65	87	106	19	383	26
Dependants	1-2	74	9	18	24	49	9	141	9
	3-4	282	33	32	42	153	27	467	31
	5-6	267	31	19	25	151	27	437	29
	7-8	114	13	5	7	113	20	232	15
	>8	126	15	2	3	93	17	221	15
Difficulty affording necessities	Never/occasionally	111	13	30	39	62	11	203	14
	Sometimes	266	32	24	32	180	33	470	32
	Always/often	464	55	22	29	303	56	789	54
Debt	Yes	514	63	32	42	331	61	877	61
	No	303	37	44	58	214	39	561	39

Table 4.5: Lifestyle characteristics

Variable	Category	Group 1		Group 2		Group 3		All data	
		n	%	n	%	n	%	n	%
Exercise	Yes	466	54	46	61	287	52	799	54
	No	392	46	30	39	268	48	690	46
Smoke	Yes	201	24	12	16	131	24	344	24
	No	622	76	61	84	425	76	1108	76
Alcohol	Never	397	48	29	38	256	46	682	46
	Once a month or less	205	25	17	22	157	28	379	26
	More than once a month	233	28	30	39	144	26	407	28
Sleep received before work	<6 hours	449	52	19	25	250	46	718	48
	≥6 hours	409	48	57	75	299	54	765	52
Sleep received on off day	<6 hours	213	25	9	12	117	21	339	23
	≥6 hours	642	75	66	88	433	79	1141	77
Sleep problems / disorder	Yes	107	13	11	15	138	26	256	18
	No	715	87	60	85	387	74	1162	82

Table 4.6: Health, safety and wellness characteristics

Variable	Category	Group 1		Group 2		Group 3		All data	
		n	%	n	%	n	%	n	%
Health	Good	546	64	65	87	464	83	1075	72
	Not good	305	36	10	13	96	17	411	28
Medication	Yes	180	21	17	23	139	25	336	23
	No	663	79	58	77	420	75	1141	77
Sick leave	<5 days	622	73	46	62	389	70	1057	71
	≥5 days	228	27	28	38	168	30	424	29
Work accident	Yes	67	8	2	3	73	13	142	10
	No	773	92	72	97	482	87	1327	90
Job satisfaction	Satisfied	472	55	33	45	284	51	789	53
	Not satisfied	386	45	40	55	274	49	700	47
Quality of life	Good	432	51	59	80	203	36	694	47
	Not good	421	49	15	20	354	64	790	53
Enough sleep	Yes	512	60	52	68	315	61	879	61
	No	341	40	24	32	201	39	566	39
Fatigue	Very tired	138	16	16	22	80	14	234	16
	Alert/refreshed/a little tired	702	84	57	78	478	87	1237	84
Fall asleep at work	Yes	266	31	41	55	134	24	441	30
	No	590	69	34	45	420	76	1044	70

Group-related differences are shown in Tables 4.2 to 4.6. It is evident, for example, that in Group 2 (the platinum smelter) there were higher percentages of females, non-Blacks, local workers, and more educated workers than the groups from the mines. Additionally, fewer of the participants from Group 2 lived in informal housing, fewer shared rooms with two or more other people, and more drove private vehicles, than the other groups. Similarly, higher incomes, lower indebtedness, and better quality of life scores, were evident in Group 2. The differences between Group 1 and Group 3 were not as distinct, likely because both included mine workers from the gold and platinum sectors. Findings from Group 1 revealed that socio-economic conditions were generally worse in gold and platinum mines, than in mines of other sectors (in particular the diamond and coal mines).

A summary of associations between variables and fatigue, as presented in Papers 2, 3 and 4, are shown in Tables 4.7 to 4.11. These associations are the results of Chi-square and Fisher's exact tests. Not all of the variables were included in the papers for the sake of brevity and simplicity; as such, the statistics for some of the variables are not indicated in the tables. Furthermore, slightly different measurements and categories were used across the groups of the study. As such, the tables provide an overview of the findings. All the listed variables were included in an analysis of the combined data from all three groups, and the results of these are shown in the 'all data' column of the tables. For this analysis, data from all groups were categorised into congruent categories, as per Tables 4.2 to 4.6, for appropriate assessment. The slightly different data gathered between groups is a limitation of this combined analysis. A binomial summary variable for fatigue was used for this analysis of the combined data, where a positive fatigue score was indicated by positive scores for two or more of the following: 1) a fatigue rating of more than 'a little tired'; 2) having fallen asleep at work during the previous year; and 3) a subjective assessment of usually receiving enough sleep. This variable differs slightly from the fatigue scores used for the previous analyses as a result of slightly different data gathered from the different groups. In this analysis, 23% of the participants were categorised as fatigued.

The results of the combined data are discussed further, as these findings were not included in the four papers. Increased fatigue was associated with younger age, black race, being unmarried, being local, higher levels of education, working night shifts, and permanent employment (Tables 4.7 and 4.8). Higher levels of fatigue were also associated with a lack of trust in the community and not living in permanent accommodation (Table. 4.9). The use of taxis and staff transport, living further away from the mine, and longer commutes were also associated with increased fatigue. Additionally, higher levels of fatigue were associated with increased difficulty in paying for necessities, and indebtedness. Tables 4.10 and 4.11 show that increased fatigue was also associated with a lack of exercise, poor self-reported health, increased use of sick leave, reduced job satisfaction, and poor quality of life. As expected, higher levels of fatigue were evident in those that had less sleep and reported sleep disorders. Differences between groups were not specifically assessed for this analysis as a result of the differences in the measurement of characteristics.

Table 4.7: Associations of demographic characteristics with higher levels of fatigue*

Variable	Group 1	Group 2	Group 3	All data
Sex	NS	NS	NS	NS
Age	NS	*Younger age*	*Younger age*	*Younger age*
Race	*Black*	*Black*	nd	*Black*
Marital status	nd	NS	nd	*Not married*
Province of origin	NS	nd	*Same as mine*	*Same as mine*
Country of origin	nd	NS	NS	*South Africa*
Education	NS	NS	*Higher education*	*Higher education*

*Italic values represent significance (p<0.05); nd: no data reported in paper; NS: not significant

Table 4.8: Associations of work characteristics with higher levels of fatigue*

Variable	Group 1	Group 2	Group 3	All data
Work area	nd	NS	NS	NS
Night shifts	nd	NS	NS	*Night shifts worked*
Work status	*Permanent*	NS	NS	*Permanent*
Length of service	NS	nd	NS	NS

*Italic values represent significance (p<0.05); nd: no data reported in paper; NS: not significant

Table 4.9: Associations of socio-economic and living conditions with higher levels of fatigue*

Variable	Group 1	Group 2	Group 3	All data
Housing arrangement	nd	nd	NS	NS
Housing type	*Hostel, shack*	nd	nd	NS
Housing tenure	nd	*Rented, not paid off*	nd	NS
Housing area	nd	NS	nd	NS
Distance from mine	nd	nd	nd	*Longer distance*
Level of crowding	NS	NS	NS	NS
Electricity	nd	nd	nd	NS
Piped water in dwelling	nd	NS	nd	NS
Flush toilet	nd	NS	nd	NS
Trust community	nd	nd	nd	*Less trust*
Transport type	nd	nd	nd	*Taxi, staff transport*
Commuting time	nd	NS	NS	*Longer commute*
Permanent home	nd	nd	nd	*Not permanent home*
Income	*Lower income*	nd	NS	NS
Dependants	nd	nd	NS	NS
Difficulty affording necessities	nd	NS	nd	*Always/often difficult*
Debt	nd	NS	*Yes*	*Yes*

*Italic values represent significance (p<0.05); nd: no data reported in paper; NS: not significant

Table 4.10: Associations of lifestyle characteristics with higher levels of fatigue*

Variable	Group 1	Group 2	Group 3	All data
Exercise	*Less exercise*	NS	*No exercise*	*No exercise*
Smoke	NS	NS	NS	NS
Alcohol	NS	NS	*Higher alcohol use*	NS
Sleep received before work	*Less sleep*	NS	*Less sleep*	*Less sleep*
Sleep received on off day	nd	nd	nd	*Less sleep*
Sleep problems / disorder	nd	*Yes*	*Yes*	*Yes*

*Italic values represent significance (p<0.05); nd: no data reported in paper; NS: not significant

Table 4.11: Associations of health, safety and wellness characteristics with higher levels of fatigue*

Variable	Group 1	Group 2	Group 3	All data
Health	nd	NS	*Not good*	*Not good*
Medication	nd	NS	nd	NS
Sick leave	nd	NS	*More sick leave*	*More sick leave*
Work accident	nd	nd	NS	NS
Job satisfaction	nd	*Less satisfaction*	*Not satisfied*	*Not satisfied*
Quality of life	*Not good*	NS	nd	*Not good*

*Italic values represent significance (p<0.05); nd: no data reported in paper; NS: not significant

Binary stepwise logistic regression was used to analyse the association of all the variables listed in Tables 4.7 to 4.11, with fatigue for the combined data. The inclusion criterion into the final model was set at p<0.20, as per the analysis explained in Paper 4 (Appendix D). Of the 40 predictor variables, 24 were included in the final model, as shown in Table 4.12. The variables that were significantly associated with fatigue were amount of sleep usually received before work, quality of life, working night shifts, exercise, commuting time, sleep problems/disorders, use of medication, self-reported health, race, transport type, housing arrangement, income, length of service, permanency of home, and number of dependants. Those who usually obtained less than six hours of sleep before a work shift were more than three times more likely to be fatigued than those that obtained more sleep, after adjusting for the other listed variables.

Table 4.12: Associations of multiple predictor variables and fatigue

Variable	Category	Odds ratio	95% confidence interval		p-value
Sleep received before work	≥6 hours	Ref	-	-	-
	<6 hours	3.33	2.18	5.07	*0.000**
Quality of life	Good	Ref	-	-	-
	Not good	2.09	1.27	3.45	*0.004**
Night shifts	No	Ref	-	-	-
	Yes	2.27	1.50	3.44	*0.000**
Job satisfaction	Not satisfied	Ref	-	-	-
	Satisfied	0.77	0.50	1.19	0.237
Exercise	No	Ref	-	-	-
	Yes	0.51	0.34	0.78	*0.002**
Commuting time	<15 minutes	0.91	0.48	1.72	0.764
	15-<30 minutes	Ref	-	-	-
	30-<60 minutes	1.26	0.78	2.03	0.351
	>1 hour	2.93	1.43	5.97	*0.003**
Sleep problems / disorder	No	Ref	-	-	-
	Yes	1.83	1.12	3.00	*0.016**
Medication	No	Ref	-	-	-
	Yes	0.55	0.33	0.93	*0.027**
Health	Good	Ref	-	-	-
	Not good	1.72	1.08	2.73	*0.022**
Flush toilet	No	Ref	-	-	-
	Yes	1.63	0.98	2.74	0.062
Race	Black	Ref	-	-	-
	Other	0.13	0.03	0.54	*0.005**
Transport type	Private vehicle	Ref	-	-	-
	Bus	0.36	0.19	0.69	*0.002**
	Taxi	0.70	0.37	1.32	0.269
	Staff transport	0.51	0.27	0.97	*0.039**
	Walk	0.49	0.22	1.09	0.079
Age (years)	<30	0.72	0.40	1.31	0.278
	30-39	Ref	-	-	-
	40-49	0.68	0.39	1.18	0.171
	≥50	0.47	0.21	1.07	0.071
Housing arrangement	Living-out allowance	Ref	-	-	-
	Mine accommodation	1.16	0.61	2.18	0.649
	None	0.49	0.26	0.90	*0.021**
	Other (e.g. housing subsidy)	1.19	0.50	2.81	0.691
Smoke	No	Ref	-	-	-
	Yes	1.37	0.85	2.21	0.192
Education	≤Grade 7	0.53	0.26	1.08	0.080
	Grade 8-11	0.83	0.48	1.43	0.510
	Grade 12	Ref	-	-	-
	>Grade 12	1.79	0.99	3.23	0.052
Income	≤R5000	Ref	-	-	-
	R5001-R7500	0.42	0.23	0.77	*0.005**
	R7501-R10000	0.41	0.20	0.86	*0.018**
	>R10000	0.29	0.13	0.64	*0.002**
Length of service (years)	<5	Ref	-	-	-
	5-9	1.09	0.66	1.81	0.729
	≥10	2.21	1.19	4.11	*0.012**
Permanent home	No	Ref	-	-	-
	Yes	0.62	0.41	0.95	*0.028**
Province of origin	Different to mine province	Ref	-	-	-
	Same as mine province	1.34	0.85	2.10	0.212
Work status	Contract	Ref	-	-	-
	Permanent	1.60	0.83	3.07	0.158
Trust community	No	Ref	-	-	-
	Sometimes	1.01	0.60	1.72	0.962
	Yes	0.66	0.39	1.10	0.113
Dependants	1-2	Ref	-	-	-
	3-4	0.78	0.36	1.70	0.536
	5-6	0.48	0.21	1.10	0.083
	7-8	0.69	0.29	1.67	0.412
	>8	0.36	0.14	0.94	*0.037**
Difficulty affording necessities	Always/often	Ref	-	-	-
	Sometimes	0.64	0.40	1.04	0.071
	Never/occasionally	0.79	0.40	1.56	0.498

*Italic values represent significance (p<0.05)

Together, the results from the papers and the analysis of all the data revealed factors relating to fatigue of mine workers in South Africa. The findings for the different groups were not identical, probably due to differences between the study groups, and differences in the variable categories. Demographic characteristics that were associated with fatigue across different groups and analysis methods included younger age, black race, local province of origin, and higher education. Work-related factors associated with higher fatigue were working night shifts and permanent employment. Socio-economic and living condition contributors to fatigue included lower incomes, indebtedness, and longer commuting times. Lifestyle factors associated with fatigue were lack of exercise, unhealthy diets, lack of sleep before work, and sleep problems. Poor self-reported health, increased use of sick leave, stress, low job satisfaction, and poor quality of life were also associated with fatigue.

More specific findings from the logistic regression analysis were also assessed, and can be compared to the findings from the Chi-square and Fisher's exact tests. In the logistic regression, higher levels of fatigue was associated with being Black, working night shifts, and longer length of service. Relating to living conditions, higher levels of fatigue were evident in those using LOAs compared to those with no housing arrangement, and in those who did not consider their accommodation near the mine to be their permanent home. While those with lower incomes appeared to have higher levels of fatigue, surprisingly, so did having one or two dependents compared to having over eight dependents. Meanwhile, commuting times of longer than an hour, and driving private vehicles were also associated with higher fatigue. Higher rates of fatigue were reported for those who did not participate in recreational exercise, those who did not take medication, those who had sleep disorders, and those who obtained less sleep. Additionally, poorer quality of life and poorer health were associated with higher fatigue. Similarities but also disparities were evident in the findings from the different analyses, and these findings are discussed further in the following chapter.

4.5. Conclusion of the chapter

This chapter summarised the findings of the research as reported in the PhD papers and additional outputs, and included results from the consolidated data from the research that were not included in the papers. Numerous demographic, work-related, socio-economic, living condition, lifestyle, health, safety and wellness characteristics were associated with fatigue. The following chapter synthesises the qualitative and quantitative results, and discusses the findings in relation to previous literature. A refection of the strengths and limitations of the research is also provided.

Chapter 5: Discussion

This research has identified numerous factors that are associated with fatigue of mine workers in South Africa. In this chapter, the main findings from the data collected for this research are discussed and compared with published literature on the topic. The quantitative and qualitative data are also compared and combined. The qualitative data were primarily used to explain or verify the findings from the quantitative data. As numerous observations and assessments can be made using the extensive data collected during this research, not all of the possible associations and findings were fully discussed in the scientific papers. As such, some additional topics of interest in relation to fatigue of mine workers are discussed in more detail, as they are currently relevant (e.g. women in mining, and commuting times). Observations regarding the research process are also summarised. Finally, the strengths and limitations of the study are discussed.

5.1. Observation of study findings

The research findings are discussed in accordance with the main categories of variables that were studied, namely demographic characteristics, work factors, socio-economic and living conditions, lifestyle characteristics, and factors relating to health, safety and wellbeing. The findings relate to the variables that were included in the conceptual framework of the study in Chapter 2 (Figure 2.3).

The basic findings of the study, which aimed to assess socio-demographic contributors to fatigue of mine workers in South Africa, are summarised in Figure 5.1. The diagram illustrates a range of socio-demographic variables, and health, safety and wellness factors that were associated with fatigue. The variables that were selected for inclusion in this model were those that were found to be associated with fatigue in both the quantitative and qualitative analyses. If there were conflicting findings between the data types (i.e. qualitative and quantitative data) and analysis methods (e.g. Chi-square or binomial logistic regression), or a lack of corroborating evidence regarding the relationship of a variable with fatigue, then the variable was excluded from the diagram. This approach is supported by the notion that conclusive results should not be purely based on whether associations are statistically significant according to selected thresholds (Wasserstein *et al.*, 2019). The variables included in the model were based on the findings from the analysis of the quantitative data, while the findings were explained and validated by the qualitative data.

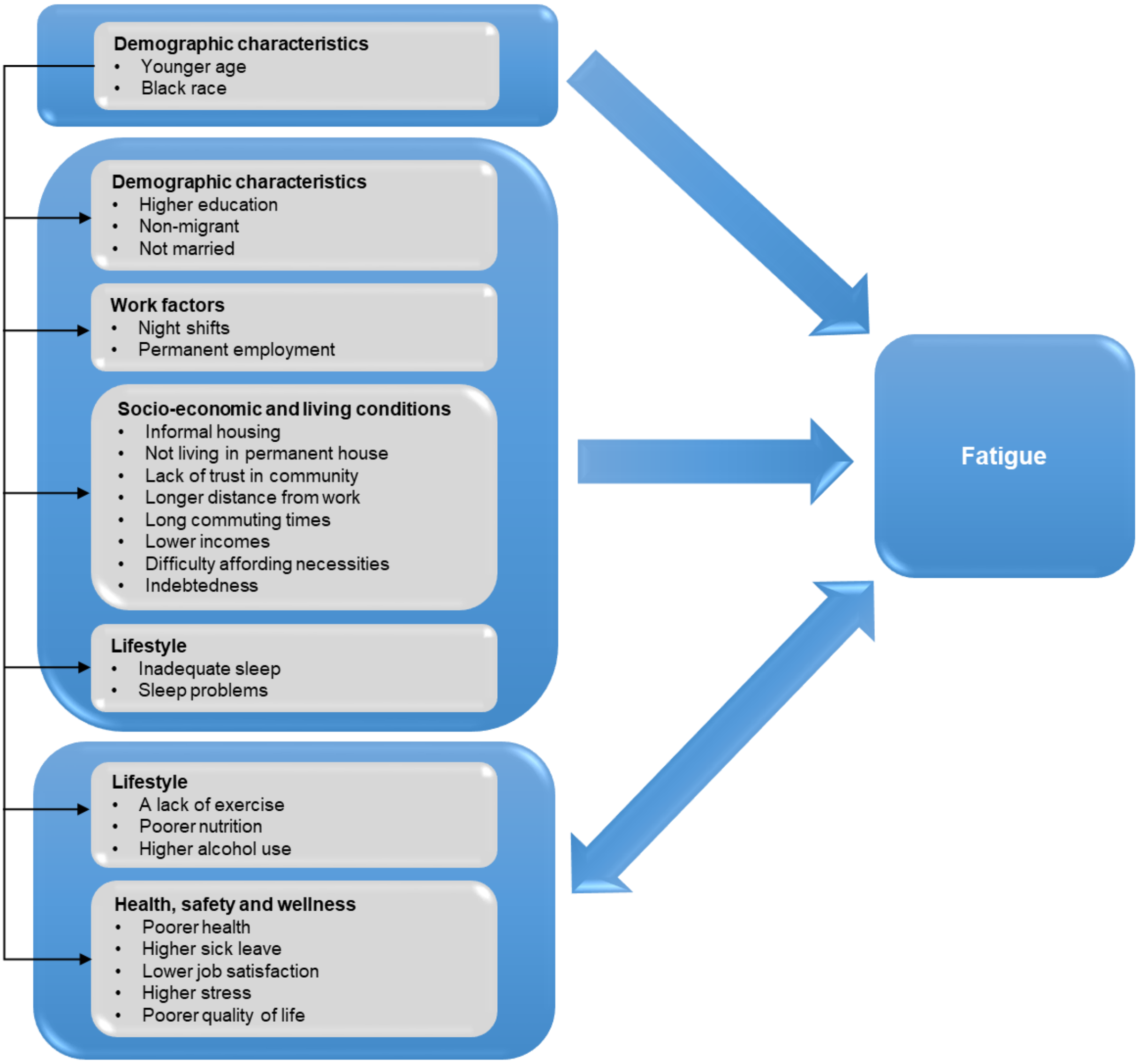

Figure 5.1: Model illustrating findings from this research

Fatigue can result from independent causes and be exacerbated by a combination of factors. In addition, it has a range of potential consequences. Most of the variables in Figure 5.1 were considered to cause or contribute to fatigue; however, some of the variables were impacted by fatigue, or a bi-directional relationship was reported. For example, poor health can be a cause or a consequence of fatigue. The association of the variables with fatigue were based on the statistical analyses conducted, while the potential direction of the relationship was based on the results from the qualitative analysis. This approach, involving the use of mixed methods and methodological triangulation, is supported by that taken in previous research (e.g. Bekhet and Zauszniewski, 2012; Mengshoel, 2012; Moilina-Azorin, 2016). Additionally, associations between the predictor variables could likely result in confounding. For example, there might be associations between socio-economic indicators of income, living conditions, race and health. It is also possible that some factors, such as those related to health and wellness, could further play a mediating role between socio-demographic variables and fatigue. The findings are discussed in further detail in this section.

5.1.1. Demographic characteristics and fatigue

Demographic variables that were assessed in this study included sex, age, education, race, marital status, and country or province of origin (i.e. whether local or migrant). The quantitative association of these variables with fatigue is discussed in relation to findings from the interviews and focus group discussions, and published literature.

5.1.1.1. Sex

More women are entering the SAMI as a result of changes in legislation, which requires a minimum participation of 10% of women in mining (South Africa, 2002a, 2000b, 2008b). The percentage of women in the study (13%) generally reflected industry targets and percentages (COMSA, 2018; DMR, 2015; South Africa, 2015a).

Based on the literature reviewed, it was expected that women would experience higher levels of fatigue than men (Åkerstedt *et al.*, 2014; Di Milia *et al.*, 2011; Edwards *et al.*, 2011; Flechtner and Bottomley, 2003). However, no significant associations were found between sex and fatigue in this research. Women are generally physically weaker than men and, therefore, might find it more difficult to complete the same workload as men or work closer to their maximal capacities (Dlamini, 2016; van Aardt *et al.*, 2008). Additionally, women usually have more domestic responsibilities than men, which could reduce sleep time and contribute to fatigue (Alhola and Polo-Kantola, 2007; Di Milia *et al.*, 2011). For these reasons, some of the participants argued that women would get more fatigued than men. However, other participants reported that the men in the work teams needed to assist women with tasks that they were not able to complete; this could result in in men being more fatigued than women as they were required to do more work. The participants also observed that women were generally employed in less physically demanding positions than male workers, although some women were able to physically work at the same levels as men. Another consideration was that pregnant or breastfeeding women are not allowed to work in underground workplaces and, as their positions are not filled in this time, the remaining team members might experience additional strain. Therefore, the introduction of women in mining could contribute to increased fatigue of work team members as a result of increased demands.

5.1.1.2. Age

Younger age was associated with fatigue. Some literature has reported that older individuals experience higher levels of fatigue than younger workers, due to changes in physical abilities and sleep structure (Abu-Mourad *et al.*, 2010; Di Milia *et al.*, 2011; Flechtner and Bottomley, 2003; Härmä *et al.*, 2018). However, other literature has indicated that younger individuals experience higher levels of fatigue (Åkerstedt *et al.*, 2014; Halvani *et al.*, 2009a; Park *et al.*, 2001; Winwood *et al.,* 2006). The study findings might reflect that workers who are most able to cope with the demands of the work are more likely to stay in the work for longer. Similarly, in the interviews and focus group discussions it was noted that the older, migrant workers, tended to be stronger, more skilled and experienced, and worked harder than the younger workers. Social and domestic activities of younger workers were also perceived by the study participants to contribute to a lack of sleep and fatigue.

5.1.1.3. Education

Higher levels of education were associated with higher levels of fatigue. Mixed results on the associations between education and fatigue have been reported in literature (Di Milia *et al.*, 2011; Halvani *et al.*, 2009a; Szalontai, 2006; Winwood *et al.*, 2006). Higher levels of fatigue in more educated individuals could result from increased demands placed on those who are more educated. Additionally, recruitment criteria at mining companies currently require higher educational qualifications than in the past; as a result, many of the younger workers (who were found to experience higher levels of fatigue) are more likely to be better educated than the older workers. Similarly, Westaway and Mosaka (2011) noted a negative association between age and years of education in the SAMI, as a result of a lack of educational opportunities for older black Africans. As such, the association between education and fatigue could be confounded by age, or vice versa. Meanwhile, in the interviews and focus group discussions it was also mentioned that the younger, more educated workers may feel more prepared to stand up for their rights than the older workers, and also have higher expectations of promotion to improved, less physically demanding, employment. As such, the less educated workers could experience less fatigue because of lower job demands, or being more willing and able to cope with the physical job demands.

5.1.1.4. Race

Race was associated with fatigue, with non-black workers reporting less fatigue than black workers. Black workers might experience higher levels of fatigue because of socio-economic factors, including jobs with higher manual demands, lower incomes, higher levels of stress, and perceived discrimination (Galobardes *et al.*, 2006a, 2006b; Williams *et al.*, 2010).

5.1.1.5. Marital status

Marital status was significantly associated with fatigue, with those who were married reporting lower levels of fatigue than those who were not married. Literature has indicated that being married could help mitigate fatigue (Di Milia *et al.*, 2011; Halvani *et al.*, 2009a; Winwood *et al.*, 2006). Similarly, in the discussions some participants mentioned that partners assisted with household chores, such as cooking and cleaning, which provided more time for sleep and rest. Conversely, being married has also been associated with reduced sleep time (Szalontai, 2006). This could be related to factors such as having and looking after young children (Araújo *et al.*, 2016). The association between marital status or family composition and fatigue was not studied in depth in this research, as many of the married workers had families in labour-sending areas and lived alone while working at the mine. Some also had 'second wives' or duel families while living near to the mines, which could have mitigating or contributing effects on stress and fatigue.

5.1.1.6. Migrancy

Province and country of origin were associated with fatigue. The finding that local workers reported more fatigue was unexpected, as migrant workers were expected to face more social and financial stressors than local workers, such as living apart from families, increased household responsibilities, and long travelling times when returning from leave. Migrant workers may also face higher risks of HIV/AIDs and TB, and healthcare service disruptions (Stuckler *et al.*, 2011; Williams *et al.*, 2010). However, these findings could be explained by the 'healthy migrant hypothesis', which suggests that the healthiest migrants are selected into the workforce (Collinson, 2010; Lu, 2008). Some of the participants mentioned that migrant workers tended to work harder and be stronger than the local workers. However, in many of the discussions, the participants did not think that fatigue would differ between migrant and local workers.

5.1.2. Work factors and fatigue

The focus of this study was on socio-demographic contributors to fatigue. However, as work-related contributors to fatigue were often highlighted during data collection, and as these factors are often associated with socio-demographic characteristics, a discussion of work-related factors is warranted. The work-related factors that were analysed quantitatively included work area (e.g. surface or underground), type of shifts worked (e.g. night shifts), work status (e.g. permanent or contract), and length of service. It was not possible to assess associations of fatigue for different work positions as there were numerous job titles.

A number of other work-related contributors to fatigue were discussed in the interviews and focus group discussions. Long working hours, overtime, high job demands, and production pressure were reported to be causes of fatigue across different categories of workers. Poor planning, the aging infrastructure of the mines, human resources and equipment constraints, and service or equipment breakdowns contributed to long working hours, increased job demands and fatigue. The work climate and communication between workers and management were also highlighted, as workers often felt that production was prioritised over safety, and that they were pressurised to work even when fatigued. The reviewed literature similarly revealed that factors such as the workplace culture, understaffing, equipment failure, poor work organisation, and a lack of communication were associated with fatigue (Fletcher and Dawson, 2001; Gander *et al.*, 2001; Jing-Gang and Lei, 2013).

5.1.2.1. Work area

No association between work area and fatigue was found. It was expected that working underground, rather than on surface, would be associated with higher levels of fatigue. Underground workplaces are generally characterised by harsher conditions and demands, including long times spent travelling underground, confined spaces and high levels of heat and humidity (particularly in gold mines) (Nowrouzi-Kia *et al.*, 2018). The type of work performed and work environments, including those that require high physical demands and those with extreme temperatures, noise, and dust, are known causes of fatigue (Amponsah-Tawiah *et al.*, 2014; Schutte, 2010; Shaw, 2003; South Africa, 2014). It is expected that those who worked on surface had different job demands that could contribute to fatigue, such as overtime or ‘on-call’ work. Fatigue of participants from the different sites or commodities was only assessed in Paper 2; however, no significant differences were found for the different mine types.

5.1.2.2. *Night shifts*

Shift work, and non-traditional work hours, are commonly associated with fatigue (Araújo *et al.*, 2016; Baulk *et al.*, 2009; Dawson and Fletcher, 2001; Ferguson *et al.,* 2012; Halvani *et al.*, 2009b; Härmä *et al.,* 2018; Hossain *et al.*, 2003; Kalmbach *et al.*, 2018). In the combined and multivariable analyses, those who worked night shifts had higher levels of fatigue than those who worked day shifts only. Additionally, overtime was assessed in Group 1 and 2, but no significant associations were found with fatigue. Many of those who worked day shifts, such as engineering personnel, did overtime or standby work. Overtime work is also associated with long work hours and fatigue (Di Milia *et al.*, 2011; Shaw, 2003; South Africa, 2014). As such, different causes of fatigue associated with work hours were evident for both day and night shift workers. In the interviews and focus group discussions, the topic of working hours, or working shifts longer than official hours, and overtime, was raised much more frequently than the issue of working night shifts or rotating shifts. However, some did note difficulty in adjusting to changing shift times (e.g. from day shift to night shift). Long work hours have been shown to be associated with increased accident and fatigue risks (Di Milia *et al.*, 2011; Folkard *et al*., 2007; Spencer *et al.*, 2006).

5.1.2.3. *Permanent or contract work*

Work status was associated with fatigue, with the permanent employees reporting higher levels of fatigue than the contract workers. This finding was surprising, as contract work is commonly associated with worse working conditions, including less regulation of working hours, worse living conditions, lower pay, and fewer benefits than for permanent employment. Additionally, a few participants commented that contract workers tended to work harder than permanent employees, and some contract workers hoped to be able to get permanent employment at the mines. However, because of low job security of contract workers, it is possible that the most capable workers are selected for contract work, while the workers who are more prone to poor health or fatigue do not remain in the positions. A distinction between short- and long-term contractors was not made in this study; however, it was observed and assumed that the participating contract workers were mostly employed on a long-term basis.

5.1.2.4. *Length of service*

No associations between length of service and fatigue were found in the Chi-squared analyses. However, length of service was associated with fatigue in the multivariable analysis, in which fatigue was significantly higher in those with lengths of service of over 10 years, compared to those of less than five years. It could be expected that the association would be related to the age of the participants, or to occupational exposures. In this case, it appeared that the association did not reflect that of age, but rather could indicate that working in the mining environment for longer increased the likelihood of fatigue.

5.1.3. Socio-economic and living conditions and fatigue

Wages and living conditions in the SAMI have received much attention over the past few years, and have been associated with labour disputes (Benya, 2015; Chinguno, 2013b; Twala, 2012). Additionally, mine closures and job losses continue to be a concern in the industry, as a result of sustainability challenges (Gumede, 2018). Changes in legislation have been implemented to attempt to address previous challenges relating to poor living conditions in mining hostels (South Africa, 2002a, 2002b, 2008b, 2010a). As noted in Paper 1, while many improvements in the living conditions of workers are evident, challenges still remain, and new challenges have emerged. A number of socio-economic and living condition variables were assessed in this research. In the questionnaires, living condition variables included housing arrangement, type, tenure, area, perceived permanency, levels of crowding, access to amenities, and distance from the mine. Mode of transport and commuting times were also assessed. Additionally, average monthly income, number of dependants, difficulty paying for necessities, and indebtedness were examined.

5.1.3.1. *Housing arrangement, type, tenure, area, and permanency*

House type, housing tenure, arrangement, and permanency were associated with fatigue, while area of housing was not. Those who lived in hostels and shacks reported the highest levels of fatigue. At the time of the study, while some mines had attained the hostel occupancy rate of one worker per room, many mine workers still had to share a room with others, and noise from other residents could be a cause of sleep disruptions and fatigue. House type is associated with housing arrangements, and many that received LOAs opted to live in informal accommodation, such as shacks or backrooms, which are associated with poor conditions, including a lack of access to amenities, exposure to the weather, and noise (Bezuidenhout and Buhlungu, 2010; Sandberg *et al.*, 2014; The Bench Marks Foundation, 2012). The participants noted that these conditions can contribute to poor health, inadequate sleep and fatigue. The workers who considered their accommodation near the mine to be their permanent dwellings reported lower levels of fatigue than those who did not. Additionally, housing tenure was also associated with fatigue, with those who rented housing, or those who owned but had not paid off housing, reporting higher levels of fatigue than those who owned and had paid off housing, or those that occupied the dwelling rent-free. These findings could be a related to financial stress.

5.1.3.2. Overcrowding, trust in neighbours, and access to amenities

Level of crowding was assessed based on the number of individuals with whom the participant shared a room. Overcrowding was expected to be associated with fatigue, as it could result in sleep disturbances due to noise, and because of the association with health due to the spread of disease (APA, 2013a; Burridge and Ormandy, 2007; Galobardes *et al.*, 2006a; Sandberg *et al.*, 2014). However, no association was found between crowding and fatigue in this study.

Higher levels of fatigue were associated with a lack of trust of those living in the community. Trust of those living in the neighbourhood is an indication of the living conditions in the community, and crime was indicated as a cause of inadequate sleep in informal settlements.

Access to amenities, including water, electricity, and toilets, was a challenge at many of the mines. In this research no associations were found between lack of access to electricity, piped water and flush toilets, and fatigue. However, these factors are associated with poor living conditions, such as those in informal settlements, and could also be linked to the spread of disease (Galobardes et al., 2006a; PricewaterhouseCoopers, 2012). A lack of access to amenities could cause fatigue as a result of increased effort required to perform household tasks, such as cooking and washing, and SES contributors, such as poor health and stress.

5.1.3.3. Travelling distances, transport type, and commuting times

The effects of travelling between home and the workface are not well understood, particularly with regard to fatigue (Gumbie, 2018; Pfeifer, 2017). Further work in this domain has been recommended as part of the South African Mining Extraction Research, Development and Innovation (SAMERDI) strategy, which was established to enhance the sustainability of the SAMI through collaborative research and the use of innovative technologies (Pelders *et al.*, 2019b; Singh, 2017).

Travelling distance, commuting time and mode of transport, were associated with fatigue. This finding was expected, as the literature has indicated a link between long commuting times and fatigue, health, productivity and absenteeism (Di Milia et al., 2011; Pfeifer, 2017; Shaw, 2003; South Africa, 2014; van Ommeren and Gutierrez-i-Puigarnau, 2009). In the discussions, workers frequently mentioned challenges with transport to get to and from work, and how travelling times, in addition to the long working hours, reduced the time available to sleep. Distance from the mine was, similarly, associated with higher levels of fatigue. It is assumed that distance from the mines is related to commuting times, although other factors can also affect the time taken to travel to work, such as mode of transport and road conditions. The participants used a range of modes of transport to commute, including staff transport, public transport (e.g. taxis and buses), and walking. Fatigue could result from long waiting times to catch public transport, the time taken to walk to or from the transport pick-up points, the conditions in the vehicles, and conditions in communities with different transport availability and use. The participants also noted that walking to get to work, or to catch public transport, added to the physical demands experienced by the workers. Other transport concerns related to poor road conditions and safety challenges, as a result of accidents or crime.

5.1.3.4. Income, dependants, difficulty affording necessities, and debt

Lower incomes, increased difficultly in paying for necessities, and indebtedness were associated with higher levels of fatigue. The finding in the multivariable analysis indicating that having over eight dependants was associated with lower fatigue than having one or two dependants was not confirmed by the Chi-square analysis, and was in conflict with findings in the qualitative data; therefore, this variable was not included as a study finding. Dissatisfaction with income, high numbers of dependants, and high levels of indebtedness are challenges in the SAMI, as indicated in the research discussions and the published literature (Lim *et al.,* 2011). The participants also hoped for improved opportunities for promotion or development. The associations with fatigue were probably a result of financial strain, but could also be associated with the material benefits of income, including better food, housing, transport and healthcare (Galobardes *et al.*, 2006a). Additionally, many workers worked extra hours to receive bonus and overtime pay to boost low incomes, which could result in higher levels of fatigue. Some reported not taking all of their leave days, coming to work when sick, or even failing to report work-related injuries, to qualify for bonus payments. Financial issues were the most common cause of stress among the participants, and worries or stress were a major cause of sleep disturbances. Additionally, indebtedness was frequently highlighted in the interviews and focus group discussions to be a cause of sleeplessness. The use of loan sharks, and illegal garnishee orders, were related concerns that contributed to debt.

5.1.4. Lifestyle and fatigue

Various lifestyle factors were assessed in this research, in relation to fatigue. Lifestyle variables that were recorded in the questionnaires included recreational exercise, smoking habits, alcohol use, and diet. These variables have been associated with SES, and are also associated with health, including non-communicable diseases such as hypertension, diabetes and high cholesterol (APA, 2013a; Hulsegge *et al.*, 2016; Lowden *et al.*, 2010; Williams *et al.*, 2010). Average amounts of sleep received, and sleep problems were also assessed. Lifestyle factors were also discussed qualitatively in this research, along with activities outside of work that could contribute to fatigue. The participants explained that workers often did not have enough time to attend to responsibilities outside of work and rest, because of long working hours and commuting times. Activities outside of work that could contribute to fatigue included family responsibilities such as cooking, cleaning and looking after children, studying, and social activities. Previous research has, similarly, indicated that long work hours and activities performed outside of work compete with the time to sleep (Dawson and Fletcher, 2001; Ferguson *et al.*, 2010; Jing-Gang and Lei, 2006).

5.1.4.1. Exercise

A lack of exercise was associated with higher levels of fatigue, with fatigue being a cause or consequence of not exercising. Many participants commented that they did not have the time or energy to participate in recreational exercise after work. Some stated that additional exercise was not needed as their work was physically demanding in itself. Others cited a lack of adequate recreational or sports facilities as a reason for not exercising, but that exercise was important to relieve stress and stay healthy. Exercise is known to have health and wellness benefits (AngloAmerican, 2005; Kalmbach *et al.*, 2018; Molarius *et al.*, 2006; Sandberg *et al.*, 2014). As such, the association between a lack of exercise and fatigue was expected.

5.1.4.2. Smoking

Smoking was not associated with fatigue in this research. This finding was not expected, as smoking has previously been associated with increased use of sick leave, occupational injuries, low SES, and fatigue (Beemsterboer *et al.*, 2009; d'Errico *et al.*, 2007; Shaw, 2003).

5.1.4.3. Alcohol use

Alcohol use was positively associated with fatigue. Alcohol use could contribute to fatigue as it results in disturbed sleep and is associated with low SES and poor health (AngloAmerican, 2005; Williams *et al.*, 2010). In the discussions, alcohol use or abuse was attributed to stress and a lack of alternate recreation; these factors were also linked to criminal activity and violence. Alcoholism has previously been identified as a problem prevalent in mining communities (Beemsterboer *et al.*, 2009; D'Souza *et al.*, 2013; Donoghue, 2004).

5.1.4.4. Nutrition

Those who considered their diets to be unhealthy reported higher levels of fatigue. Unhealthy diets and irregular meals times could contribute to a lack of energy and poorer health (AngloAmerican, 2005). The participants commented that workers often did not have the time or finances to eat properly. Additionally, shift work was associated with eating meals at unusual times, which could affect digestion and metabolism. Some workers also complained that they were not able to eat underground. It was noted that official meal breaks were not allowed or taken because of production requirements. Rest breaks during shifts are important to minimize fatigue, and should be long enough for workers to be rested and nourished (Folkard *et al.*; 2007; Jing-Gang and Lei, 2013; Shaw, 2003; Spencer *et al.*, 2006). Others complained that the conditions underground were not conducive to eating, because of dusty and dirty conditions, and a lack of storage facilities for food. The participants, particularly those in the larger gold mines, also mentioned that the food that they could take to work was rationed, as it was a concern that extra food could be sold to illegal miners ('zama-zamas') that operated underground; some complained that the allowed rations were not sufficient, especially when working extra hours.

5.1.4.5. Sleep

The workers who usually had fewer than six hours of sleep per 24 hours had significantly higher levels of fatigue than those who had more sleep. This finding was expected, as sleep and fatigue are associated, and the recommended amount of sleep for adults is at least seven hours per night (Åkerstedt *et al.*, 2014; Rae *et al.*, 2016; Szalontai, 2006). The multivariable analysis indicated that those who obtained less than six hours of sleep were over three times more likely to be fatigued than those who obtained more sleep, after adjusting for the other variables. Almost half (48%) of the workers usually obtained fewer than six hours of sleep before a work shift, while this percentage was lower for sleep obtained before an off day (23%). The finding that more sleep was received on off days indicates an accumulation of sleep debt between shifts (Pfeifer, 2017). In Group 1 and 2, differences in sleep quality on off days and on work days were reported; it was evident that sleep quality was better on off days. For Group 3, overall sleep quality was reported; 20% reported usually sleeping badly, 24% moderately and 56% well. The main sleep disturbances reported by the participants were stress or worries and noise. Sleep quantity and quality are important for good health and performance (Kim *et al.*, 2011). Sleep problems or disorders were also associated with fatigue, as expected (Boosman *et al.*, 2011; Hossain *et al.*, 2003; South Africa, 2014). Some participants also noted difficulties with sleeping during the day when working night shifts. These circadian effects on fatigue have been frequently reported (Åkerstedt *et al.*, 2008; Alhola and Polo-Kantola, 2007; Fletcher and Dawson, 2001; Schutte, 2010).

5.1.5. Health, safety, and wellness and fatigue

Variables indicative of health, safety and wellness that were assessed in this research included self-reported health, the use of medication, sick leave, work accidents, job satisfaction, stress, and quality of life.

5.1.5.1. Self-reported health and use of medication

Lower levels of fatigue were reported by those who considered their health to be good. Health and fatigue have commonly been associated, and poor health can lead to fatigue, while fatigue can also lead to poor health (Åkerstedt *et al.*, 2014; Boosman *et al.*, 2011; Dawson *et al.*, 2001; Di Milia *et al.*, 2011; Halvani *et al.*, 2009a; Sandberg *et al.*, 2014; Schutte, 2010; Shaw, 2003; Shen *et al.*, 2006). The use of medication could result in drowsiness, and could affect fatigue as a result of the association with health (South Africa, 2014). However, in the multivariable analysis, the use of medication was associated with lower levels of fatigue; this could result from the benefits of the use of medication in mitigating the effects of health problems. Commonly mentioned health concerns of the workers were non-communicable diseases such as high blood pressure and diabetes, HIV/AIDs, TB, and respiratory diseases. Poor living conditions, the work environment, and lifestyle factors were also considered to impact health.

5.1.5.2. Sick leave

Fatigue was associated with increased use of sick leave. This association was frequently mentioned in the interviews and focus group discussions, and the associations of fatigue and shift work with sick leave or absenteeism have been highlighted in literature (Åkerstedt, 2006; Åkerstedt *et al.*, 2014; d'Errico and Costa, 2011; Merkus *et al.*, 2012; ter Wolbeek *et al.*, 2007). Workers sometimes abused sick leave when feeling fatigued and needing to recuperate. The use of sick leave could also result from the association of health and fatigue, while social, cultural, and individual factors could also play an important role (d'Errico and Costa, 2011; Jacobsen and Fjeldbraaten, 2017).

5.1.5.3. Work accidents

The finding that there was no association between fatigue and having been involved in a work accident in the previous year was unexpected; this finding was likely because there are additional factors that contribute to accidents. Additionally, average levels of fatigue were measured, while accidents could have occurred as a result of the experience of acute fatigue. In the discussions, it was evident that fatigue was a safety concern, and was related to a lack of focus, poor decisions, taking shortcuts or not following proper procedures, errors, and accidents at work. Fatigue is commonly cited as a causal or contributing factor to accidents in the mining industry (Hoefel *et al.*, 2013; Schutte, 2010; South Africa, 2014), due to impaired concentration and alertness, slowed reaction times, and reduced ability to judge levels of impairment (Balkin *et al.*, 2011; Bates, 2009; Jing-Gang and Lei, 2013; Schutte, 2010; Shaw, 2003; Williamson *et al.*, 2011).

5.1.5.4. Job satisfaction, stress, and quality of life

Higher job satisfaction, lower levels of stress, and better quality of life was evident in those with lower levels of fatigue. These findings were expected, as fatigue is commonly associated with mental health or wellness, including stress (Åkerstedt *et al.*, 2014; Dawson *et al.*, 2011; Shen *et al.*, 2006), job satisfaction (Halvani *et al.*, 2009a), and quality of life (Abu-Mourad *et al.*, 2010; Araújo *et al.*, 2016). Psychological problems were similarly associated with fatigue in the focus group discussions. Quality of life could be attributed to numerous factors, including psychological wellbeing, health, working conditions, and socio-economic and living conditions, and could be a cause or consequence of fatigue. Similarly, reduced job satisfaction could result from fatigue, or mediate the relationship between work or other socio-demographic characteristics and fatigue.

The most commonly reported causes of stress were money issues, while work-related factors, family problems, and poor living conditions were also noted. Stress was highlighted as a safety challenge because it was seen to result in a lack of concentration at work, and because of the relationship with fatigue. Stress was also a noted cause of sleeplessness, which could result in fatigue. Results of the binary logistic regression analysis reported in Paper 4 showed stress to be the largest contributor to fatigue of the participating mine workers. The concepts of stress and fatigue appear to be associated. For example, Davy (2018) noted that fatigue is associated with reduced resources or performance capacity. Meanwhile, stress has been defined as an imbalance between the demands placed on an individual and the resources for coping with the demands and, as such, could result from increased demands, or reduced resources (such as by increased fatigue).

5.1.6. General comments

It is difficult to separate the effects of the numerous contributors to fatigue, such as ‘work’ and ‘non-work' aspects, as these factors are intertwined. For example, long work hours compete with time to perform activities and rest outside of work. Commuting time also affects time that workers have to rest. Additionally, living conditions are closely associated with work, as mining companies have responsibilities relating to the accommodation of workers. Income could also be considered as both a ‘work’ and ‘non-work’ contributor to fatigue; while use of income is a personal choice, pay is aligned with the job performed, bonuses and overtime work.

5.2. Obstacles and enablers to the research

There were a number of both obstacles and enablers to this research, including those relating to access to sites to collect data, disseminating results, and applying the findings. These matters are summarised below.

5.2.1. Access to data collection sites

Gaining access to mining sites in order to conduct research often results in study delays. Individuals in mining companies often do not have time to be involved in activities that could disrupt production and are not seen to have direct benefits for the operation. Requests for participation from recognised authorities in the mining industry who acknowledge the usefulness of the research and having contacts at mining sites enabled the data collection.

5.2.2. Dissemination of results to stakeholders

The sensitivity of findings relating to conditions in the SAMI made it difficult to disseminate the study results to various stakeholders. For example, obtaining permission to publish findings from data gathered in the first group was a lengthy process, because of concerns of sensitivity by one of the funders of the study. The provision of feedback of results to study participants is a related consideration. It was not possible to provide feedback to individual participants because of anonymity and confidentiality of the data. Feedback was generally provided to those who had the authority to grant permission for the research to take place. However, it is not certain whether the findings were used or disseminated further; this could have been constrained by competing demands for time, and concerns relating to the dissemination of sensitive findings. During the research, some participants expressed concern that they were not provided with results from previous research conducted, and that they have not seen the anticipated improvements from it; this could lead to disillusionment about research in the industry and hinder future research through non-participation. Means to facilitate the uptake of findings and to implement results that could lead to workplace improvements is recommended, as the purpose of the research is for the findings to be implemented to benefit the industry and workforce.

5.2.3. Difficulty of application

Recommendations arising from the findings of this research might be difficult to apply, because of the numerous factors that contribute to fatigue, many of which are outside the bounds of the workplace. Mines are expected to contribute to improved conditions for workers, both at and outside of work, while also struggling with economic issues. Additionally, there is often misunderstanding or disagreement between the numerous stakeholders, including government, mining companies, and traditional leaders, about respective responsibilities, such as the provision of housing and services.

5.3. Strengths and limitations of the research

This research contributed to filling a research gap in terms of understanding socio-demographic contributors to fatigue, and the findings can contribute to interventions to reduce fatigue-related risks in the SAMI. Extensive data were collected, and mixed methods were used to validate the findings. However, there were several acknowledged limitations in this research due to its nature and scope, including the sampling method, the cross-sectional study design, measurement concepts and tools, and research dynamics. The limitations, along with the strengths, of the research are discussed in this section.

5.3.1. Sampling

The study made use of purposive and convenience sampling to select study sites and recruit participants. Random sampling was not feasible because of limitations in gaining access to mine sites, and because it would have resulted in production disruptions at the participating mines, not all workers were at the sites at the time of data collection, the voluntary nature of participation, and due to budget and time constraints. The use of convenience sampling could result in sampling bias. The 'healthy worker effect' could apply as, for example, the participants might be healthier or less fatigued than the general workforce, as they were not absent from work at the time of the study. The sampling methods employed limited the generalisability of the findings (external validity). However, it was ensured that workers from a range of job positions, work areas and shifts, were included to make the sample as representative as possible. Although the findings of the research could not be representative of workers in the SAMI or in industry internationally, the extensive data gathered from a range of participants (mine workers, unions, and management representatives), in a number of sectors (gold, platinum, coal, manganese and diamond), provided important data to contribute to better understanding of contributors to fatigue.

5.3.2. Cross-sectional research

The cross-sectional nature of the study did not allow for the determination of cause and effect, or for the analysis of the effect of changes that have taken place over time (Bangdiwala, 2019). However, this study design allowed for the analysis of associations of a number of variables with fatigue from a sizeable sample. Mixed methods were used to increase the validity and reliability, and to provide more comprehensive data, as information gathered during the interviews and focus group discussions helped to understand the associations that were found in the quantitative data.

5.3.3. Assessment and analysis

Methodological triangulation, or the use of multiple (mixed) methods, was used in this research, as the benefits include balancing the strengths and weaknesses of each individual method. For example, the use of interviews and focus group discussions assisted to provide rich data and an understanding of numerous aspects that could affect fatigue of mine workers in South Africa, and to explain findings from the quantitative data. The benefits of the use of the questionnaires included being able to quantitatively assess relationships between numerous variables and fatigue from a large number of participants.

The use of subjective measurement tools was a limitation, as these could be prone to social desirability bias, effects of personality or mood, differences in understanding, and limitations in memory or recall. Common method bias could result in biased or inflated relationships, such as from the use of self-report questionnaires (Podsakoff *et al.*, 2012). However, misconceptions about this bias in self-reported variables have been reported (Conway and Lance, 2010). Nevertheless, the use of multiple measurement methods or sources in this study assisted to mitigate this effect, as responses were gained from the use of interviews and focus group discussions in addition to self-report questionnaires. These data were further gained from a range of participants, which included managers, labour representatives, and the mine workers themselves. The validity and reliability of the measurement tools might also be questioned. For example, although single-item scales, such as those used for fatigue, sleepiness, stress, job satisfaction and quality of life, have been validated, some concepts could be culturally mediated.

There might have been differences in understanding of participants, especially with regard to the concepts of fatigue, stress and quality of life. Fatigue, in itself, is a multi-dimensional concept. A broad concept of fatigue was used, which incorporated physical and mental fatigue, and sleepiness; this was in line with the definition used by Folkard *et al.* (2007) and Schutte (2010). A number of different items or scales were used to determine the binary fatigue score for the quantitative analysis, which could have assisted to balance shortcomings of the use of individual scales. Additionally, fatigue was not measured at specific time points for this research, but rather as an average over time, so specific times of extreme fatigue risks in individuals were not recorded.

The inclusion of a range of variables that were examined in relation to fatigue was a strength of this research, as there is an evident lack of research that has assessed the effect of multiple socio-demographic factors on fatigue as independent factors rather than confounders (Di Milia *et al.*, 2011; Horrey *et al.*, 2011; Noy *et al.*, 2011). However, some factors that might be associated with fatigue and other study variables were not included, such as additional organisational aspects, job-related demands, working conditions, and work design factors. Inclusion of these factors might have provided a more complete understanding of fatigue. However, they were excluded from the scope of the study as there is already much research on work-related factors; this study aimed to address the gap relating specifically to non-work factors, including demographic and socio-economic characteristics. Many psychological variables that might be associated with fatigue were also not measured, such as personality and mood. Furthermore, specific interactions or confounding of many of the variables were not assessed in the analysis of data.

In addition, the categorisation of data into groups for statistical analysis might have affected the outcomes. Data for some of the variables were combined or grouped to allow for analysis if there were too few numbers in each category, or to allow for comparison between the different research groups. Caution was taken to ensure that the most appropriate groupings were made, as it was evident that differences in groupings could result in differences in the significance of the outcomes. Additionally, the use of qualitative data helped to verify findings obtained from the quantitative data.

5.3.4. Research dynamics

Power dynamics, and aspects relating to gender, age, education and occupation, might have influenced responses in the interview and focus group discussions. Assumptions and background knowledge of the researchers could also have influenced the discussions. The researcher and research assistants were well-educated females. The researcher was White and English-speaking, while the research assistants were Black and spoke home languages that included Zulu and Sepedi. It is possible, for example, that the female participants were more open and honest than other participants, as they might have felt a higher level of trust and understanding with the researchers than the male participants, despite being located in a male-dominated industry in which males might generally feel more secure.

5.4. Conclusion of the chapter

This chapter discussed findings from the research to assess contributors to fatigue in the SAMI. The findings of the qualitative and quantitative data collected were combined, and were compared to published literature. A range of variables was associated with fatigue, as causes or consequences, and interrelationships between the variables were also evident. In the sample, demographic contributors to fatigue included younger age, higher levels of education, black race, migrancy, and marital status. Work-related contributors included working night shifts and permanent employment. Socio-economic factors associated with higher levels of fatigue included lower incomes, difficulty affording necessities, and indebtedness. Longer commuting times, poor living conditions, and temporary housing also contributed to fatigue. Lifestyle factors that were associated with fatigue included a lack of exercise, inadequate nutrition, increased alcohol use, inadequate sleep and sleep problems. Fatigue was further associated with higher stress, lower quality of life, poorer health, and increased use of sick leave. Limitations and strengths of the research were discussed. The following chapter provides a conclusion and recommendations based on the research.

Chapter 6: Conclusion and recommendations

This chapter presents a summary of the aim, methods and results of the research to examine socio-demographic contributors to fatigue of mine workers in South Africa. Following the synopsis, recommendations for implementation and suggestions for further research are presented.

6.1. Overview of study

The aim of this study was to assess socio-demographic contributors to fatigue of mine workers in South Africa. Fatigue is an occupational health and safety risk, as it has been identified as a causal or contributing factor in accidents and fatalities in the mining industry. In addition to health and safety risks, mine workers in South Africa face challenges relating to poor socio-economic and living conditions. The research findings contributed to filling a research gap, as it was previously identified that there is a lack of research that has assessed the association of numerous demographic and socio-economic variables with fatigue. The objectives of the study were fulfilled in the writing of four scientific papers that have been published in peer-reviewed journals.

6.2. Summary of procedures

This study was cross-sectional and made use of mixed methods. Data were collected from three groups located at 12 mines and one platinum smelter in South Africa from 2014 to 2017. Qualitative data were collected in 71 interviews and 37 focus group discussions, from a total of 125 individuals in management positions, 43 labour representatives and 227 mine or smelter workers. Quantitative data were collected via questionnaires completed by 1 515 workers. The data related to demographic characteristics, socio-economic and living conditions, lifestyle, health, safety, and fatigue of mine workers. The quantitative data were analysed using descriptive and inferential statistics, including Chi-square tests and stepwise binary logistic regression, while the qualitative data were analysed using thematic analysis. Methodological triangulation was used to confirm and validate the findings. Ethics approval to conduct the study was granted.

6.3. Summary of results

The study revealed that fatigue was a challenge across all levels of workers in the SAMI, as it contributes to incidents and accidents, and can lead to poor health and reduced productivity. Numerous socio-demographic factors were found to contribute to fatigue of mine workers in South Africa. Demographic characteristics associated with fatigue in this research included younger age, black race, and higher levels of education. Socio-economic conditions associated with fatigue included lower incomes, difficulty paying for necessities, and being in debt. Factors relating to living conditions, including living in informal accommodation, were associated with fatigue. Increased commuting times were also associated with higher levels of fatigue. Lifestyle factors associated with fatigue included a lack of exercise, greater use of alcohol, unhealthy diets and a lack of sleep. Higher levels of fatigue were further associated with worse health, increased use of sick leave, higher levels of stress, reduced job satisfaction, and poor quality of life. Many of these variables are linked to each other, and to work stressors. The findings could be used towards interventions to improve health, safety and productivity in the SAMI.

6.4. Recommendations for implementation

Numerous recommendations have been made in relation to the study findings to reduce fatigue of mine workers in South Africa. Suggestions from the study participants were also recorded, and have been included in the recommendations. Some of the recommendations are more applicable to certain workplaces (e.g. underground mines) than others, but many can be applied more broadly, potentially beyond the SAMI. However, fatigue management should be adapted to the local context and the specific workplace. A holistic systems approach should be taken, as various stakeholders and a wide range of factors need to be considered. Additionally, fatigue management is a joint responsibility between management and workers in the mining industry.

6.4.1. Improved communication and awareness

Although not studied directly in this research, workplace culture was associated with fatigue, as demonstrated by participant reports of high levels of production pressure and some perceptions that management did not care for the workers. Mine workers often felt pressurised to work long hours, even when dangerously fatigued, and with a lack of resources, to complete work requirements; this is a safety concern. A culture of blame was also referred to by the participants, and some workers were afraid to refuse work in unsafe conditions, or to report fatigue to their superiors, for fear of being punished. Inadequate supervision was a related concern, which could further be related to human resources matters, as supervisors did not have the capacity to complete all the required tasks in the allocated time. It is important for mines to focus on safe production, instead of considering safety and production to be competing goals.

Improved communication and engagement between management, unions and workers could help to increase understanding between parties and to improve the workplace culture maturity. This would also likely improve job satisfaction of the workers, which could further help to mitigate fatigue and improve productivity. Better communication will also enhance awareness of what can and is being done to address concerns relating to fatigue, and would help to improve worker engagement in fatigue management programmes or measures. Furthermore, workers and communities should be educated about mitigation of fatigue in the workplace and at home. These mitigating measures include those of attaining sufficient sleep, eating well, avoiding excessive use of alcohol, and exercising, which can contribute to better health and wellness, and reduce fatigue. Improved communication and training about workplace programmes and processes would also help to reduce uncertainties and workers' frustration with management. The need for culture transformation and improved communication in the SAMI has been frequently highlighted in literature, and is supported by The Culture Transformation Framework for the South African mining sector (COMSA, 2017; Hattingh and Keys, 2010; Hermanus, 2016; Pelders *et al.*, 2019a).

6.4.2. Human resources matters

The mine workers often worked extended hours or overtime to receive bonus pay or boost their incomes, and financial stress was a cause of sleeplessness and fatigue. As a result of these identified issues, mines should assess pay, job grading, and bonus structures, and the implications of these on workers. Some pay structures can promote fatigue by providing incentives to work long hours (ORR, 2012). Better communication and understanding of pay and salary structuring would also help to avoid related frustration and disappointment experienced by the workers. Improved management of contractors, and monitoring of what is paid to contract workers, is also recommended. Other reasons for extended working hours and fatigue included a lack of human and equipment resources. These shortages should be addressed. Many participants complained that they had extra workloads, or were not able to take leave, as no one was able to replace them at work, especially when others were absent; this could result in fatigue. Better job planning, improved management of staffing, and better support, is recommended.

Additionally, better monitoring and evaluation of working hours is recommended, as work schedules and extended shifts are important contributors to fatigue. Real-time information systems could be implemented. For example, a system could be implemented to prevent workers from entering the workplace if excessive hours had been worked, to prevent high fatigue risks. It was noted that, while overtime hours were generally recorded, those with specialised skills often had to work beyond guideline hours because no one else was available. Additionally, at some mines, fatigue shifts were officially provided for on-call work continuing after midnight, but these procedures were not well implemented in practice. Extra hours did not appear to be monitored for production workers, as these did not reflect as overtime work or pay (but rather towards bonus pay for work achieved). Evidence of substantial involuntary long hours in the mining industry has been reported in literature (Peetz and Murray, 2011). It is recommended that these hours be monitored to better manage fatigue. Workers need to be provided with sufficient time to rest and attend to personal responsibilities. The shifts worked should also be assessed in relation to worker commuting times and living conditions. Reassessment of shift schedules, including working days, shift lengths and shift start times might be beneficial. These recommendations support previous research findings in the SAMI (Rupprecht, 2018; Theron, 2014). Additionally, systems to identify fatigue, and to mitigate the negative effects of fatigue, are recommended.

6.4.3. Employee wellness programmes

Stress was closely linked to fatigue, and was primarily attributed to financial strain. Stress was also a noted cause of alcohol abuse. Stress and alcohol abuse were further linked to poor living conditions, a lack of exercise and inadequate recreational facilities. The promotion of physical activity and increased access to exercise facilities is recommended to improve health and reduce stress (Kalmbach *et al.,* 2018). Additionally, improved employee wellness programmes could assist the workers to better handle stress and mental health issues. The promotion and use of employee assistance programmes, workplace health promotion, and wellness programmes are beneficial for reducing absenteeism, controlling healthcare costs, improving productivity, and retaining workers (Azzone *et al.*, 2009). Financial management programmes are also useful mechanisms to assist workers to better manage their finances and avoid debt, and have been implemented at mines in South Africa (Minerals Council South Africa, 2019; Rodin, 2015). Management support, promotional marketing, and ease of accessibility to these programmes are likely to increase employee participation (Azzone *et al.*, 2009).

6.4.4. Living conditions and transport matters

Living conditions, mode of transport and commuting times were associated with fatigue of workers in the SAMI. The housing, living conditions and transport of workers should be addressed by partnerships between stakeholders such as government (including the DMR and local municipalities), traditional leaders, NGOs, private organisations, organised labour, mining companies, and researchers (Brunette *et al.,* 2011; Cronjé and Chenga, 2009; Littlewood, 2014; Marais, 2013). It is important to improve access to services and amenities, including housing, roads, refuse removal, sanitation, water, electricity, recreation facilities, and healthcare. A number of workers hoped for affordable family accommodation close to the mines. Additionally, the provision of efficient transport services could help to reduce fatigue associated with long commuting times, or long walking distances to get to and from work. Holistic solutions should be found that consider the needs of a range of workers at different operations. Monitoring the effects of new housing regulations is also recommended, to assess the effects of these changes, and how housing in the mining industry could best be managed.

6.4.5. Mid-shift breaks

A number of participants commented on food eaten during work to boost energy levels and mitigate fatigue. Some participants recommend that food or supplements be provided and be easily accessible to all workers. The provision of rest breaks during work is a related concern, as the participants often commented that the workers were not able to take official breaks to eat. The provision of rest breaks is an important strategy to manage and mitigate fatigue (Folkard *et al.*, 2007; Shaw, 2003; South Africa, 2014; Spencer *et al.*, 2006). Section 14 of the Basic Conditions of Employment Act (Act No. 75 of 1997) states that meal intervals of at least one continuous hour must be provided to employees who work continuously for more than five hours; this can be reduced to 30 minutes, subject to an agreement in writing (South Africa, 1997b). Guidelines for self-pacing and requirements for water breaks per hour are also provided in the industry (South Africa, 2015b). Other related recommendations include a reassessment of rations allowed underground, where applicable, to ensure that workers have enough food and drink to remain nourished throughout the entire work shift, and when extended hours are worked.

6.5. Recommendations for future research

Further research will assist to gain further understanding, and better manage and mitigate fatigue. Opportunities for further research that were identified during this research are summarised in this section.

6.5.1. Additional analysis of collected data

There were a large amount of data gathered in the study, and further qualitative and quantitative analyses could provide a better understanding of numerous aspects relating to the sample. For example, further statistical assessments could include associations between the numerous socio-demographic variables and health, safety and wellness outcomes, including stress, quality of life, job satisfaction, and self-reported health. Interactions between the variables, and confounding, could be explored in more complex analyses.

6.5.2. Objective assessment of fatigue

The use of self-report data provided valuable information relating to fatigue of mine workers in this research. However, despite limitations relating to the use of objective measures of fatigue, further research using objective, real-time data would help to better understand and manage fatigue. In particular, further research on the assessment of working time data from mines is recommended. These data would include clock-in and clock-out times of workers, and could be analysed in terms of absenteeism, and accident or lost-time injury reports. Further objective measures could include the use of actigraphy to assess sleep of workers across different shifts.

6.5.3. Longitudinal study

To build on the findings from this research, a longitudinal analysis of changes over time could provide a better understanding of cause and effect between numerous socio-demographic variables and fatigue. The results of interventions could take time to reflect, such as the effect of changes in housing arrangements on health and safety outcomes. An intervention study is further recommended, to monitor and review improvements or unintended consequences of interventions to reduce fatigue.

6.5.4. Engagement with stakeholders

This research focused on gathering extensive data from mine workers, labour representatives and mine managers. Further research involving a wider range of stakeholders, including those outside of the mine operation boundaries, is recommended. This would include engagements with those in mining communities, government (e.g. DMR and DOL), and local municipalities and organisations. Various stakeholders have an influence on conditions that affect mine workers. For example, families can influence the sleep obtained by mine workers, while local authorities, government, and organisations affect intervention efforts to improve housing and service delivery in mine communities. Further interaction with stakeholders about the current study results and what can be done to address the challenges that are faced would be beneficial.

6.5.5. Fatigue in the context of mining industry modernisation

Future research is recommended to assess changes that take place as mines modernise, and the effects that these could have on worker fatigue. The modernisation of technology and processes in the mining sector has an impact on mine workers (Kramer *et al.*, 2017). The aim of modernisation in the SAMI is to make operations safer, healthier, more productive, and sustainable (Jacobs and Webber-Youngman, 2017; Minerals Council South Africa, 2018b). Modernisation takes place in the context of the Fourth Industrial Revolution (or Industry 4.0), and involves the adoption of new technologies which incorporate automation and the use of robots (Jacobs and Webber-Youngman, 2017; Kramer *et al.*, 2017; Pelders, 2019). This process could involve, for example, the use of systems to migrate conventional, labour-intensive mining to the use of automated continuous mining methods, along with improved monitoring and tracking systems (Deloitte, 2014; Singh, 2017). These processes can eliminate, substitute, or reduce some of the hazardous exposures, for example, by removing mine workers from the most dangerous areas of mines (e.g. the stope face), but could also result in the creation of new risks (Kramer *et al.*, 2017; MacFarlane, 2001; Willis *et al.*, 2004). Modernisation results in less labour-intensive activities and could therefore better accommodate women and occupationally-challenged workers (Gumede, 2018). Additionally, modernisation requires increased skills and higher paid labour, but has also resulted in fewer workers employed in the industry (Kramer *et al.*, 2017; MacFarlane, 2001; Singh, 2017; Vogt and Hattingh, 2016; Willis *et al.*, 2014). Thus, modernisation in the SAMI could help to mitigate factors associated with fatigue that were identified in this study, including aspects associated with low SES, and with the younger but more educated workforce. Modernisation could also affect down- and upstream mining activities, including secondary industries that could develop in mining communities (Deloitte, 2014). As such, continued monitoring and evaluation of the fatigue effects of changes in the mining industry will be necessary, and fatigue management should consider the changes relating to modernised mine and community environments.

6.6. Conclusion

Fatigue leads to impaired focus, productivity, motivation, health, and safety in the mining industry and can result from numerous factors. This research has contributed to the body of knowledge relating to fatigue of mine workers in South Africa. It has also assisted to fill identified research gaps in the area of demographic and socio-economic contributors to fatigue. Interventions should be implemented, based on the findings, which could lead to improved health and safety of workers, and sustainability of the mining industry.

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Appendices

Appendix A: Pelders, J. and Nelson, G. (2019) Living conditions of mine workers from eight mines in South Africa. *Development Southern Africa, 36*(3): 265-282. https://doi.org/10.1080/0376835X.2018.1456909.

Appendix B: Pelders, J. and Nelson, G. (2019). Socio-demographic contributors to health and safety of mine workers in South Africa. *Work, 64*: 67-76. http://doi.org/10.3233/WOR-192969.

Appendix C: Pelders, J. and Nelson, G. (2019). Contributors to fatigue at a platinum smelter in South Africa. *The Journal of the Southern African Institute of Mining and Metallurgy, 199*: 313-319. http://dx.doi.org/10.17159/2411-9717/2019/v119n3a11.

Appendix D: Pelders, J. and Nelson, G. (2019). Contributors to fatigue of mine workers in the South African gold and platinum sector. *Safety and Health at Work, 10*: 188-195. https://doi.org/10.1016/j.shaw.2018.12.002.

Appendix E: Pelders (Hodgskiss), J. (2017). Contributors to fatigue at four gold mines in South Africa. *Research Day 2017 – Public Health for Sustainable Development in Africa.* Wits School of Public Health. University of the Witwatersrand, Johannesburg. 27 November 2017 *(abstract)*.

Appendix F: Pelders, J. and Nelson, G. (2018). Contributors to stress of mine workers in South Africa. *6th CSIR Emerging Researchers' Symposium.* The Council for Scientific and Industrial Research (CSIR), Pretoria. 28-29 June 2018 *(poster)*.

Appendix G: Pelders, J. and Nelson, G. (2018). Contributors to fatigue of mine workers in South Africa. *9th Wits Cross Faculty Postgraduate Symposium.* University of the Witwatersrand, Johannesburg. 29-30 October 2018 *(poster)*.

Appendix H: Pelders, J. and Nelson, G. (2018). Socio-demographic contributors to fatigue of mine workers in South Africa. *Wits Integrated Mine Health and Safety Research Group – Postgraduate Research Seminar.* University of the Witwatersrand, Johannesburg. 21 August 2018 *(abstract)*.

Appendix I: Pelders, J., Nelson, G. and Magweregwede, F. (2019). Shift cycles and fatigue in the South African mining industry. *International Mine Health and Safety Conference 2019.* The Southern African Institute for Mining and Metallurgy. Johannesburg. pp. 81 - 88 *(conference paper)*.

Appendix J: Deviations from study protocol

Appendix K: Interview and discussion guide on the effects of socioeconomic and living conditions on health and safety

Appendix L: Interview and discussion guide on contributors to fatigue

Appendix M: Mine worker questionnaire

Appendix N: Ethics approval from the CSIR Research Ethics Committee

Appendix O: Ethics clearance certificate from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand

Appendix P: Plagiarism declaration

Appendix Q: Turnitin report

Appendix A: Paper 1

Pelders, J. and Nelson, G. (2019) Living conditions of mine workers from eight mines in South Africa. *Development Southern Africa, 36*(3): 265-282.

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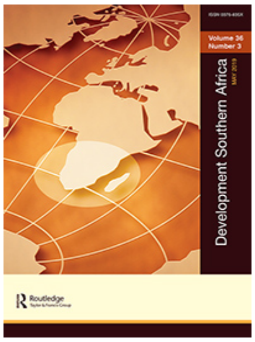

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Living conditions of mine workers from eight mines in South Africa

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ABSTRACT

Poor living conditions are a consequence of the history of the South African mining industry (SAMI), despite legislation having been implemented to attempt to address this challenge. This paper describes the living conditions of mine workers from eight mines in South Africa in 2014, and assesses changes made over the previous decade. Qualitative and quantitative data were collected at three platinum, two gold, one coal, one diamond, and one manganese mine in 53 interviews with mine management, 11 interviews with labour representatives, 14 focus groups with mine workers, and 875 questionnaires completed by mine workers. The use of single-sex hostels and hostel room occupancy rates has reduced, while the use of living-out allowances (LOAs) has increased. Problems included the high proportions of informal accommodation; a lack of access to water, sanitation, and electricity; and poor roads. While improvements to the living conditions in the SAMI are evident, challenges still remain.

KEYWORDS

Housing; South African mining industry; hostels; living-out allowances; services and facilities

1. Introduction

The workforce of the South African mining industry (SAMI) was traditionally housed in single-sex mining compounds or hostels from the late 1800s (Marais & Venter, 2006; Republic of South Africa, 2009b). Migrant labourers were employed in the mining industry, and African men had to leave their families in rural parts of South and southern Africa and travel to mining centres, where they lived in these hostels while working at the mines (Bezuidenhout & Buhlungu, 2011). The housing and living conditions for many workers in this industry were sub-standard, which had adverse effects on their health, productivity, and social wellbeing (Republic of South Africa, 2009b). Organised labour played a role in driving new housing policies and legislation, with campaigns against migrant labour and the hostel system (Bezuidenhout & Buhlungu, 2011). Mining firms formally abandoned the preference for hostel accommodation in 1986 (Bezuidenhout & Buhlungu, 2011).

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A consequence of the history of the SAMI is that most South African mining towns maintain poor social and economic conditions, such as poverty, unemployment, bad housing and infrastructure, prostitution, poor health, and a high influx of single migrant labourers (Cronjé & Chenga, 2009). Housing currently available to mine workers, in addition to conventional hostels, includes limited married quarters, Reconstruction and Development Programme (RDP) houses, mine workers' own houses in new suburbs, township houses, informal settlements, villages near mines, flats rented from companies, and backrooms (Bezuidenhout & Buhlungu, 2011). Mines commonly offer living-out allowances (LOAs) to employees in order to subsidise employees' accommodation. However, some employees set up minimal housing in informal settlements around the mine, in order to save a portion of the LOA to send to their rural homes.

Policies and legislation relating to the living conditions in the SAMI have been implemented with the aim to improve the housing of mine workers (e.g. Republic of South Africa, 1996a, 1996b, 1997, 2002a, 2002b, 2008a, 2008b, 2009a, 2009b, 2009c, 2010). The Mining Charter and its amendment (Republic of South Africa, 2002a, 2008b) compelled mining companies to 'convert or upgrade hostels into family units by 2014', 'attain the occupancy rate of one person per room by 2014', and 'facilitate home ownership options for all mine employees in consultation with organised labour by 2014'. The Framework Agreement for a Sustainable Mining Industry of 2013 ascertained organised labour, organised business, and governments' commitment to upgrade human settlements in mining towns (Republic of South Africa, 2013).

Policy changes can and have also had unintended consequences on mine worker housing. For example, changes in housing policies can result in urban sprawl and constraints to the delivery of basic services (SACN, 2017). Other changes in the industry, including a trend toward shift work and outsourcing or contract work, which is associated with lower salaries and fewer benefits, also have an impact on workers' living conditions (Bezuidenhout & Buhlungu, 2011; SACN, 2017; Marais et al., 2018). Housing developments in remote mining areas have led to the creation of 'ghost towns' in the past, and there is a risk of this in the future due to the limited life of mines, and mine downscaling in terms of employment (Cloete et al., 2009; Marais & Nel, 2016).

A study conducted by Lewis (2003), regarding housing in the SAMI, revealed that the most common housing arrangements at the time were single-sex hostels and LOAs, which accommodated 46% and 31% of the workforce, respectively. Of the single-sex hostel dwellers, 65% resided in a room with seven to eight occupants, 16% resided in rooms with five to six occupants, and 18% with four or fewer occupants (Lewis, 2003). Lewis also found that, of those who stayed in off-mine accommodation, 50% lived in houses or brick structures on their own stands and 41% lived in shacks or backyard dwellings, while the rest stayed in local authority houses, self-built houses on local authority land, in flats, or in rooms in houses. The main problems with the housing of off-mine dwellers were the quality of building materials, bulk basic services (such as water, electricity, and sewerage), violence and insecurity, access to and quality of health services and transport, and the perceived permanence of the housing. The main reported deficits for hostel dwellers were overcrowding, a lack of sleep, rest, and privacy, violence and insecurity, and poor access to services such as schools for their children and private cooking facilities.

A study by Marais & Venter (2006) revealed that 67% of the participating mine workers in the SAMI were unhappy with their housing situations, 15% were satisfied, and 19%

were happy. Causes for unhappiness included that they did not own houses and that they did not live with their families.

Poor living conditions are associated with various health and safety outcomes and quality of life (Alnsour & Meaton, 2014; Burridge & Ormandy, 2007; Galobardes et al., 2006; Statistics South Africa, 2011; Williams et al., 2010). These include the spread of infectious disease or infection, owing to overcrowding or a lack of water or sanitation, and illness and accidents (Galobardes et al., 2006; Burridge & Ormandy, 2007). They may further have an impact on access to education, healthy foods, health care, and recreation facilities, and on physical safety, crime or victimisation, and other stressors (Williams et al., 2010).

This paper describes the living conditions of mine workers working at eight mines in South Africa in 2014. Although it was assumed that changes in government policy led to improvements in living conditions, there was a lack of evidence to support this hypothesis. The aim of this research was to assess the living conditions of workers in the SAMI, to assess changes made between the early 2000s and 2014, and to identify remaining shortcomings, with a view to assist in the development of strategies and prioritised interventions to further improve the living conditions of mine workers in South Africa.

2. Methods

2.1. Study design

This was a cross-sectional mixed methods study, as both qualitative and quantitative data were gathered, and methodological triangulation was used to verify the results.

2.2. Study population and sample

At the time of the study there were approximately 1700 operating mines and quarries in South Africa, and the industry directly employed close to 500 000 people (Republic of South Africa, 2011). The study population comprised all workers employed at eight mines in South Africa; the study mines were identified by commodity, and included those in the platinum ($n = 3$), gold ($n = 2$), coal ($n = 1$), diamond ($n = 1$), and manganese ($n = 1$) sectors. The participating mines employed approximately 10% of the SAMI workforce in 2014. The diamond mine was open-pit, while the seven other mines ran underground operations. The mines were located in six of the nine provinces in South Africa, and were purposively selected based on input from professionals with knowledge and understanding of the SAMI. A range of mining sectors was chosen so that this study could best represent the SAMI as a whole. The platinum and gold sectors employ the highest number of people in this industry, so more than one of each of these mines was selected.

The study participants included those in mine management, labour representatives, and mine workers. Those in mine management and the labour representatives were purposively selected based on the roles they played at the mines. Those in mine management included mine managers (general or operational), human resources managers, industrial relations officers, occupational health or wellness managers, safety managers, hostel managers and/or transformation managers, or those in equivalent or representative positions at each mine. Convenience sampling was used to recruit the mine workers that participated in the study, and included unskilled, semi-skilled, and skilled labourers performing work relating to production at the mines. Stakeholder interviews were conducted with 67 individuals in mine management and 18 labour representatives. Focus groups were conducted with 120 mine workers, and questionnaires were completed by 875 mine workers.

2.3. Study tools

The data collection tools developed for this study included a stakeholder interview and focus group question guide, and a questionnaire for mine workers. The interview and focus group guides consisted of open-ended questions to gain insight from the participants regarding their concerns relating to the living conditions of the mine workers at the mines and the services and facilities available to them. The questionnaire consisted of forced-choice questions relating to aspects such as worker demographics, living conditions, access to services and facilities, and lifestyle.

2.4. Study procedures

Data collection took place from June to November 2014. The interviews and focus group responses were voice recorded. The interviews with management and labour were conducted in English. Most of the interviews were held in one-on-one sessions; however, some were held with more than one individual at a time. The focus groups were conducted by trained research assistants who were fluent in the local languages (the languages that were most readily understandable by the participating mine workers). The research assistants also assisted the mine workers to understand and complete the questionnaires, to eliminate any barriers of language and literacy levels.

2.5. Data analysis

The interviews were transcribed, and the focus group responses were translated and transcribed. Thematic content analysis was used to identify main themes that arose. Data from the questionnaires were captured electronically, and basic statistical analyses were performed. A comparison of the data from different sources was conducted.

2.6. Ethical considerations

Ethical approval to conduct the study was obtained from the CSIR Research Ethics Committee and the University of the Witwatersrand Human Research Ethics Committee (reference and clearance certificate numbers 85/2013 and M140222, respectively). Permission was also provided by the mines to conduct the study at these sites. Voluntary informed consent was gained from each of the research participants. All data gathered in this study remain confidential.

3. Results

3.1. Interviews and focus groups with management, labour representatives, and mine workers

A total of 53 interviews with management, 11 interviews with labour representatives, and 14 focus groups were conducted across the eight mines. Discussions about the living conditions of the mine workers were categorised into the topics of hostel accommodation, other mine accommodation, home ownership schemes, housing outside of the mine, and services and facilities.

3.1.1. Hostel accommodation

The Mining Charter required the mines to convert or upgrade their hostels into single accommodation or family units by 2014. As this was the year in which the study was conducted, the studied mines had either completed these developments or planned to complete them by the end of the year. Some of the studied mines did not have hostel accommodation at all, or only had this for contract workers, while contract workers at some of the other mines were not able to reside in mine accommodation. The study participants generally expressed that the conditions in the hostels had improved. For example, a participant commented that 'Those in the residences are happier now that there is only one person per room. They get more privacy […] The conditions have improved tremendously'. However, one hostel resident said that, 'Even where we are staying in the hostel, we don't like it. […] You can imagine how many years I have stayed away from my family […] Hostels are meant for school kids, not men with families'. Some concerns specific to the mine studied included the food provided, if applicable, and that workers wanted be allowed to have visitors to stay overnight. A problem with the reconverted hostels was that they housed fewer people than the hostels did in the past, which resulted in a shortage of accommodation, and led to more mine workers living in informal settlements. Some expressed the desire for more family accommodation to be provided.

3.1.2. Mine accommodation

Traditional mining villages existed at a number of the participating mines, in which houses were available for mine employees and their families to live in at a very low cost. Conditions here were generally seen to be good. However, this accommodation was generally limited to higher category workers, such as supervisors and managers. Examples of participant responses were:

> When I started here I was given two options: either you get an LOA or you are given a mine house. The house where I am living is very safe and I cannot complain about anything. I enjoy staying there

and 'We don't all qualify for mine houses. Only those on a higher band get mine houses'.

3.1.3. Home ownership schemes

The management at many of the mines indicated that the mines were either in the process of planning or had already established facilitated home ownership schemes, through which mine workers could buy houses from the mines at subsidised rates. These schemes were particularly seen to assist those whose salaries were too low to qualify for mortgage bonds, but were too high to qualify for RDP or governmental housing. The need was highlighted by comments such as:

> The money we get here is too little to afford houses. You find that you are the only one working in your family and you have to support a lot of people with it. How can I build a house with that little money I get? It's difficult

and 'We wish for the mine to provide us with houses. Not for us to rent, but the ones that we can be able to own'. It was generally agreed that the home ownership schemes were important mechanisms to improve the living conditions of mine workers. However, challenges that participants noted regarding the home ownership schemes included affordability and the distance of the housing from the mines. A participant stated: 'It's a good thing but the lower band employees cannot afford the houses'. Reasons for the far distances included spatial development planning and considerations of the lifespan of the mine, or because the areas close to the mines were tribal lands, so the mines were not able to build there. Some expressed that they wanted to own homes in rural areas. However, as this land belonged to tribal chiefs, it was not possible to obtain financing for these houses. Other workers already had homes in other areas and, as such, did not want to own a second house. A participant commented that: 'Some of us are coming from different places, and some of us already have bond houses where we come from'. However, another worker noted: 'I'm originally from Lesotho. But even if home is Lesotho I would still want to own a house here because I work here'. Other workers wanted the mines to provide them with land or with financing to build their own houses.

3.1.4. Accommodation outside of the mine

The majority of mine workers lived outside of accommodation provided by the mine. Most of the participating mines offered LOAs to these workers. A participant commented, 'We have moved away from the hostel-type accommodation, and hence the housing allowance that we are giving to people', and 'Getting a housing allowance to me is good in terms of freedom'. The main challenge that was noted regarding the use of LOAs was that this allowance was often not used towards decent housing, but was rather used to supplement the mine workers' incomes. One participant noted, 'Each person gets an LOA or housing allowance […] but the risk to that is not everyone uses this to get a proper house or apartment to live in', while another said: 'Most of us here prefer to stay in the townships because we cannot afford houses in town, and we don't have money to build beautiful houses, so some of us stay in shacks'. A further comment was:

> Hostels are a problem, and the dismantling of hostels brought in another problem, where three or four men are staying in a house […] And for hostel people to save money, a lot of people are staying in outside rooms or other places. Contractor workers are worse off.

Many of the mine workers were migrant labourers who opted to live in cheap, informal housing, such as 'shacks' or backrooms, close to the mine, and sent the extra money received from their LOAs to their rural homes. A number of workers expressed that they preferred renting, rather than staying in mine accommodation, as it gave them more freedom of choice. Many mine workers lived in various other forms of housing, including shacks, backrooms, RDP housing, rental rooms or houses, and their own homes in towns or rural areas. Problems that were encountered by many living in informal settlements or townships, and some in rural communities, included a lack of sanitation, water, and electricity, and poor roads. One participant noted, 'The problems are with those staying outside, in shacks, where there is no sanitation, water and street lights', and another noted, 'Sometimes the community grows very fast and you find that some things (services) become limited for the people'.

3.1.5. Services and facilities

The services and facilities that were discussed included transport, health care, schooling, shops, and recreation. The adequacy of the services and facilities available to workers varied from mine to mine and also depended on where the mine workers lived.

Some of the mines provided transport, or transport subsidies, to their workers. Other forms of transport included workers' private vehicles, public transport, such as buses and minibus taxis, and walking. Some of the roads to the mines were in poor condition, especially when it rained, and accidents and fatalities occurred. The problem of crime was also noted for those who walked to or home from work. These aspects were highlighted in comments, including: 'The workers do not have enough transport. Some of them suffer, who are staying in the location', 'There's no tar road to the mine. The last time I had an accident. Some of my colleagues had accidents too, on the same road', and 'When people have to walk there are muggings happening'.

Health care was also frequently discussed. Mine clinics offered services such as occupational and primary health care. However, it was not always possible for employees' family members or contract workers to be treated at these facilities. The health care available outside of the mines varied. There were usually clinics available in the areas where the mine workers lived, and mobile clinics also operated. However, health care was difficult to access in certain areas, and the quality of and length of time taken to receive treatment at state services could be problematic. Hospitals were generally available, but the distance from some of the mines was a concern.

Other services that were discussed included schooling, shops, and recreation facilities. In terms of education, adult basic education and training (ABET) was often offered by the mines. There were generally crèches, nursery, primary, and high schools available in the areas surrounding the mines. However, tertiary education facilities, such as colleges or universities, were scarce. Small shops or kiosks were generally available on mine property or surrounding the mine, but the workers often had to travel to nearby towns to access a wider range of services. Recreation facilities, such as sports fields, were often available at the mines, but those in the communities surrounding the mines were not always adequate. A lack of recreation facilities was associated with increased alcohol and substance abuse, and crime.

3.2. Questionnaires completed by mine workers

A total of 875 questionnaires were completed by mine workers across the eight mines. The average response rate to the questions was 95% (±4%). The questions related to demographics, housing, and living conditions.

Table 1. Demographic characteristics ($n = 875$).

Characteristic	Participants *n*	Participants %
Gender:		
Male	746	88.6
Female	96	11.4
Age (years):		
<25	66	7.8
25–29	152	17.9
30–34	204	24.0
35–39	166	19.5
40–44	98	11.5
45–49	76	8.9
50–54	59	6.9
≥55	29	3.4
Education:		
No schooling	19	2.2
Some primary (Grade 1–6)	75	8.8
Completed primary (Grade 7)	49	5.8
Some secondary (Grade 8–11)	199	23.4
Completed secondary (Grade 12)	334	39.2
Higher than Grade 12	158	18.6
Other	17	2.0
Marital status:		
Married	459	53.7
Engaged	49	5.7
Unmarried but living with partner	92	10.8
Single	233	27.3
Divorced	8	0.9
Widowed/widowered	14	1.6
Race:		
Black/African	793	92.1
Coloured	23	2.7
Indian/Asian	5	0.6
White	36	4.2
Other	4	0.5
Home language:		
Southern Sotho	215	24.8
Setswana	177	20.4
isiXhosa	147	17.0
isiZulu	88	10.1
Northern Sotho	71	8.2
Xitsonga	60	6.9
Afrikaans	54	6.2
English	15	1.7
SiSwati	15	1.7
Tsivenda	5	0.6
isiNdebele	5	0.6
Other	15	1.7
Nationality:		
South African	749	86.4
Basotho	53	6.1
Mozambican	44	5.1
Swazi	12	1.4
Batswana	6	0.7
Zimbabwean	1	0.1
Other	2	0.2

3.2.1. Demographics

Basic demographic characteristics of the study participants are displayed in Table 1. Most were male (89%); the majority (44%) were aged 30–39; and 58% had completed secondary education (Grade 12) or above.

Over half of the participants (54%) were married. The majority of the participants (92%) were black Africans. A wide variety of home languages were spoken, of which the most common was Southern Sotho (25%), followed by Setswana (20%), isiXhosa (17%), and isiZulu (10%). Most of the sample (87%) was South African, while the rest came from neighbouring countries. Half (50%) of the participants came from the same province as the mine in which they were working.

According to commodity, 37% of the participants worked at platinum mines, 30% in gold, 13% in diamond, 10% in coal, and 10% in manganese. The majority (82%) of the participants were permanent employees at the mines, while 18% were contract workers. In terms of shifts worked, 42% worked shifts of 12 hours or longer, and 46% worked night shifts in their work schedules.

3.2.2. Housing

The types of dwellings in which the participants resided are illustrated in Figure 1. Formal brick dwellings were the most common type (37%), followed by backyard rooms or houses (19%), hostels (15%), shacks or informal dwellings (14%), and flats, townhouses, or cottages (12%). Almost half (48%) reported to receive LOAs, a quarter did not have any housing arrangement with the mine, and 8% received housing capital or bond repayment subsidies (Figure 2). Of those receiving LOAs, approximately 37% reported living in formal brick houses, 43% in shacks, informal dwellings, or backyard houses or rooms, and the remaining 20% in other accommodation, including flats, townhouses, cottages, and traditional dwellings.

Figure 3 displays the areas in which the dwellings were located, of which the most common were mine property (24%), townships (24%), and rural areas (21%). In terms

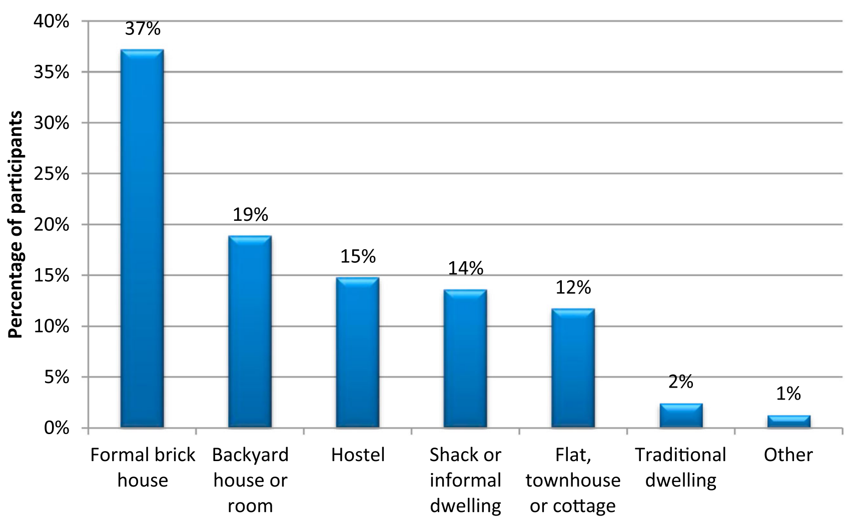

Figure 1. House type ($n = 852$).

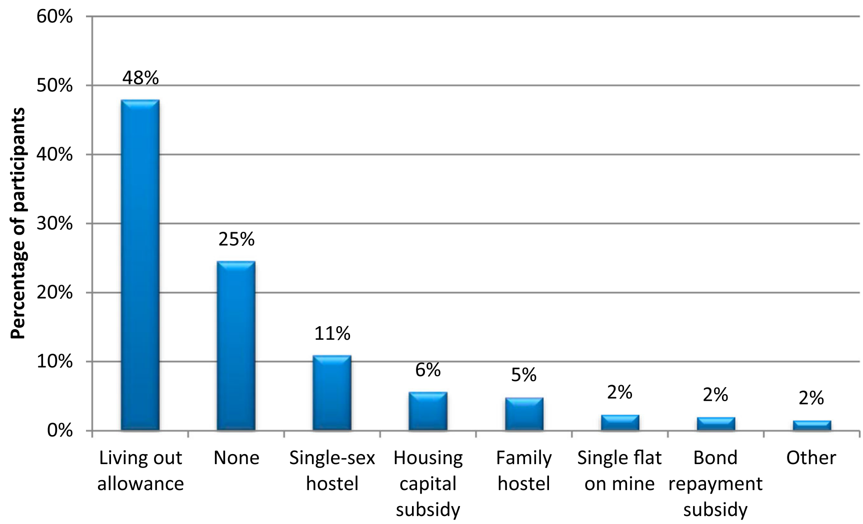

Figure 2. Housing arrangement with mines ($n = 834$).

of housing tenure, 50% of the sample was renting, 32% owned their homes, 16% occupied their dwellings rent free, and 2% had 'other' arrangements. The participants were also asked whether they considered their dwellings by the mine to be their permanent homes. Around 41% said they did, while 59% said they did not.

Differences between the housing of contract workers and permanent employees were evident. Contract workers were more likely to reside in shacks, informal dwellings, or backrooms and less likely to stay in formal brick houses or hostels than the permanent employees. Contract workers were also less likely to have a housing arrangement with the mine.

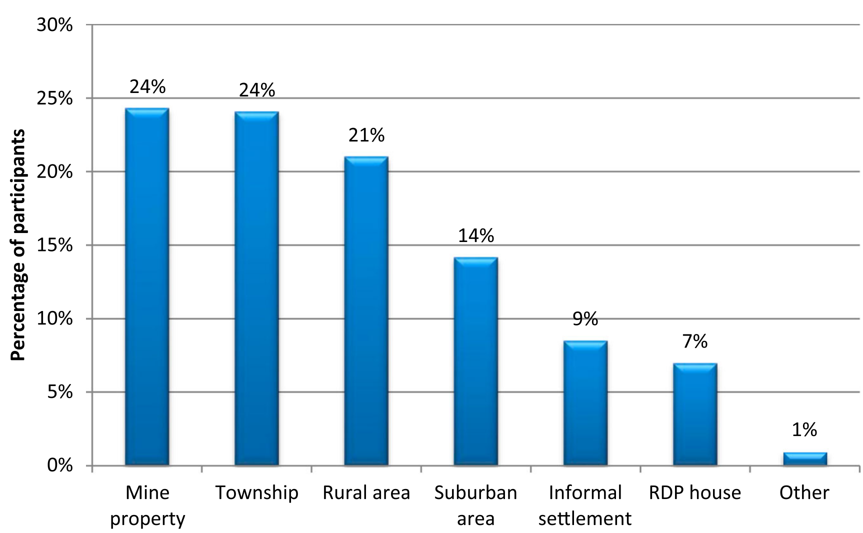

Figure 3. Area of dwelling ($n = 847$).

The housing of participants working at mines of different commodities in the study sample also differed. The gold mines had a higher percentage of participants residing in hostels compared to the other commodities; the platinum mines had a higher percentage living in shacks or informal dwellings; and higher percentages stayed in formal brick houses for the coal, diamond, and manganese mines. However, longer travelling distances were also evident for those in coal, diamond, and manganese mines. LOAs dominated for all of the mines except for the diamond (open-pit) mine, where most participants reported having no housing arrangement with the mine.

3.2.3. Living conditions

Participants were also asked about the level of crowding in their dwellings, their access to services and facilities, and disturbances they faced near to their dwellings. Figure 4 illustrates the number of people with whom the participants shared their rooms, wherein 36% had their own room, 32% shared a room with one other person, and 32% shared with two or more others. Of those reporting to live in hostel accommodation, 58% did not share a room with anyone else, 17% shared with one other person, 7% with two others, and 18% with three or more other people.

As can be seen in Figure 5, around 82% of the sample reported access to piped water in their dwellings or in their gardens, while 13% had access to piped water outside of their gardens, and 5% did not have access to piped water. Electricity was the main source of energy that was used for lighting (92%), cooking (88%), and heating (71%), while other sources of fuel included gas, paraffin, and wood. The majority of the participants had flush toilets (67%), while 26% made use of pit toilets (with or without ventilation), and 6% used bucket toilets, chemical toilets, or did not have toilet facilities (see Figure 6). The majority of the sample (71%) had their refuse removed by a local authority, while 19% used their own or a communal refuse dump, and 10% had no mode of refuse disposal (see Figure 7). Those staying in shacks, informal dwellings, or backrooms reported lower

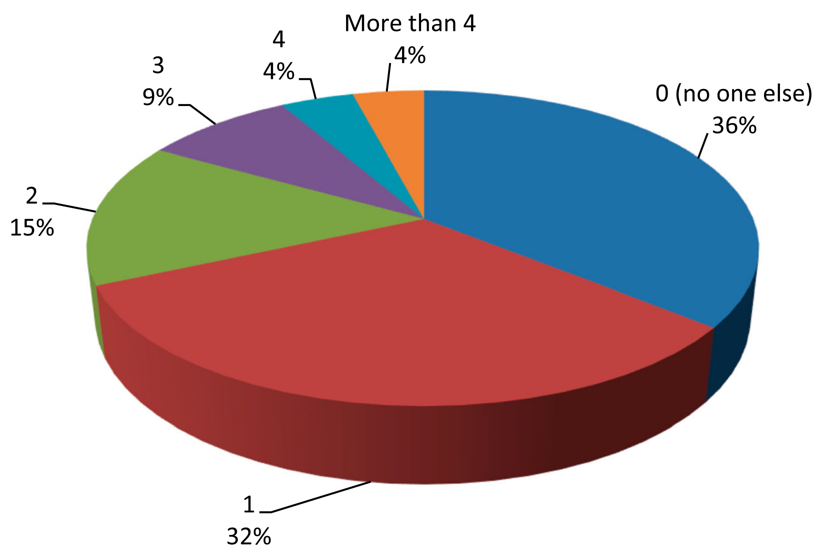

Figure 4. Number with whom room is shared ($n = 856$).

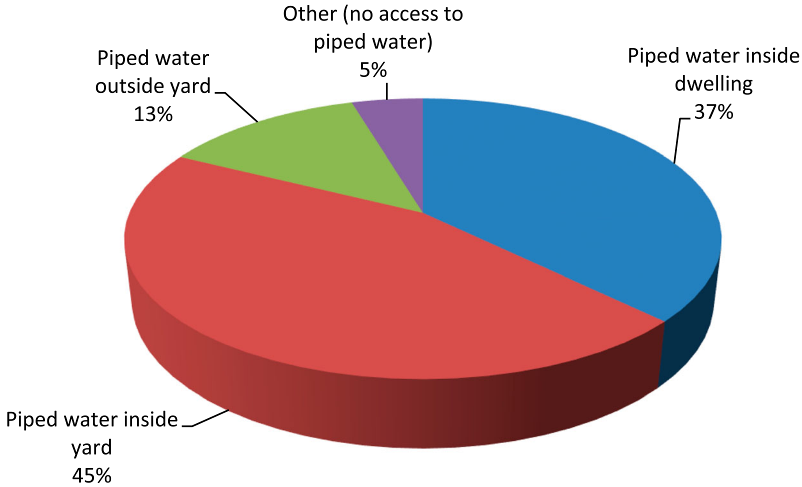

Figure 5. Access to water ($n = 845$).

access to services compared to those in formal dwellings and hostel accommodation. Similarly, contract workers had less access to services than permanent workers. Those from the platinum and manganese mines, which also employed higher percentages of contract labour and were more commonly located in rural areas, reported lower levels of access to services than workers from the other mines.

Participants were asked to rate how often they faced various disturbances in the areas of their dwellings, on a scale of 'often', 'sometimes', 'seldom', and 'never'. Noise and violence or crime, were the most commonly reported disturbances (62% and 57% of the participants indicated these were 'often' or 'sometimes' experienced, respectively). The other disturbances listed were dust or smoke (48%), no drinking water (46%), bad smell (45%), littered environment (44%), and damage to buildings (32%).

In terms of access to health care, 82% of the participants indicated that they had access to what they considered to be proper health care at work, and 75% said they had access to

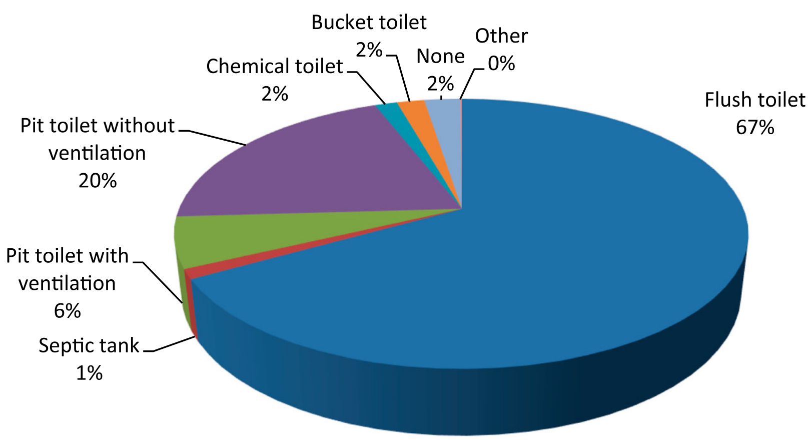

Figure 6. Type of toilet ($n = 868$).

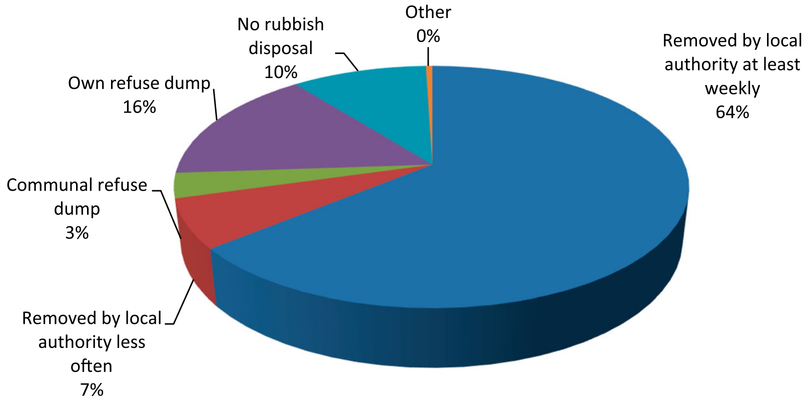

Figure 7. Mode of refuse removal ($n = 839$).

proper health care close to their dwelling. Buses were the most commonly used mode of transport to get to and home from work (22%), followed by minibus taxis (21%). Private vehicles were also common, and 16% drove these, while 5% made use of lift clubs in these vehicles. Around 19% of the participants used company transport to get to and from work, while 14% walked and 3% used a combination of modes of transport.

The participants were also asked to rate their levels of satisfaction with their living conditions and their quality of life. Around 35% were dissatisfied or very dissatisfied with their living conditions, 12% were neither satisfied nor dissatisfied, and 52% were satisfied or very satisfied (see Figure 8). In terms of quality of life, 30% considered theirs to be poor or very poor, 19% as neither poor nor good, and 51% as good or very good. Levels of satisfaction with living conditions and good quality of life reported by permanent employees were 54% and 51%, respectively, compared to 48% for both in contract workers.

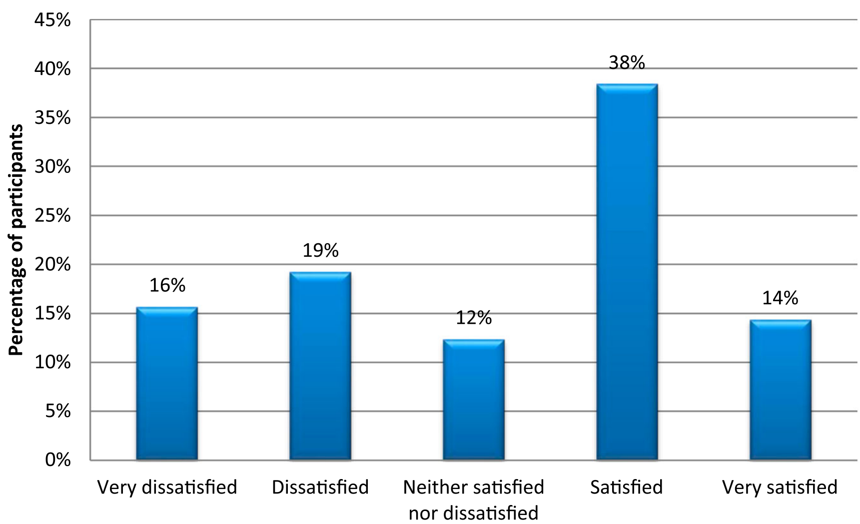

Figure 8. Satisfaction with living conditions ($n = 843$).

Satisfaction with living conditions and quality of life was highest for participants at the coal mine and lowest at the platinum mines.

3.3. Comparison of data from literature, interviews, focus groups, and questionnaires

The qualitative data gathered in the interviews and focus groups were compared with the quantitative data gathered in the questionnaires. The housing and living conditions of the participating mine workers were also compared with findings from studies in the SAMI in the past in order to assess general developments. While the study participants were not entirely representative of the SAMI, the data are believed to provide a general depiction of the living conditions of mine workers in South Africa.

Housing arrangements provided in the SAMI include hostel accommodation, facilitated home ownership schemes, and the use of LOAs. When comparing current data to that obtained from a study conducted by Lewis (2003), it is evident that fewer mine workers resided in single-sex hostels in 2014 (11%) compared to the early 2000s (46%), while more workers received LOAs (48%) compared to the previous study (31%). This finding was expected, as a result of industry preferences and Mining Charter requirements for the upgrading and conversion of hostels. The hostel room occupancy rate was considerably lower compared to the past, as Lewis reported only 18% residing in rooms with four occupants or less, compared to 82% in the current study.

Compared to findings from a study relating to living conditions in the SAMI by Marais & Venter (2006), mine workers appeared more satisfied with their living conditions in 2014. This is likely due to policy changes and initiatives that have been implemented by the industry to redress challenges relating to living conditions. However, 35% of the participants in the current study did indicate dissatisfaction with their living conditions. This could be a result of factors such: as not being able to live with families; affordability; a lack of access to services such as water, sanitation, and electricity; poor roads; transport challenges; noise; and crime.

Additionally, challenges with access to health care were indicated in the interviews and focus groups, including a lack of access for contract workers and for mine workers' family members, and the accessibility of health care in the communities surrounding the mines. In the questionnaires, 82% of the participants reported that they had access to proper health care at work, while 75% reported to have access to proper health care close to their dwellings.

Comparisons between permanent and contract workers, and between participants from mines of different commodities, were also made. Contract workers were more likely to stay in informal dwellings, have less access to services, and report lower quality of life than the permanent employees. Those working at the platinum mines were most likely to stay in informal housing and reported lowest satisfaction with living conditions, compared to the other mines.

4. Discussion

Living conditions in the mining areas of South Africa are shaped by government and mine policies and regulations, as well as personal choices. This is evidenced by changes in living conditions in the SAMI that have occurred since the early 2000s.

Legislation aimed at reducing occupancy rates in hostels and the provision of LOAs has resulted in fewer mine workers residing in mine hostels and more workers residing in informal settlements surrounding the mines. The reduction of hostel occupancy rates is important to safeguard worker privacy and freedom, but has resulted in fewer being able to stay in hostel accommodation. Additionally, an unintended result is that many workers opt to live in sub-standard conditions in order to save money received from the LOA. As workers move away from hostels, reduced access to services and amenities, travelling distances, transport challenges, and crime are factors that can affect health, safety, and wellbeing.

A lack of decent and affordable housing, particularly family housing, for mine workers to rent or buy was a challenge in this study. A number of mine workers expressed the wish to own houses in mining areas. Home ownership schemes proposed by mines are a means to assist with this. However, the uptake of these appeared to be low; many of these plans were still in the development phase, and affordability and the location of the houses were problems noted by the study participants. Migrant workers were also less likely to want to own houses close to the mine. The migrant workforce in the SAMI is steadily decreasing, but still plays a significant role in the mining industry. It is evident that some workers who live away from their families while working at the mines and who opt to live outside of hostel accommodation may set up second families in mining areas, which can increase financial and social strains.

Important differences in living conditions between mines and between worker groups were also observed. A variation in living conditions between different mine types was evident, such as the higher percentage living in hostel accommodation in the gold mines, in informal dwellings in the platinum mines, and in formal dwellings further away from the mines in the coal, diamond, and manganese sectors. While differences were noted across commodities, some of these findings could also result from attributes of the specific mines sampled. Differences in the location of the mines in relation to urban centres, municipal or tribal authorities, and differences in socioeconomic status and income of the workers at mines of different commodities are also likely contributors. In terms of worker status, contract workers were more likely to live in informal settlements and have less access to services than permanent employees. Contract workers can experience greater challenges as a result of receiving fewer benefits, such as housing and transport, and generally lower pay than permanent employees.

Successful collaboration between relevant stakeholders, including companies, the government, and the local community, is important for implementation of development goals. The mining sector in South Africa is currently dealing with sustainability-related concerns, including financial pressures, retrenchments, and labour unrest, and mines increasingly need to balance the needs of the workers with production pressures. Workforce needs include housing and service delivery. Mines have a responsibility in terms of Social and Labour Plans to uplift mining communities; however, the involvement of municipalities is vital for successful community development. The government should also play a role in these interventions and in the development of a holistic strategy for mining towns (SACN, 2017). In addressing sustainability in mining, Littlewood (2014) noted that multi-stakeholder partnership is vital and that planning and decision-making should be transparent and participatory.

Further research would assist in developing solutions to address challenges facing the SAMI. The future of mining needs to be considered, and the effects that these changes could make should be evaluated. Additionally, a comparison of living conditions between the local and global mining industry could help to provide direction to housing strategies in the SAMI. Meanwhile, continued monitoring and evaluation in the current context remains necessary. The broader study from which this paper was based examined effects of the living conditions on mine worker health and safety. Further publication of these findings is warranted.

5. Conclusion

While there have been improvements to the living conditions of mine workers in the SAMI, various challenges still remain, and some new ones have developed as a consequence of policy changes. Some of the changes made include the upgrading or conversion of hostels into single accommodation or family units, to provide more privacy and dignity to the mine workers. The preference for single-sex hostel accommodation has been abandoned, and more mine workers are making use of LOAs. Mine workers are seen to reside in various types of dwellings in addition to hostels, such as formal brick houses, flats or townhouses, backyard flats or houses and shacks, in towns, townships, informal settlements, or rural areas. Many mines have implemented facilitated home ownership schemes in order to assist mine workers to own their own homes, and this is seen as a way to improve the quality of life of mine workers in the SAMI. Problems relating to the living conditions of mine workers included not living with families, affordability, distance away from the mines, transport issues, noise, and violence or crime. A lack of services such as water, electricity, and sanitation was also an issue at many of the mines. Access to adequate health care was also sometimes a challenge, especially for contract workers and the family members of mine workers.

Industry initiatives have highlighted the importance of partnerships, such as with government, in improving the living conditions in the SAMI. It is anticipated that compliance with these initiatives and continued commitment to the improvement of the living conditions and education and awareness of mine workers will contribute to improved health, safety, productivity, and wellness, and reduced instability in the SAMI.

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No potential conflict of interest was reported by the authors.

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Appendix B: Paper 2

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Socio-demographic contributors to health and safety of mine workers in South Africa

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Abstract.
BACKGROUND: Mine workers in South Africa face various health and safety risks, and socioeconomic challenges.
OBJECTIVE: This study aimed to assess the associations between socio-demographic factors and health, safety and wellness in the South African mining industry.
METHODS: Qualitative and quantitative data were collected from 64 interviews with mine management and labour representatives, 14 focus groups with mine workers, and 875 questionnaires completed by mine workers from three platinum, two gold, one coal, one diamond, and one manganese mine in South Africa.
RESULTS: Health challenges included non-communicable diseases, HIV/AIDS, tuberculosis (TB), and respiratory diseases, while safety challenges included worker behaviour, stress and fatigue. Socio-demographic factors associated with disease, sick leave, fatigue, accidents and job satisfaction included age, length of service, race, nationality, education, mining sector, work status, income, housing, domestic crowding, sleep, exercise, alcohol use, and perceived quality of life.
CONCLUSION: Socio-demographic factors should be taken into consideration when developing workplace health and safety programmes.

Keywords: Disease, sick leave, fatigue, work accidents, job satisfaction

1. Introduction

Occupational health and safety risks are prevalent in the mining industry [1–3]. Mine hazards can result in injuries and fatalities, cumulative trauma disorders, noise-induced hearing loss, and heat stroke or exhaustion [1–6]. Pulmonary diseases, including silicosis and lung cancer, can result from exposure to dust and hazardous chemicals, while fatigue and shift work are accident risks [1, 5, 7]. Psychosocial job demands, poor work environments, job dissatisfaction, job stress, and older age have also been associated with occupational injuries [4, 6]. Psychosocial risks associated with mining include drug and alcohol abuse, stress from being separated from families in the case of migrant workers, working conditions, a lack of control over the work that is performed, high workloads, the work schedule, stress resulting from incidents and accidents, and socioeconomic consequences of occupational injuries [4, 5, 8–11]. Reduced health, safety and job satisfaction of workers has negative impacts for the industry and the communities surrounding mines, as a result of direct and indirect costs, including absenteeism and a loss of productivity [7, 11].

The South African mining industry historically relied on a male-dominated migrant workforce that was housed in substandard conditions in mining compounds (‘hostels’), which had negative effects on health, productivity and social well-being [12–14].

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The preference for mining compounds was formally abandoned in 1986, and strategies to improve the housing and living conditions of mine workers have since been implemented [12, 14–18]. Furthermore, a baseline of 10% participation of women in the workforce is now required [16, 17].

Nevertheless, most South African mining towns have poor social and economic conditions, including poverty, unemployment, bad housing and infrastructure, prostitution, and a high number of single migrant labourers [19–21]. Migrancy is linked to tuberculosis (TB) risk factors, including HIV/AIDS, healthcare service disruptions and low socioeconomic status [22]. Mine workers have been estimated to be three to four times more likely to be infected with HIV than non-mine workers [22]. Additionally, silicosis and HIV/AIDS have been found to pose an interactive risk for developing TB, and mine workers in sub-Saharan Africa have been reported to have a higher incidence of TB than any other working population in the world [7, 22, 23]. Lim et al. (2011) found that the presence of HIV was also associated with an increased risk of work-related injury in gold miners [24]. South Africa, as a whole, is faced with a quadruple burden of disease, namely, the epidemics of poverty-related illnesses, non-communicable diseases, HIV/AIDS, and violence and injuries [25].

Indicators of socioeconomic status include income, occupation, education, household conditions and race [26–30]. Low socioeconomic status is associated with poorer education, poorer health, higher psychological distress, and reduced quality of life, along with higher rates of cigarette smoking and heavy drinking, a higher likelihood of being sedentary, domestic crowding, and violence [26, 31]. d'Errico et al. (2007) reported that the occurrence of injury at work was higher in those with lower education and those in lower occupational classes [27]. This might be because those working in higher socioeconomic strata are generally employed in less hazardous jobs, while lower education could act as an independent risk factor, through lower risk perception, or because of less access to information [27]. Socioeconomic conditions and lifestyle factors, including employment status, education, economic hardship, and physical inactivity, are further associated with self-rated health, which is an established predictor of morbidity and mortality [32].

It is evident that socioeconomic conditions are associated with health, safety and wellbeing. As a result of related changes and challenges within the South African mining industry, further study was warranted to identify where intervention efforts can be better focused. The aim of this study was to examine associations between socio-demographic factors and the health, safety and wellbeing of mine workers in South Africa.

2. Methods

This was a cross-sectional mixed methods study, as both qualitative and quantitative data were gathered. Methodological triangulation was used to analyse the results.

Data were gathered at three platinum, two gold, one coal, one diamond, and one manganese mine. In total, more than 50 000 people were directly employed by these participating mines. The eight mines were located in six of the nine provinces of South Africa, and were purposively selected to best represent the South African mining industry. There were approximately 1 700 operating mines and quarries in South Africa, and the industry directly employed around 496 000 people in 2014, with the highest numbers employed in the platinum and gold sectors [33, 34]. Participants from each mine included management, labour representatives, and mine workers. Individuals in mine management and the labour representatives were purposively selected based on their positions. Those in management included the mine, human resource, industrial relations, occupational health and wellness, safety, residence, and transformation managers, or those in equivalent or representative positions. For the purposes of this study, the term 'mine worker' refers to labourers rather than individuals in management or in office-based positions at the mines. The mine workers were selected using convenience sampling, and were recruited from places such as training centres or work groups at the start of shifts, so that production would not be disturbed by removing individuals from workplaces. Workers from a range of job categories, including production workers and artisans, were selected, to enhance the representivity of the study participants.

Interview and focus group guides, and questionnaires, were developed for the study. The guides included open-ended questions to establish what the participants considered to be the main health and safety challenges at the mines, along with the potential contributors. The questionnaires included forced-choice questions regarding socio-demographics, health and safety. Socio-demographic variables (16-items) related to worker demographics, work factors, socio-economic and living conditions, lifestyle and quality of life. Health and safety were inferred from the presence of a disease, sick leave taken in the previous year, fatigue at work, involvement in an accident at work in the previous year, and job satisfaction. Job satisfaction has previously been associated with both health and safety outcomes [6, 35].

Data collection took place from June to November 2014. The interviews and focus group discussions were conducted in languages understood by the participants. A total of 53 interviews with mine management, 11 interviews with labour representatives, and 14 focus group discussions with mine workers were held, with a total of 205 participants. Voice recordings of the interviews and focus group discussions were made. Questionnaires were completed by 875 mine workers. Research assistants were available to assist the mine workers to complete the questionnaires and to translate questions, where required, to eliminate literacy or language barriers.

The interviews and focus group discussions were translated, where necessary, and transcribed. Thematic analysis was used to identify the main topics from the discussions. Questionnaire responses were captured electronically. Descriptive and inferential statistics were performed. Chi-squared analyses were performed to assess associations between socio-demographic and health, safety and wellness data ($p < 0.05$). Data were grouped or omitted, where necessary, to allow for appropriate statistical analyses. Comparisons were made between the qualitative and the quantitative data.

Ethical approval to conduct this study was obtained from the CSIR Research Ethics Committee (reference number 85/2013) and from the University of the Witwatersrand Human Research Ethics Committee (clearance certificate number M140222). Permission to conduct the study was granted by each of the participating mines. Voluntary informed consent was received from each of the study participants. All of the data collected in this study remain confidential.

3. Results

3.1. Perceptions of health and safety

Various health and safety challenges were reported in the interviews and focus group discussions. Those in mine management and the labour representatives generally considered HIV/AIDS and TB to be the main health challenges that were faced by the mine workers. The migrant labour system was seen to contribute to this, as some workers had partners both at the mine and in the areas from where they originated. Prostitution was also noted as a contributing factor. A manager stated: "*HIV/AIDS and TB are the main challenges*" while one of the workers admitted: "*... since we are staying here without our wives, there are challenges there as we have needs. We end up getting infected with diseases*".

Respiratory diseases, such as asthma and chronic obstructive respiratory disease, were mentioned by all participant groups, and were the main concerns amongst the participating mine workers. Silicosis was, to a lesser extent, also identified as a problem. These respiratory diseases were considered to result primarily from dust from the mines. A labour representative said: "*Underground there is the dust, and it's making people sick*" while one of the workers commented that "*Dust and smoke from the machines is killing us*". Smoke from coal or wood fires that some cooked on, and dust from the roads, were also perceived to contribute to these conditions. A participant added: "*There is also dust in the township, as there are not tarred roads; this leads to coughs. People also don't have enough money for electricity and therefore use coal; this smoke also leads to coughing*". Other occupational diseases, including noise-induced hearing loss, were also mentioned. The mine workers said that working conditions, such as exposure to chemicals, heat, and poor hygiene, were additional problems.

Chronic or non-communicable diseases, such as high blood pressure and diabetes, were reported to be prevalent. The participants related these diseases to lifestyle, such as poor nutrition, and a potential lack of recreational exercise, particularly in the more mechanised mines. For example, one manager said: "*Lifestyle diseases are a big problem ... People don't exercise and activity levels are relatively low*". A lack of nutrition or balanced diets, and alcohol and drug abuse, were further challenges. More common diseases like influenza and pneumonia, and headaches and stomach cramps, were also mentioned. Participants commented: "*In the informal settlements there is poorer food and nutrition, and this leads to illness such as flu and stomach cramps, which in turn affects performance at work*", "*If you get little money you can't afford to buy healthy food. Then you become unhealthy. We are dependent on loans*", and "*If people don't have enough money and there* *is not enough recreation available then this leads to high levels of drinking over weekends*". The participants also associated poor living conditions, such as a lack of access to water, electricity, decent sanitation, or refuse removal, and cramped living conditions, with the spread of illness. Participants mentioned: "*Hygiene issues at the community are also a concern. You'll find that 30 people are renting rooms in one block. Of those 30 rooms you'll find that there are only two pit toilets*", and "*In the villages there are pit latrines and these could leak into the water systems. For refuse removal, people are burning their rubbish, which can be poisonous.*" Aspects such as fatigue and stress were also perceived to contribute to poor health. Poor health, in turn, was perceived to lead to absenteeism and poor performance at work.

Safety was a reported priority at the mines. However, the work environments were hazardous, and incidents and injuries occurred, such as those related to fall of ground, mobile machinery, manual materials handling, and slips, trips and falls. Worker behaviour and non-compliance with rules were the main safety challenges that were reported. Workers often took shortcuts to get their work completed quickly. A manager said: "*We've got procedures in place, but my main worry is people taking chances, people not complying with procedures, and they end up getting injured*". A culture of non-compliance with rules outside of the workplace was seen to contribute to these problems at work. It was noted that workers faced a high level of risk outside of the workplace and, as a result, became tolerant of risks within the workplace. A participant commented: "*As South Africans we have a high tolerance to risk… For example, on the streets people don't stop at stop streets and (they) speed… (People drive on) non-roadworthy taxis… People grow up in such an environment of non-compliance, and then we expect people to have a different approach to work and have a different mind-set to safety*".

Additionally, workers were seen to take shortcuts when there was a lack of materials with which to work or when under pressure to meet their production targets. Related comments by participants included: "*When we don't have enough equipment we take shortcuts and we end up getting injured*", "*Workers start taking shortcuts when working under pressure*", "*Even us, we do take shortcuts sometimes. You see every day before we work, we talk about safety, but when you work it's a different story*", and "*Safety is preached but not practiced in the work environment. Everything is about production*". The bonus system was a potential problem, and some felt that production was incentivised over safety.

Insufficient supply of personal protective equipment (PPE) was also a potential cause for accidents. A worker commented: "*A lack of PPE is a problem. We only get one overall. So if I want more they have to deduct (the cost) from my salary*". Workers sometimes felt unable to practice safety laws or to refuse to work in unsafe conditions, for fear of being penalised for poor work performance or because of pressure from their superiors, including management, shift bosses and supervisors. A worker commented: "*Sometimes even if the conditions are not good, people are just told to go in and work because they are scared of shift bosses, so they just work in unsafe areas*". A culture of blame was a related problem. Other safety challenges that were noted included a lack of education and understanding.

Fatigue and stress were further safety risks. Fatigue was attributed to various factors, such as the physically demanding work performed, harsh work conditions, long work hours, shift configurations, long travelling distances to work, poor health, use of medication, poor diets, alcohol use, insufficient sleep, potentially poor conditions in which to sleep, and psychological problems. Participants commented: "*Fatigue is a challenge, as a result of the travelling distances to the mine, along with shift configurations*", and "*Even the areas that you live counts. Because you find that if there is too much noise you can't rest well*". Stress was seen to lead to a lack of focus and concentration at work. Stress was associated primarily with financial problems. Examples of participant comments were: "*People are suffering from emotional strain and bring their problems to work*", "*Stress results from the conditions of the work, and finances*", and "*Immediately when you are stressed and lose concentration you end up making mistakes*".

3.2. Mine workers' data

Characteristics of the mine workers who completed the questionnaire are shown in Table 1. Two thirds of the participants (67%) were recruited from gold and platinum mines. Most were male (89%); this reflected the proportion of males to females in the industry at the time. The majority were aged 30 to 39 years (44%), and were black (92%). Most were South African (86%), while the remainder came from neighbouring countries. More than half (59%) had an educational qualification of Grade 12 (completed

Table 1
Participant characteristics ($N = 875$)

Variable	Category	Number of participants	Percentage of participants
Sex	Male	746	89
	Female	96	11
Age (years)	<30	218	25
	30–39	370	44
	40–49	174	21
	≥50	88	10
Race	Black	793	92
	Other	68	8
Nationality	South African	749	86
	Other	118	14
Education	≤Grade 7	143	17
	Grade 8–11	199	24
	Grade 12	334	40
	>Grade 12	158	19
Commodity of mine	Gold	261	30
	Platinum	325	37
	Coal	91	10
	Diamond	110	13
	Manganese	88	10
Work status	Permanent	705	82
	Contract	154	18
Length of service (years)	<1	100	12
	1–4	323	37
	5–9	232	27
	≥10	207	24
Average monthly income	≤R5000	247	29
	R5001–R7500	256	30
	R7501–R10000	139	16
	>R10000	212	25
House type	Formal brick dwelling	317	39
	Flat/townhouse/cottage	100	12
	Hostel	126	15
	Shack/Informal housing	116	14
	Backroom	161	20
Sharing of room (number of people)	0 (no one else)	307	36
	1	278	32
	2	127	15
	≥3	144	17
Sleep received	<6 hours	449	52
	≥6 hours	409	48
Exercise	Never	393	46
	Once a week or less	237	28
	More than once a week	229	27
Smoke cigarettes	Yes	201	24
	No	622	76
Alcohol use	Never	397	48
	Once a month or less	205	25
	Once a week or less	146	17
	More than once a week	87	10
Quality of life	Good	432	51
	Not good	421	49
Disease	None	607	71
	One or more	247	29
Sick leave (previous year)	<5 days	622	73
	≥5 days	228	27
Fatigue	Not fatigued	702	84
	Fatigued	138	16
Accident at work (previous year)	No	773	92
	Yes	67	8
Job satisfaction	Satisfied	472	55
	Not satisfied	386	45

secondary education) or higher. The majority (82%) were permanent employees. Around half (49%) had been working at the respective mines for less than five years. Only a quarter (25%) usually earned a net monthly income of more than R10 000. Participants resided in a range of dwellings, including formal brick houses, flats or townhouses, mine hostels, informal housing and backrooms. Over a third (36%) did not share a room with anyone, 31% shared with one other person, and 32% shared with two or more others. Around half (52%) usually received less than six hours of sleep in the 24 hours before a work shift. A quarter (24%) smoked, 27% drank alcohol more frequently than once a month, and 46% never exercised physically in their leisure time. Around half (51%) rated their quality of life as “good”.

In terms of health, safety and wellness, 29% of the participants reported having at least one disease or disorder. High blood pressure was the most commonly reported condition, while hearing loss, high cholesterol, diabetes, tuberculosis, and silicosis were also listed. Over a quarter (27%) had taken five or more days of sick leave in the previous 12 months. Fatigue was indicated by 16%, who usually felt “very sleepy” when at work; and 8% of the participants had been involved in an accident at work in the previous 12 months. Over half (55%) were satisfied with their jobs.

Associations between the socio-demographic and the health, safety and wellness variables are shown in Table 2. No significant differences were evident in terms of sex. According to age, it was evident that the older workers tended to have more diseases, but higher levels of job satisfaction than the younger workers. The black participants reported a lower rate of disease, but a higher prevalence of fatigue, and lower job satisfaction than the participants of other races. The South African participants reported a lower rate of disease and relatively fewer accidents than the foreign migrant workers. Those with lower levels of education had a higher prevalence of disease and accidents, but higher levels of job satisfaction than those with higher qualifications.

According to work sector, the highest prevalence of disease was in the gold and manganese mines, the highest rate of accidents at work was in the gold and platinum mines, while the highest rating of job satisfaction was in the coal sector. Permanent employees reported a higher rate of disease, sick leave, and fatigue than the contract workers. Increased length of service was associated with a higher prevalence of disease; those who had been working for less than a year had the lowest rate of sick leave; and job satisfaction was lowest for those who had been working for one to 10 years.

Lower incomes were associated with increased fatigue and more accidents at work. The lowest rates of disease and fatigue were reported by those living in formal brick houses, the highest accident rates were reported by hostel-dwellers, and the lowest job satisfaction was reported by those living in informal dwellings and backrooms. Higher room occupancy rates were associated with increased prevalence of accidents at work. Those who usually received less sleep were more likely to be fatigued and to have lower levels of job satisfaction than those who received more sleep. Those who did not exercise had a higher prevalence of disease, fatigue and accidents than those who did recreational exercise. Drinking alcohol more frequently than once a week was associated with a higher prevalence of disease. Those reporting better quality of life had lower levels of sick leave, fatigue and accidents, and higher job satisfaction.

4. Discussion

Socio-demographic characteristics were associated with the prevalence of disease, sick leave, fatigue, accidents and job satisfaction of mine workers at eight mines in South Africa. Health challenges faced by the mine workers included non-communicable illnesses, HIV/AIDS, TB, and respiratory diseases. Safety challenges that were highlighted included behavioural aspects such as non-compliance with rules and taking of shortcuts, production pressure, fatigue, and stress. These findings reflect what has previously been reported in the literature [4, 5, 22]. Additionally, poor health could result in increased fatigue, accidents, absenteeism and reduced job satisfaction; increased fatigue and accidents could lead to detriments in health and job satisfaction, and increased absenteeism; and reduced job satisfaction could result in increased accident risk, fatigue and absenteeism.

Age and length of service were related in terms of the associations with health and safety data. Data from the questionnaires suggested that health was better in younger individuals, and it was expected that those who were older would have a higher incidence of disease [35, 36]. In this case, the “healthy worker effect”, which refers to healthier workers remaining in work longer, did not appear to apply. Length of

Table 2
Associations of socio-demographic characteristics with health, safety and wellness variables* ($N = 875$)

Variable	Category	Disease (%)		Sick leave (%)		Fatigue (%)		Accident at work (%)		Job satisfaction (%)	
		No	Yes	<5 days	≥5 days	No	Yes	No	Yes	Satisfied	Not satisfied
Sex	Male	71	29	73	27	83	17	92	8	54	46
	Female	77	23	72	28	86	14	95	4	60	40
Age (years)	<30	*85*	*15*	73	27	84	16	95	5	*56*	*44*
	30–39	*75*	*25*	70	30	82	18	93	8	*50*	*50*
	40–49	*56*	*44*	76	24	84	16	90	10	*57*	*43*
	≥50	*52*	*48*	80	20	87	13	91	9	*72*	*28*
Race	Black	*73*	*27*	73	27	*82*	*18*	92	8	*53*	*47*
	Other	*55*	*45*	75	25	*96*	*4*	97	3	*69*	*31*
Nationality	South African	*73*	*27*	73	27	84	16	*93*	*7*	54	46
	Other	*61*	*39*	77	23	80	20	*84*	*16*	63	37
Education	≤Grade 7	*54*	*46*	72	28	85	15	*87*	*13*	*71*	*29*
	Grade 8–11	*68*	*32*	72	28	81	19	*90*	*10*	*55*	*45*
	Grade 12	*78*	*22*	74	26	83	17	*95*	*5*	*49*	*51*
	>Grade 12	*77*	*23*	72	28	86	14	*95*	*5*	*51*	*49*
Commodity of mine	Gold	*57*	*43*	68	32	79	21	*88*	*12*	*60*	*40*
	Platinum	*79*	*21*	75	25	82	18	*92*	*8*	*48*	*52*
	Coal	*74*	*26*	80	20	94	6	*97*	*3*	*68*	*32*
	Diamond	*81*	*19*	78	22	88	12	*96*	*4*	*58*	*42*
	Manganese	*64*	*36*	69	31	83	17	*96*	*4*	*50*	*50*
Work status	Permanent	*67*	*33*	*70*	*30*	*83*	*17*	91	9	56	44
	Contract	*88*	*12*	*86*	*14*	*86*	*14*	95	5	50	50
Length of service (years)	<1	*85*	*15*	*88*	*12*	86	14	97	3	*61*	*39*
	1–4	*79*	*21*	*71*	*29*	86	14	93	7	*49*	*51*
	5–9	*74*	*26*	*68*	*32*	78	22	91	9	*53*	*47*
	≥10	*49*	*51*	*75*	*25*	86	14	90	10	*63*	*37*
Average monthly income	≤R5000	76	24	75	25	*76*	*24*	*92*	*8*	53	47
	R5001-R7500	68	32	69	31	*83*	*17*	*89*	*11*	53	47
	R7501-R10000	71	29	70	30	*88*	*12*	*92*	*8*	57	43
	>R10000	69	31	78	22	*90*	*10*	*96*	*4*	59	41
House type	Formal brick dwelling	*76*	*24*	75	25	*90*	*10*	*94*	*6*	*58*	*42*
	Flat/townhouse/cottage	*61*	*39*	71	29	*82*	*18*	*90*	*10*	*56*	*44*
	Hostel	*65*	*35*	72	28	*76*	*24*	*82*	*18*	*62*	*38*
	Shack/Informal housing	*71*	*29*	76	24	*80*	*20*	*91*	*9*	*44*	*56*
	Backroom	*72*	*28*	70	30	*82*	*18*	*95*	*5*	*50*	*50*
Sharing of room (number of people)	0 (no one else)	76	24	77	23	84	16	*92*	*8*	53	47
	1	69	31	75	25	87	13	*96*	*4*	59	41
	2	65	35	66	34	79	21	*88*	*12*	54	46
	≥3	71	29	68	32	80	20	*87*	*13*	50	50
Sleep received	<6 hours	69	31	72	28	*77*	*23*	91	9	*50*	*50*
	≥6 hours	71	27	74	26	*91*	*9*	93	7	*60*	*40*
Exercise	Never	*67*	*33*	71	29	*79*	*21*	*89*	*11*	54	46
	Once a week or less	*74*	*26*	76	24	*89*	*11*	*96*	*4*	52	48
	More than once a week	*76*	*24*	75	25	*86*	*14*	*95*	*5*	60	40
Smoke cigarettes	Yes	76	24	72	28	88	12	93	7	58	42
	No	70	30	74	26	82	17	92	8	54	46
Alcohol use	Never	*69*	*31*	76	24	83	17	90	10	58	42
	Once a month or less	*79*	*21*	73	27	87	13	93	7	53	47
	Once a week or less	*73*	*27*	68	32	85	15	94	6	50	50
	More than once a week	*62*	*38*	71	29	75	25	95	5	50	50
Quality of life	Good	73	27	*78*	*22*	*92*	*8*	*96*	*4*	*72*	*27*
	Not good	69	31	*68*	*32*	*76*	*24*	*88*	*8*	*39*	*63*

*Values in italics indicate statistical significance ($p < 0.05$).

service was associated with increased risk of disease, which was likely related to the age of the participants; increased length of service could also be associated with increased cumulative exposure to occupational hazards. Meanwhile, job satisfaction was highest in the oldest group of participants, and in those with more than 10 years of service. It is possible that those with high levels of job satisfaction are likely to stay in their jobs for longer periods. It is also possible that longer length of service can contribute to increased job satisfaction as a result of potential benefits, such as improved pay or promotion, and familiarly or experience that can enable jobs demands to be fulfilled more efficiently. Lowest rates of sick leave were found for those working for less than a year, which was attributed to the shorter reporting period.

Race and migrancy were associated with health, safety and wellbeing. Higher rates of fatigue and job dissatisfaction were reported by the black participants. Historical factors have often resulted in blacks having poorer socioeconomic status and health than other racial groups, and the findings could also reflect a higher prevalence of black workers in more physically demanding jobs [30, 37]. The finding that black mine workers had a lower incidence of disease was unexpected. South Africans reported better health and a lower rate of accidents than foreign workers, which could be a result of better access to healthcare and better social and living conditions than those from neighbouring countries. Reported risks facing migrant workers included HIV/AIDs, TB, healthcare service disruptions, and stress from living apart from families [22].

Those with higher levels of education had better health and a lower rate of accidents. Molarius et al. (2006) found that low educational level was associated with poor self-rated health in males, but not in females, while Beemsterboer et al. (2009) reported higher sick leave frequency and duration in those with lower education [32, 35]. Those with higher levels of education may better understand and mitigate health and safety risks, and potentially have less hazardous working conditions and better income than those with lower levels of education [27, 28]. Meanwhile, those with the lowest level of education had the highest levels of job satisfaction. Those with higher levels of education might have felt that the menial work tasks and status were not suited to their qualifications.

Work-related factors were also associated with the health and safety variables. Poorer health was recorded by those in the gold and manganese mines, which could reflect tasks and environments in and surrounding these mines [28]. Williams et al. (2010) noted that specific work conditions are likely to have an effect on health due to differences in exposure to occupational hazards [30]. Participants from the coal, diamond and manganese sectors had lower rates of accidents, probably because these mines are generally less labour-intensive and more mechanised than gold and platinum mines. Furthermore, salaries in the gold and platinum mines were generally lower than the other sectors that were included in the study. Those in the coal mine had the highest job satisfaction levels, which could reflect the nature of the work and socioeconomic conditions. Work status was associated with self-rated health in a study by Molarius et al. (2006) [32]. However, it was unexpected that permanent employees would report a higher prevalence of disease, sick leave, and fatigue than contract workers, as contract work in the industry is often associated with poorer work and economic conditions.

Income and housing were associated with both fatigue and accidents at work, and house type was further associated with the prevalence of disease and job satisfaction. Lower incomes could be associated with poorer safety outcomes because financial constraints lead to higher levels of stress which, in turn, lead to a lack of focus at work, and impaired sleep between shifts. Higher incomes could also be used to obtain better nutrition, living conditions, and access to health services [28]. Additionally, it is likely that those with lower incomes were employed in more labour-intensive and hazardous jobs than higher income earners [27]. Poorer living conditions are associated with poorer health and fatigue, for reasons including a lack of access to amenities and services [28, 38]. The lower prevalence of disease and fatigue reported by those living in formal brick houses could reflect the better conditions in these dwellings. Reduced job satisfaction was found for those in informal accommodation, and could be associated with poor socioeconomic status, not having housing provided by the employer, poorer living conditions and amenities, and increased stress. Social stressors of living away from families in hostel accommodation also possibly contribute to a lack of focus and accidents at work. Sharing a room with a number of individuals was also associated with increased accidents at work. This finding could potentially be a result of the mind-set of workers, as those with higher domestic crowding could experience higher strain. Galobardes et al. (2006) noted that overcrowded households are often those with few economic resources, and overcrowding may also have a direct effect on health through the spread of infectious diseases [28].

Lifestyle factors and quality of life were associated with health, safety and wellbeing. A lack of exercise was associated with an increased prevalence of disease and a higher fatigue and accident risk. Conversely, poor health, fatigue, and having been involved in a work accident could also contribute to less exercise being performed. Molarius et al. (2006) reported that a lack of exercise is associated with obesity and chronic disease, and d'Errico et al. (2007) recorded exercise level as a risk factor for injury at work [27, 32]. Increased prevalence of disease was also found in those who frequently drank alcohol. A positive association between sick leave taken and alcohol consumption has been previously found [35]. Insufficient sleep (e.g. less than six hours before a work shift) was a significant contributor to fatigue, as expected, and was associated with reduced job satisfaction. Halvani et al. (2009) similarly noted that fatigue was a cause of job dissatisfaction [39]. Poorer reported quality of life was associated with higher levels of sick leave, fatigue, accidents and job satisfaction, as expected, and could be causal or consequential.

4.1. Limitations

This study relied on the use of self-report data. Thus, factors such as mood, attitudes, and personality could affect subjective responses, such as fatigue, quality of life, and job satisfaction. It is also possible that variables that were not recorded in the questionnaire could affect health, safety and job satisfaction. As this was not a longitudinal study, cause and effect between the independent and dependant variables were not assessed, but could only be assumed.

A further limitation is that the study sample does not fully represent the South African mining industry. Data were collected at only eight of the many mines in the country, and from a small proportion of participants compared to those directly employed in the industry. Furthermore, the use of convenience sampling as a method of selecting study participants was a limitation, as the participants may not represent workers at the study sites. However, random sampling was not feasible for this study, and the results might be biased, for example in terms of health and safety outcomes. Additionally, the study was conducted in 2014. Data were not published sooner because of one of the funders' concerns about the sensitivity of the findings. As such, numerous interventions in the industry over the past few years are not reflected in this paper. However, the long term health and safety outcomes resulting from changes in the industry may, in any case, take a number of years to manifest. Despite these limitations, the findings from this study provide valuable insight into a number of factors currently affecting the mining industry in the country.

5. Conclusion

Socio-demographic factors were associated with health, safety, and job satisfaction in mine workers in South Africa in this study. These socio-demographic factors included age, length of service, race, nationality, education, mining sector, work status, income, housing, sleep received, exercise, alcohol use, and quality of life.

Recommendations to improve health and safety in the South African mining industry can be guided by outcomes of this study. For example, improved education and awareness, improved working conditions, and continued improvements to housing available for workers could lead to improved health, safety and job satisfaction. Socio-demographic factors should be considered in workplace health and safety programmes. Furthermore, interventions already implemented in the industry, including those to improve the living conditions of mine workers, to increase local employment, and educational programmes, are expected to yield positive results. Improved health, safety and wellbeing in the South African mining industry will contribute to its sustainability.

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Conflict of interest

None to report.

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Appendix C: Paper 3

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Contributors to fatigue at a platinum smelter in South Africa

by J. Pelders[1,2] and G. Nelson[2]

Synopsis

Fatigue is a significant concern in the mining industry as it is a causal or contributing factor in many incidents and accidents. Fatigue can be caused by work- and non-work-related factors. There is a lack of information about associations between demographic and other non-work factors, and fatigue. This study aimed to assess associations between demographic, work, living, and socioeconomic conditions, and lifestyle characteristics, and fatigue at a platinum smelter in South Africa. Eight interviews with management and two focus groups with production workers were conducted, and 75 questionnaires were completed by production and other workers. Both work- and non-work-related factors were considered to be causes of fatigue. These factors included overtime, shift work, high workloads, activities performed outside of work, age, race, housing tenure, diet, sleep disorders, stress, and job satisfaction. In general, higher levels of fatigue were reported by younger participants, those who rented accommodation, ate less healthily, had a sleep disorder, and those with high levels of stress and low job satisfaction. As various demographic, lifestyle, and wellness-related factors were associated with fatigue, both work and non-work contributors should be addressed in fatigue management plans.

Keywords

Sleepiness, living conditions, lifestyle, fatigue management, mining industry.

Background

Fatigue may be defined as 'a state of impaired mental and/or physical performance and lowered alertness arising as a result of, or a combination of, hard physical and mental work, health and psychosocial factors or inadequate restorative sleep' (BHP Billiton, 2005). Williamson *et al.* (2011) define fatigue as a biological drive for recuperative rest. Sleepiness and fatigue are related, and the terms are often used interchangeably. However, sleepiness, more specifically, can be defined as sleep propensity, or a person's tendency to fall asleep (Hossain *et al.*, 2003; Shen, Barbera, and Shapiro, 2006).

Increasing levels of fatigue and sleepiness are associated with lapses in attention, errors, response slowing, fluctuations in alertness and effort, and impaired attention, working memory, long-term memory, decision-making, and creativity (Alhola and Polo-Kantola, 2007; van Dongen and Dinges, 2000). Fatigue is also associated with adverse effects on mood and impulsive behaviours (Alhola and Polo-Kantola, 2007; Minkel *et al.*, 2011; Schwarz *et al.*, 2013). It is a significant concern in the mining industry as it is commonly identified as a causal or contributing factor in many accidents and injuries (Schutte, 2009). Fatigue can also lead to long-term health problems, including digestive problems, heart disease, stress, and mental illness (Shaw, 2003).

Fatigue can be caused by both work-related and non-work-related factors. Work-related causes include work schedules and design, task requirements at work, and the work environment conditions. Work scheduling factors include the number and pattern of hours worked, time of day, shift work, and night work (Di Milia *et al.*, 2011; NSW, 2009; Schutte and Maldonado, 2003; Shaw, 2003). Task requirements associated with fatigue include high mental and physical demands, especially monotonous tasks or tasks requiring sustained attention (Åkerstedt *et al.*, 2014; Jing-Gang and Lei, 2013; NSW, 2009; Schutte and Maldonado, 2003; Shaw, 2003; Williamson *et al.*, 2011). Work environment factors include noise, temperature extremes, or the psychosocial environment (Jing-Gang and Lei, 2013; NSW, 2009; Shaw, 2003).

Individual and non-work contributors to fatigue include aspects such as sleep, health, fitness for work, lifestyle factors, and commuting time (Åkerstedt *et al.*, 2014; Di Milia *et al.*, 2011; Horrey *et al.*, 2011; NSW, 2009). Age, diet, drug and alcohol use, medical conditions, quality and quantity of rest before a work period, circadian rhythm ('body clock'), sleep disorders, strenuous activities outside of work (*e.g.* a second job), family commitments, and psychological issues such

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as stress also play a role in the levels of fatigue experienced (Åkerstedt *et al.*, 2014; Molarius *et al.*, 2006; ORR, 2012; Schutte and Maldonado, 2003; Shaw, 2003). In addition, living conditions are likely to influence the levels of fatigue experienced by mineworkers due to poor conditions in which to sleep, long commuting times between work and home, and poor health arising from a lack of access to services and amenities (Åkerstedt *et al.*, 2014; Galobardes *et al.*, 2006).

Horrey *et al.* (2011) reported that many demographic, personality, and workplace factors can impact the levels of fatigue experienced and their consequences. De Milia *et al.* (2011) noted that the interaction between demographic factors and fatigue is a neglected area of research and that, apart from age and sex, the influence of many demographic factors is largely unknown. There is a lack of information about associations between demographics, living conditions, and various other non-work factors and fatigue (Di Milia *et al.*, 2011; Horrey *et al.*, 2011). Living and socioeconomic conditions have been highlighted as a particular concern in the South African mining industry. Further study on these factors is warranted to assist in broadening the understanding of their effects on fatigue so that they might be considered in fatigue management programmes in order to implement appropriate interventions. The aim of this study was to assess associations between demographic, work, living and socioeconomic conditions, and lifestyle characteristics, and fatigue in the South African Mining Industry.

Methodology

The study design was cross-sectional. Although most data collected was quantitative, qualitative data was also gathered, and methodological triangulation was used to verify the results. Participants were recruited from a platinum smelter located in Limpopo Province in South Africa, in 2016.

Semi-structured interviews were held with eight individuals in management positions or their representatives. These individuals were selected based on their positions at the smelter, namely those from human resources, finance, health and safety, laboratory, production, engineering, and protection services. Two focus group discussions were held with groups of 11 (9 male and 2 female) and 13 (7 male and 6 female) production workers, respectively. Convenience sampling was used to select these participants. The interview and focus group participants were asked about fatigue experienced at the smelter and its potential causes, both at work and outside of work, and were requested to make recommendations for reducing it. The interviews and focus group discussions were held in the language most readily understood by the participants which, in this case, was English. The interviews and discussions were voice-recorded.

Quantitative data was collected using questionnaires that were completed by workers employed at the smelter. Participants were selected using convenience sampling. The smelter employed 188 permanent employees in the workgroups included in the study, and around one-third of these were sampled. The study focused on production workers, such as those working at the furnace, as it was assumed that they would be at a high risk of fatigue and its effects. However, other groups of workers, such as those working in engineering departments and in laboratories, were also included.

Closed-ended questions were used to gather information about participant demographics, work, living and socioeconomic conditions, lifestyles, health and wellness, and fatigue. Four questions were used to assess levels of fatigue, namely (1) whether participants thought they received enough sleep, (2) general sleepiness using the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg, 1990), (3) a subjective rating of fatigue at work, adapted from the Samn-Perelli fatigue scale (Samn and Perelli, 1982), and (4) whether the participant had unintentionally fallen asleep at work in the past 12 months. For the KSS, participants were asked to rate how sleepy they generally felt on a scale from 1 ('extremely alert') to 9 ('very sleepy, great effort to stay awake'). Subjective fatigue at work was recorded on a five-point Likert scale from 'fully alert, wide awake', to 'completely exhausted.' The participants completed the questionnaires under the guidance of researchers who were fluent in local languages.

Data from the voice recordings was downloaded and transcribed. Thematic content analysis was used to summarize responses from the interviews and focus groups. Data from the questionnaires was captured electronically using Excel software. A binomial fatigue variable was created using data from the four questions in the questionnaire that were designed to assess fatigue. If data from two or more of these questions indicated high levels of fatigue (*i.e.* not receiving enough sleep, a KSS score of over 5, a fatigue rating of more than 'a little tired', and/or falling asleep at work unintentionally in the past year), a positive fatigue score was indicated for the participant. In addition to descriptive analyses, Pearson chi-squared and Fischer's exact tests were conducted using Stata 13 software to determine whether there were significant associations between each of the demographic, work, living and socioeconomic condition, and lifestyle variables, and the summary fatigue variable. To improve the integrity of the inferential statistics, data was grouped or omitted, where appropriate, to increase the number of responses per category. Fisher's exact test was used in cases where the number of participants per cell was less than five. Statistical significance was set at 95% ($p < 0.05$).

Ethical approval to conduct this study was obtained prior to data collection from the CSIR Research Ethics Committee (reference number: 158/2015) and the University of the Witwatersrand Human Research Ethics Committee (certificate number: M140222). Necessary permission to conduct the study was obtained from the company.

Results

Perception of fatigue by management and production workers

Participants in the interviews and focus groups generally felt that fatigue was a problem at the smelter, especially for those working in hazardous occupations. However, it was considered to be relatively well managed. Those in management identified various work-related causes of fatigue, including overtime, shift work, repetitive and monotonous work, and work that required high levels of concentration. Overtime work was a particular concern for engineering personnel as they worked on 'standby' in addition to working normal day shifts. Production and laboratory workers, on the other hand, worked 12 hour shifts that included night shift work. The production workers noted short staffing, including that resulting from absenteeism, as the main concern relating to fatigue, as this led to increased workloads.

Activities outside of work were also considered to contribute to fatigue by both those in management positions and the production workers. These included family responsibilities, part-time studies, and social activities. Personal differences such as age, intrinsic sleeping rhythms, and stress were also linked to fatigue. The socioeconomic conditions (*e.g.* income, education, transport, and housing) of the smelter workers were seen to be relatively good, and the daily commuting times were not generally excessive; as such, these factors were not of particular concern for fatigue.

Levels of fatigue

A total of 75 questionnaires were completed. The average response rate to each of the questions was 98%, ranging from 95% to 97%.

Table I shows the demographic profile of the study participants. The majority of the participants were male (68.5%) and the average age was 37 (±7) years, with a range of 22–60 years. Most of the participants were Black Africans (87.7%). All were South African, and most (79.5%) came from Limpopo, the province where the smelter was located. The participants were relatively well educated: 56.9% had a post-Grade 12 qualification and only 5.6% had not completed secondary school.

Selected work-related variables are shown in Table II. The majority of the participants (53.4%) worked in the furnace section, 17.8% in the engineering department, 15.1% in the regional laboratory, and 13.7% in the process laboratory. Most (86.3%) were permanent employees, and 67.1% worked shifts. In general, those working in the furnace section and in the process laboratory worked shifts, while those in the engineering department and the regional laboratory did not. The shifts were 12 hours long, and included night shifts. About one-third (34.2%) of the participants reported that they often worked overtime.

Findings relating to the living and socioeconomic conditions of the sample are included in Table III. Access to services was relatively high, and most (97.2%) had electricity in their dwellings. Most of the participants lived within a 50 km radius of the smelter, and the majority (84.7%) had commuting times of less than 30 minutes. Most used their own vehicles to travel to and from work. The median number of people that relied on the participants' incomes was four. Over a quarter (27.4%) reported always or often finding it difficult to pay for all the things they needed, and 39.7% reported owing money to someone.

With regard to lifestyle, 32.9% reported exercising in their leisure time more than once a week, 15.7% smoked, and 41.1% drank alcohol more than once a month (Table IV). In terms of nutrition, 76.7% considered the food they ate to be healthy or very healthy; none reported it to be unhealthy or very unhealthy. Over a quarter of the participants (26.0%) reported usually having fewer than 6 hours of sleep in the 24 hours before a work shift; 27.4% slept for 6–7 hours, and 46.6% slept for 7 or more hours. These values compare to

Table I

Demographic characteristics and the associations with fatigue

Variable	Participants n (%)	Fatigue Yes n (%)	Fatigue No n (%)	p-value
Sex				
Male	50 (68.5)	21 (42.0)	29 (58.0)	0.641 (P)
Female	23 (31.5)	11 (47.8)	12 (52.2)	
Age				
≤35 years	36 (51.4)	21 (58.3)	15 (41.7)	**0.015* (P)**
>35 years	34 (48.6)	10 (29.4)	24 (70.6)	
Race				
Black	64 (87.7)	32 (50.0)	32 (50.0)	**0.004* (F)**
Other	9 (12.3)	0 (0.0)	9 (100.0)	
Marital status				
Married	37 (50.7)	16 (43.2)	21 (56.8)	0.918 (P)
Not married	36 (49.3)	16 (44.4)	20 (55.6)	
Home province				
Limpopo	58 (79.5)	25 (43.1)	33 (56.9)	0.804 (P)
Elsewhere in South Africa	15 (20.5)	7 (46.7)	8 (53.3)	
Highest level of education				
Grade 12 or less	31 (43.1)	10 (32.3)	21 (67.7)	0.070 (P)
Higher than Grade 12	41 (56.9)	22 (53.7)	19 (46.3)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

Table II

Work variables and the associations with fatigue

Variable	Participants n (%)	Fatigue Yes n (%)	Fatigue No n (%)	Chi^2 p-value
Work area				
Furnace	39 (53.4)	20 (51.3)	19 (48.7)	0.318 (F)
Process laboratory	10 (13.7)	5 (50.0)	5 (50.0)	
Regional laboratory	11 (15.1)	4 (36.4)	7 (63.6)	
Engineering	13 (17.8)	3 (23.1)	10 (76.9)	
Work status				
Permanent	63 (86.3)	29 (46.0)	34 (54.0)	0.497 (F)
Contract	10 (13.7)	3 (30.0)	7 (70.0)	
Shift work				
Yes	49 (67.1)	25 (51.0)	24 (49.0)	0.077 (P)
No	24 (32.9)	7 (29.2)	17 (70.8)	
Overtime				
Yes	25 (34.2)	12 (48.0)	13 (52.0)	0.605 (P)
No	48 (65.8)	20 (41.7)	28 (58.3)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

11.1%, 16.7%, and 72.2%, respectively, prior to days off work. Participants also generally reported having better quality sleep before a day off work than before a work day.

Table V shows that 21.4% of the participants reported having a medical condition and 23.3% reported taking medication. Most (86.3%) considered their health to be good or very good, and 34.7% had not taken any sick leave in the previous year. While some of the participants were unsure if they had a sleep disorder or not, 15.9% reported having one. Around 4.2% of the sample reported having a work-related injury, and 2.8% had been involved in a work-related

Table III

Living and socioeconomic condition variables and the associations with fatigue

Variable	Participants	Fatigue		Chi2
	n (%)	Yes n (%)	No n (%)	p-value
Location of dwelling				
Mine (smelter) property	8 (11.3)	5 (62.5)	3 (37.5)	0.230 (F)
Suburban area	34 (47.9)	15 (44.1)	19 (55.9)	
Township	18 (25.3)	9 (50.0)	9 (50.0)	
Rural area	11 (15.5)	2 (18.2)	9 (81.8)	
Housing tenure status				
Owned and fully paid off	6 (8.7)	1 (16.7)	5 (83.3)	**0.037* (F)**
Owned but not yet paid off	25 (36.2)	10 (40.0)	15 (60.0)	
Rented	33 (47.8)	19 (57.6)	14 (42.4)	
Occupied rent-free	5 (7.3)	0 (0.0)	5 (100.0)	
Level of crowding (number in room)				
One	17 (23.6)	9 (52.9)	8 (47.1)	0.415 (P)
Two	40 (55.6)	15 (37.5)	25 (62.5)	
More than two	15 (20.8)	8 (53.3)	7 (46.7)	
Piped water in dwelling				
Yes	60 (87.0)	26 (43.3)	34 (56.7)	0.724 (F)
No	9 (13.0)	3 (33.3)	6 (66.7)	
Flush toilet				
Yes	64 (88.9)	31 (48.4)	33 (51.6)	0.068 (F)
No	8 (11.1)	1 (12.5)	7 (87.5)	
Commuting time				
Less than 15 minutes	9 (12.5)	3 (33.3)	6 (66.7)	0.598 (F)
15 to less than 30 minutes	52 (72.2)	25 (48.1)	27 (51.9)	
30 minutes to less than an hour	11 (15.3)	4 (36.4)	7 (63.6)	
Difficultly affording necessities				
Always/often	20 (27.4)	11 (55.0)	9 (45.0)	0.076 (P)
Sometimes	24 (32.9)	13 (54.2)	11 (45.8)	
Occasionally/never	29 (39.7)	8 (27.6)	21 (72.4)	
Indebtedness				
Yes	29 (39.7)	15 (51.7)	14 (48.3)	0.270 (P)
No	44 (60.3)	17 (38.6)	27 (61.4)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

Table IV

Lifestyle variables and the associations with fatigue

Variable	Participants	Fatigue		Chi2
	n (%)	Yes n (%)	No n (%)	p-value
Exercise				
Once a week or less	49 (67.1)	24 (49.0)	25 (51.0)	0.206 (P)
More than once a week	24 (32.9)	8 (33.3)	16 (66.7)	
Smoke				
Yes	11 (15.7)	6 (54.5)	5 (45.5)	0.394 (P)
No	59 (84.3)	24 (40.7)	35 (59.3)	
Drink alcohol				
Less than once a month	43 (68.9)	15 (34.9)	28 (65.1)	0.065 (P)
More than once a month	30 (41.1)	17 (56.7)	13 (43.3)	
Healthiness of diet				
Healthy or very healthy	56 (76.7)	21 (37.5)	35 (62.5)	**0.048* (P)**
Neither healthy nor unhealthy	17 (23.3)	11 (64.7)	6 (35.3)	
Average hours of sleep – before work				
<7 hours	39 (53.4)	20 (51.3)	19 (48.7)	0.170 (P)
≥7 hours	34 (46.6)	12 (35.3)	22 (64.7)	
Average hours of sleep – before off-days				
<7 hours	20 (27.8)	8 (40.0)	12 (60.0)	0.745 (P)
≥7 hours	52 (72.2)	23 (44.2)	29(55.8)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

Table V

Health and wellness variables and the associations with fatigue

Variable	Participants	Fatigue		Chi2
	n (%)	Yes n (%)	No n (%)	p-value
Medical condition				
Yes	15 (21.4)	6 (40.0)	9 (60.0)	0.801 (P)
No	55 (78.6)	24 (43.6)	31 (56.4)	
Sleep disorder				
Yes	11 (15.9)	8 (72.7)	3 (27.3)	**0.024* (P)**
No	58 (84.1)	21 (36.2)	37 (63.8)	
Medication				
Yes	17 (23.3)	10 (58.8)	7 (41.2)	0.155 (P)
No	56 (76.7)	22 (39.3)	34 (60.7)	
Self-reported health				
Good or very good	63 (86.3)	27 (42.9)	36 (57.1)	0.740 (F)
Not good	10 (13.7)	5 (50.0)	5 (50.0)	
Sick leave in previous year				
0 days	25 (34.7)	8 (32.0)	17 (68.0)	
1–9 days	34 (47.2)	16 (47.1)	18 (52.9)	0.202 (P)
More than 10 days	13 (18.1)	8 (61.5)	5 (38.5)	
Stress				
Not at all / a little stressed	48 (67.6)	13 (27.1)	35 (72.9)	**0.000* (P)**
Very stressed	23 (32.4)	18 (78.3)	5 (21.7)	
Job satisfaction				
Not satisfied	39 (54.9)	26 (66.7)	13 (33.3)	**0.000* (F)**
Satisfied	32 (45.1)	5 (15.6)	27 (84.4)	
Quality of life				
Good	57 (79.2)	23 (40.4)	34 (59.7)	0.366 (P)
Not good	15 (20.8)	8 (53.3)	7 (46.7)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

Table VI

Fatigue ratings

Variable	Participants	Fatigue		Chi2
	n (%)	Yes n (%)	No n (%)	p-value
Enough sleep				
Yes	49 (67.1)	11 (22.5)	38 (77.6)	**0.000* (P)**
No	24 (32.9)	21 (87.5)	3 (12.5)	
KSS ratings of general sleepiness				
1 – 5: Not sleepy	38 (53.5)	8 (21.0)	30 (79.0)	**0.000* (P)**
6 – 9: Sleepy	33 (46.5)	24 (72.7)	9 (27.3)	
Fatigue rating – in general while at work				
Fully alert, wide awake	9 (12.7)	0 (0.0)	9 (100.0)	
Somewhat fresh, lively	18 (25.4)	5 (27.8)	13 (72.2)	
A little tired	29 (40.8)	11 (37.9)	18 (62.1)	**0.000* (F)**
Moderately or very tired	9 (12.7)	8 (88.9)	1 (11.1)	
Completely exhausted	6 (8.5)	6 (100.0)	0 (0.0)	
Fallen asleep unintentionally at work in past year				
Yes	38 (52.1)	30 (79.0)	8 (21.1)	**0.000* (F)**
No	35 (47.9)	2 (5.7)	33 (94.3)	
Summary fatigue variable				
Fatigued	32 (43.8%	32 (100.0)	0 (0.0)	N/A
Not fatigued	41 (56.2)	0 (0.0)	41 (100.0)	

*Indicates significance at $p < 0.05$. (P) Pearson's chi-square test performed. (F) Fisher's exact test performed.

accident in the previous 12 months. Almost half of the participants (45.1%) reported being satisfied with their jobs, 23.9% were neither satisfied nor dissatisfied, and 31.0% were dissatisfied. Most (79.2%) considered their quality of life to be good. One-third (32.4%) reported being very stressed.

A summary of the fatigue ratings of the participants can be found in Table VI. Two-thirds (67.1%) thought that they received enough sleep. The average level of sleepiness recorded in the KSS was 5 ('neither alert nor sleepy'); 46.5% reported some degree of sleepiness, as indicated by a score of 6 or higher. When the participants were asked to rate how fatigued they usually felt while at work, 21.2% reported feeling moderately tired or completely exhausted. Over half (52.1%) reported having unintentionally fallen asleep while at work in the past year. From the summary variable based on the results for these four fatigue-related items, 43.8% of the participants were classified as fatigued. A summary variable could not be calculated for two participants, as a result of missing data, reducing the sample size for the chi-square and Fisher's exact tests to 73.

Associations with fatigue

Results of the Pearson chi-square and the Fisher's exact tests are shown in Tables I to VI, together with the percentage of participants in each category that were identified as fatigued. Both age and race were associated with fatigue ($p<0.05$, Table I). A higher proportion of those aged 35 years or younger reported to be fatigued than those older than 35. Black participants reported fatigue more frequently than those of other race groups. The proportion of participants that was not black was small, which could influence the validity of this result. Most of the non-black participants (89.9%) were over 35 years and only 22.2% of this group did shift work. No statistically significant associations with fatigue and sex, marital status, home province, or education were seen.

None of the recorded work-related variables were significantly associated with fatigue (Table II). However, some trends were evident, such as higher levels of fatigue in those working at the furnace and the process laboratory than in those working in the regional laboratory and the engineering department. Higher levels of fatigue were also reported by those that did shift work, those that worked overtime, and permanent employees, although the differences were not statistically significant.

Housing tenure was associated with fatigue ($p<0.05$, Table III). Those who owned and had fully paid off their homes and those who occupied dwellings rent-free reporting lower levels of fatigue than those who rented or owned but had not yet paid off their dwellings. Area of dwelling, level of crowding, access to piped water and flush toilets, commuting time, difficulty affording necessities, and indebtedness were not significantly associated with reported fatigue.

Those who considered their diets to be healthy or very healthy reported less fatigue ($p<0.05$), but exercise, alcohol use, smoking, and sleep received were not significantly associated with fatigue (Table IV).

Sleep disorders, stress, and job dissatisfaction were positively associated with fatigue ($p<0.05$) (Table V). Those reporting as having a sleep disorder, high stress levels, and poor job satisfaction reported higher levels of fatigue. Having a medical condition, taking medication, self-reported health conditions, sick leave, and quality of life were not statistically associated with the fatigue variable in this study. The four variables that were used to predict fatigue were significantly associated with the summary fatigue variable ($p<0.001$, Table VI).

Discussion

Fatigue was identified in 44% of the study participants, as indicated by subjective responses and reports of falling asleep unintentionally while at work. From the interviews and focus groups conducted, both work- and non-work-related factors contributed to fatigue. The factors that were significantly associated with fatigue were age, race, housing tenure status, healthiness of diet, sleep disorders, stress and job satisfaction.

The higher levels of fatigue reported by the younger workers could be a result of the 'healthy worker effect', as those that can best handle the work demands are most likely to remain in the job. It might also be a result of social activities that the younger participants are involved in outside of work. This was mentioned in the focus groups. Reasons for the non-black group reporting lower levels of fatigue could be because they were, on average, older than the black participants, and because a lower percentage of them did shift work. However, only nine (12.3%) of the participants were non-black, which could have biased the results.

It was unexpected that none of the work-related variables were significantly associated with fatigue. It was anticipated that factors such as working shifts and working overtime would be associated with higher levels of fatigue. However, it is noteworthy that the participant groups generally either worked shifts (*i.e.* production and laboratory workers) or commonly worked overtime (*e.g.* those in engineering). As such, it is possible that these factors counteracted the associations, as shift work and overtime would both affect fatigue in the different groups.

Those who rented accommodation or were paying housing debts reported higher levels of fatigue than those who lived rent-free or had paid off their housing. The latter group might be less stressed and under less pressure to work harder or longer hours to earn production bonuses. As the living conditions, commuting times, and socioeconomic conditions of the participants were generally not seen to be problematic, this could explain the lack of association of these factors with fatigue in this sample.

Those who considered their diets to be healthy reported lower levels of fatigue. Healthier diets might lead to better or more sustained energy levels. Reports of healthy eating might also be linked to personality or psychosocial states or traits, with those who are more optimistic reporting better health and lower fatigue.

As might be expected, those who reported having a sleeping disorder experienced higher levels of fatigue, likely due to inadequate restorative sleep. It was unexpected that hours of sleep obtained were not significantly associated with fatigue. This could point to the importance of sleep quality in relation to fatigue, including the ability to adapt to shift work, rather than sleep length alone. It could also be that the 7-hour cut-off used in the study as an indicator of insufficient sleep was too high.

Higher stress levels and poorer job satisfaction were both strongly associated with fatigue. Stress and job dissatisfaction could be either causes or consequences of fatigue. Workers might be stressed and dissatisfied because they are fatigued, or fatigue may result from high levels of stress and dissatisfaction (*e.g.* because of impaired sleep quality). Stress and fatigue have commonly been considered to be associated, and fatigue has been associated with impairments in mood (Åkerstedt *et al.*, 2014; Republic of South Africa, 2014; Shaw, 2003). Stress and job dissatisfaction have also been linked (*e.g.* Coomber and

Barriball, 2007). Extraneous variables, such as high workloads or challenging work conditions, might contribute to the experience of stress, job dissatisfaction, and fatigue, simultaneously. Although some research has shown fatigue to be associated with increased sick leave or absenteeism and poor health (*e.g.* Åkerstedt *et al.*, 2014), the current study failed to demonstrate these associations. Nevertheless, some trends were evident in the data, such as correlation of increased fatigue with increased sick leave, poorer subjective health, and poorer quality of life

A limitation of the study is the small sample size, which might have reduced the statistical significance of the findings. The use of convenience sampling was a further limitation, as it could result in sampling bias. The study participants might not have represented the workforce, being healthier and less fatigued workers, as they were not absent from work or on sick leave at the time of the study. Another limitation is that the study made use of self-reported data. Factors such as personality, mood, and understanding could have affected the responses. Furthermore, as the focus of the study was to gather more information about non-work contributors to fatigue, only basic data about work-related factors was gathered. The inclusion of more detailed work-related information, such as work design, scheduling, and environmental factors, would have allowed for a more complete understanding of contributors to fatigue at these operations. It should also be noted that as the study was conducted at a single workplace, the findings may not be generalizable. Notwithstanding these limitations, we believe that the results provide an indication of levels of fatigue and contributors to them.

Conclusion and recommendations

Several demographic, living condition, lifestyle, health, and wellness variables were associated with fatigue in this group of smelter workers. Generally, factors within the work environment receive most attention when it comes to fatigue management. It is recommended that mining workplaces also take factors outside of the workplace into consideration in their fatigue management programmes. Further study in different settings and with larger sample sizes would be worthwhile in order to confirm these findings, and to generate recommendations relating to non-work contributors to fatigue that can be applied more broadly.

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Appendix D: Paper 4

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Original Article

Contributors to Fatigue of Mine Workers in the South African Gold and Platinum Sector

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ABSTRACT

Background: Mine workers in South Africa face challenges relating to poor health and safety, including fatigue risks, and poor socioeconomic and living conditions. Fatigue results in impaired mental and physical performance. The aim of this study was to assess contributors to fatigue of mine workers in South Africa.

Methods: Data collection took place at four gold mines and one platinum mine in South Africa. A total of 21 focus groups were held with individuals in management, union representatives, and mine workers, and 564 questionnaires were completed by mine workers to gather information about fatigue and potential contributors to fatigue at these mines.

Results: Qualitatively (through focus groups), fatigue was attributed to extended working hours, harsh working conditions, high workloads, production pressure, and resource constraints, along with aspects relating to demographic and socioeconomic factors, living conditions, lifestyle, health, and wellness. Greater fatigue was significantly associated with younger age, indebtedness, a lack of exercise, poor nutrition, less sleep, increased alcohol use, poor self-reported health, more sick leave, higher stress, and lower job satisfaction.

Conclusion: The aim of the study was achieved; numerous work-, sociodemographic-, lifestyle-, and wellness-related factors were linked to fatigue in the participating mine workers. Contributors to fatigue should be addressed to improve health, safety, and sustainability in the industry.

1. Introduction

The South African mining industry (SAMI) is a significant contributor to the economy of the country but faces sustainability, occupational health, and safety challenges [1,2]. The SAMI is traditionally labor intensive and takes place in difficult conditions [3,4]. In addition, the SAMI has residual problems faced by mine workers, relating to historically poor socioeconomic conditions, substandard living conditions, racial discrimination, and poor health [5–8]. Mining companies are required to contribute to the improvement of living conditions of their workforces, community development, and transformation of the industry [8–13]. Furthermore, the SAMI is required to have a minimum participation of 10% of women in mining [9–11]. Mines are also required to develop a code of practice for any matter where health and safety could be affected by mining activities; this includes fatigue management [14].

Fatigue is defined as "a state of impaired mental and/or physical performance and lowered alertness, arising as a result or combination of hard physical and mental work, health and psychosocial factors, or inadequate restorative sleep" [15 p 145]. Fatigue is a causal or contributing factor to accidents and injuries in the mining industry [15]. Increased levels of fatigue lead to reduced levels of alertness, coordination, judgment, and motivation and impaired mood and job satisfaction [16–19]. Job satisfaction refers to perceptions or attitudes that people have toward their work [20]. Fatigue can also lead to long-term health problems such as digestive problems, heart disease, stress, and mental illness and is associated with increased use of sick leave [17,21]. Stress can be defined as an imbalance between the demands placed on an individual and the resources that the person has for coping with these demands [22].

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Causes of fatigue are multifactorial. Work-related causes include shift schedules, task requirements, and work and environmental conditions [14,21,23]. Individual and nonwork causes include differences with age, sex, education, poor diet, drug and alcohol use, inadequate sleep and rest, medical conditions, psychological issues such as stress, and demanding activities or commitments outside of work [16,19,21,23–26]. Socioeconomic conditions that potentially contribute to increased fatigue of mine workers include poor housing, overcrowding, and long commuting times, which can disrupt sleep and limit sleep time, and financial constraints to affording necessities such as decent food, housing, and basic services; socioeconomic and living conditions are also associated with psychosocial factors, lifestyle, and health [21,27,28].

There is a lack of research about the association between individual characteristics and fatigue; the influence of sociodemographic variables, other than sex and age, is largely unknown [23,24]. Further research on this topic would be beneficial to identify factors associated with fatigue and, in turn, use the findings toward improving health, safety, well-being, and productivity in the SAMI. The conceptual framework that was developed for this study, based on literature reviewed and a theoretical understanding of associations between the study variables, is displayed in Fig. 1. The model shows potential contributors to fatigue, along with associations between the variables. The aim of the study was to assess contributors to fatigue of workers at gold and platinum mines in South Africa. The results could be used to implement interventions to reduce fatigue-related risks.

2. Methods

2.1. Study setting and population

Data were collected from four gold mines and one platinum mine located in four of the nine provinces in South Africa in 2017. The total estimated workforce size at these mines was approximately 40 000, and the SAMI directly employed around 464 700 people at that time (personal communication, Department of Mineral Resources, 6 July 2016) [1]. The gold and platinum sectors employed the most people in the industry in South Africa, with 112 200 and 175 770 in the gold and platinum sectors, respectively [1]. The study population comprised individuals in management, union representatives, and mine workers at each of the five mines.

2.2. Sampling procedures

Those in management and union representatives were purposively selected based on their positions at the mines. Convenience sampling was used to select the participating mine workers because it was not possible to get a probabilistic sample. The mine workers were recruited from areas including the mine training centers, so that production would not be interrupted by removing workers from the workplace. Consequently, there could be bias in the findings, such as a lower percentage of fatigued participants than the entire study population. In addition, this sampling method prevents the scientific inference of the findings to the broader population of mine workers; it rather provides an exploratory understanding of the research topic. Workers from a range of job positions and shifts were selected from each mine to enhance the representability of the sample and included engineering and production personnel.

2.3. Data collection

This was a cross-sectional, mixed-methods study. Qualitative data were gathered from a total of 21 focus group discussions that were held with 154 individuals, including 48 managers, 23 union representatives, and 83 mine workers, across the five operations. In most cases, one focus group discussion was held with management, one with union representatives, and two with workers, at each mine. The focus group discussions were semistructured, and questions were posed to gain an understanding of perceptions of fatigue and potential contributors to fatigue of the mine workers. The focus group discussions were conducted in languages that were readily understandable by the participants and were voice-recorded.

Quantitative data were gathered using questionnaires. The questionnaires included forced-choice questions to gather information about worker demographics; living and socioeconomic conditions; and lifestyle, health and wellness, including sleepiness and fatigue. The independent variables (26 items) are listed in Table 1 and were measured using single-item measures. Previous authors have validated the use of single-item measures, including those for stress and job satisfaction [29–32]. Sleepiness and fatigue were measured using an adapted version of the Samn–Perelli fatigue scale [33], the Karolinska Sleepiness Scale (KSS) [34], an indication of having unintentionally fallen asleep at work in the

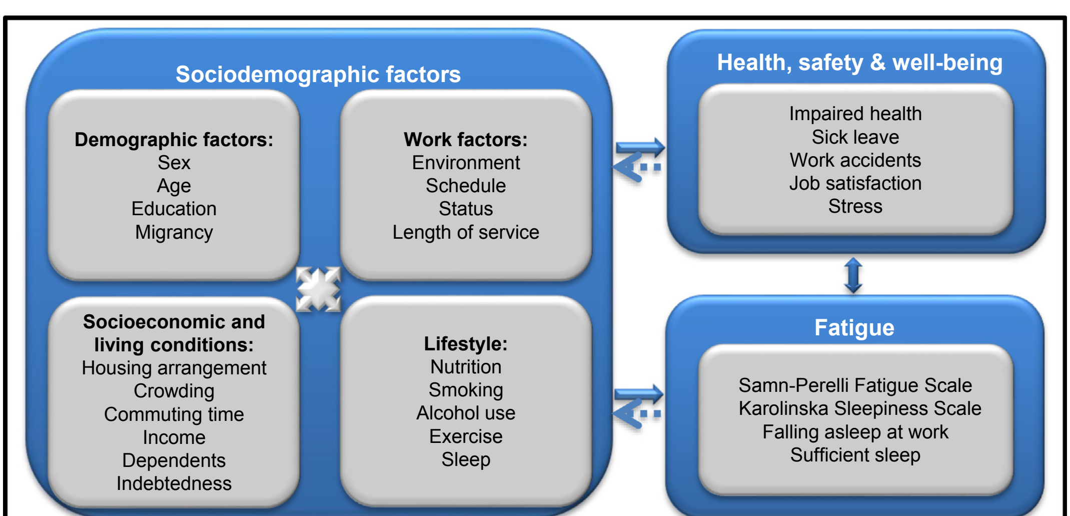

Fig. 1. Conceptual framework of the study.

Table 1
Participant characteristics and associations with fatigue* (n = 493)

Variable	Category	Participants	Fatigue		
		n (%)	Yes, n (%)	No, n (%)	*p*†
Sex	Male	431 (88)	117 (27)	314 (73)	0.370
	Female	58 (12)	19 (33)	39 (67)	
Age	<40 years	286 (60)	91 (32)	195 (68)	*0.013*
	≥40 years	191 (40)	41 (21)	150 (78)	
Education	<Grade 12	299 (61)	72 (24)	227 (76)	*0.034*
	≥Grade 12	192 (39)	63 (33)	129 (67)	
Province of origin	Same as mine province	142 (29)	48 (34)	94 (66)	0.054
	Different to mine province	349 (71)	88 (25)	261 (75)	
Country of origin	South Africa	385 (79)	118 (31)	267 (69)	*0.004*
	Other	104 (21)	17 (16)	87 (84)	
Work area	Surface	69 (14)	17 (25)	52 (75)	0.598
	Underground	408 (86)	113 (28)	295 (72)	
Night shifts	Yes	178 (37)	54 (30)	124 (70)	0.416
	No	305 (63)	82 (27)	223 (73)	
Work status	Permanent	369 (77)	109 (30)	260 (70)	0.247
	Contract	109 (23)	26 (24)	83 (76)	
Length of service	<5 years	223 (47)	70 (30)	163 (70)	0.248
	≥5 years	260 (53)	66 (25)	194 (74)	
Living out allowance	Yes	325 (68)	88 (27)	237 (73)	0.685
	No	156 (32)	45 (29)	111 (71)	
Number sharing room	1–2 people	250 (52)	73 (29)	177 (71)	0.429
	>2 people	231 (48)	60 (26)	171 (74)	
Commuting time	<30 minutes	327 (66)	90 (28)	237 (72)	0.965
	>30 minutes	166 (34)	46 (28)	120 (72)	
Salary	<R7500	314 (64)	95 (30)	219 (62)	0.099
	>R7500	176 (36)	41 (23)	135 (76)	
Dependents	<6	250 (51)	70 (28)	180 (72)	0.857
	≥6	242 (49)	66 (27)	176 (73)	
Debt	Yes	293 (61)	93 (32)	200 (68)	*0.019*
	No	191 (39)	42 (22)	149 (78)	
Exercise	Yes	247 (50)	55 (22)	192 (78)	*0.006*
	No	243 (50)	81 (33)	162 (67)	
Smoking	Yes	115 (24)	39 (34)	76 (66)	0.090
	No	372 (76)	96 (26)	276 (74)	
Alcohol use	Once a month or less	365 (74)	92 (25)	273 (75)	*0.036*
	More than once a month	126 (26)	44 (35)	82 (65)	
Diet	Healthy	350 (72)	83 (24)	267 (76)	*0.001*
	Not healthy	139 (28)	53 (38)	86 (62)	
Sleep time before work	<6 hours	218 (45)	81 (37)	137 (63)	*0.000*
	≥6 hours	265 (55)	51 (19)	214 (81)	
Sleep problems	Yes	120 (26)	53 (44)	67 (56)	*0.000*
	No	347 (74)	77 (22)	270 (78)	
Health	Good	411 (84)	100 (24)	311 (76)	*0.001*
	Not good	81 (16)	35 (43)	46 (57)	
Sick leave (previous year)	<5 days	348 (71)	86 (25)	262 (75)	*0.036*
	≥5 days	141 (29)	48 (34)	93 (66)	
Work accident (previous year)	Yes	64 (13)	23 (36)	41 (64)	0.086
	No	424 (87)	109 (26)	315 (74)	
Job satisfaction	Satisfied	254 (52)	54 (21)	200 (79)	*0.001*
	Not satisfied	239 (48)	82 (34)	157 (66)	
Stress	Low	309 (63)	62 (46)	247 (80)	*0.000*
	High	181 (37)	72 (54)	109 (60)	

* Results of Chi-squared analysis.
† Italics values indicate significance ($p < 0.05$).

previous year, and a self-report of receiving sufficient sleep or not. The Samn–Perelli scale required responses on a seven-point scale (1 = "fully alert, wide awake"; 7 = "completely exhausted, unable to function effectively"), whereas the KSS is a nine-point scale (1 = "extremely alert", 9 = "very sleepy, great effort to stay awake"). Researchers assisted the participants to complete the questionnaires, where necessary, to eliminate language and literacy barriers.

The questionnaires were completed by 564 mine workers, of which 432 worked at the four gold mines and 132 at the platinum mine. The average response rate to each of the questions was 98% (±2%), ranging from 91% to 100%. Most participants were male (88%); this reflected national mining employment statistics, as women represented 12% of the mining labor force in 2017 [1]. The average age was 38 (±9) years, ranging from 20 to 65 years. Further details of participant characteristics are shown in Table 1.

2.4. Data analysis

The focus group discussions were translated into English, where applicable, and transcribed, and data obtained from the questionnaires were captured into Microsoft Excel 2010. Thematic analysis was used to analyze the information gathered during the focus group discussions; the data were coded, and recurring themes were identified. For the quantitative data, descriptive and inferential statistics, including frequencies, percentages, means, standard deviations (indicated in parentheses following the ± sign), Chi-squared tests, and stepwise binary logistic regression, were performed using StataCorp's Stata 13.1 software at a significance level of $p < 0.05$. Data were grouped, where necessary. For the inferential analysis, a binary fatigue variable was created using a combination of variables. A positive fatigue rating was given if the participant scored positively for two or more of the following: (1) more than "a little tired" on the adapted version of the Samn–Perelli fatigue scale; (2) a score of six ("some signs of sleepiness") or more on the KSS; (3) having unintentionally fallen asleep at work in the previous year; and (4) not receiving enough sleep.

2.5. Ethical considerations

Ethical approval to conduct this research was received from the Council for Scientific and Industrial Research CSIR Research Ethics Committee (Reference No.: 85/2013) and the Human Research Ethics Committee of the University of the Witwatersrand (Certificate No.: M140444). Permission to conduct the study at each of the mines was also received. Voluntary informed consent was obtained from each of the participants. The data gathered in the study remain confidential.

3. Results

3.1. Perceptions of the mine workers, labor representatives, and management

3.1.1. Fatigue

Perceptions of fatigue frequently mentioned in the focus group discussions are described in this section. The participants generally agreed that fatigue was a challenge across all job categories. Mental and physical fatigue was seen to lead to impaired concentration, work performance, decision-making, and motivation, along with an increased likelihood of falling asleep at work, accidents, injuries, fatalities, damage to equipment, and absenteeism. A manager commented:

> *"It (fatigue) affects all our employees, because of the working environment that we are in. Remember, mining is very risky and dangerous. Therefore… it will definitely have an impact on their performance, and then it could also affect the health and safety of the employees underground. Consequently it will also lead to production loss."*

Fatigue was attributed to various factors, including the working hours, work conditions, and workload. The potential influences of demographic and socioeconomic factors, living conditions, commuting times, lifestyle, and health or wellness were also discussed.

3.1.2. Work

Extended working hours were the most frequently reported cause of fatigue. Workers often did not have enough time to get sufficient sleep as a result of the working hours and were often required to work hours longer than official shift times to complete the required work. Reported causes of extended working hours included production pressure, the bonus system, overtime work, inadequate staffing levels, delays in receiving materials, equipment and infrastructure constraints, or breakdowns. The early start times of morning shifts, night shifts, and circadian disruptions when working rotating shifts were further potential causes of fatigue. Most of the workers were required to work on weekdays and alternate Saturdays, but a number commented that they would prefer not to work on Saturdays to have enough time to attend to family responsibilities and to rest.

Production workers received bonuses when achieving certain targets and requirements. A participant said, *"The issue of bonuses is killing us. They shouldn't pressure us to work by using the bonus system. People want money, so even if they are fatigued they would still work in order to get extra money"*.

Overtime was worked on days off to complete work that could not be done during the work week or by workers, including artisans, who were on standby and responded to calls to attend to breakdowns outside of normal working hours. Some worked overtime on weekends to receive more pay. It was noted that workers with specialized skills sometimes worked excessive overtime because no one was available to replace them at work. Participants observed:

> *"You also get fatigue from long hours per day, but you can get fatigue working normal hours but never having an off Saturday or off Sunday because you work overtime on those days. So it can happen that you work for two weeks and have no day off in between."*

> *"It's the same with guy that works his morning shift, then there comes during the day or at the end of the shift a breakdown, then he must stay on until that breakdown has been rectified… it can take up to 23 to 24 hours that that guy stays underground. So definitely when he comes up from underground he's fatigued, his body is wasted."*

The work environment, job demands, and workplace culture contributed to fatigue as a result of harsh conditions, strenuous work, and production pressure associated with mining. High temperatures, humidity, dust, and long traveling distances underground were commonly mentioned. Workers often had to walk long distances to get to their workplaces once inside the mines. Physical job demands, high workloads, a lack of breaks, and monotonous work were further mentioned risks. Participants commented, *"The heat is killing us. It makes us to always be tired"* and *"The distance that we walk to our working areas is too long. We get tired before we can even start working"*.

Equipment, material, and infrastructure constraints were additional concerns. Overcrowding and delays of mine conveyors when entering or leaving the mines and a lack of transportation to underground workplaces were noted. A lack of equipment, delays in the delivery of materials, and a breakdown or insufficiency in services, such as compressed air, water, or electricity, also resulted in workers having to work longer hours than scheduled to meet the day's production targets.

Inadequate staffing levels were a further contributor to fatigue. Reduced staffing resulted in higher workloads for the remaining team members and was a particular challenge when some were on leave or were absent. Participants said, *"There's too much work and too little people"* and *"They must provide enough labour if they want to control fatigue"*. Workers often complained about not being able to take leave when it was due or requested because no one was available to relieve them at work, which precluded the opportunity for rest and recovery. Conversely, absenteeism and the abuse of sick leave were seen to result from fatigue. A participant admitted, *"We end up being absent from work because of fatigue. Sometimes even accidents occur due to being too tired at work. There are always complaints that we are always absent from work, but they can't realise that we are fatigued?"* However, other workers came to work even when sick or dangerously fatigued to still qualify for a bonus or because they were afraid of being accused of abusing sick leave.

3.1.3. Demographics

The demographic characteristics of workers, including sex, age, education, migrancy, and work status, were discussed in terms of their potential associations with fatigue. More women were entering the mining industry, but women were acknowledged to be less physically strong than men, which could result in higher levels of fatigue of the work team as the men helped the women to complete tasks that they could not do. A female participant stated, *"… really it's impossible to work the same as the men. You can try, but you can't perform like they are doing"*. In addition, pregnancies were seen to lead to increased strain in the work team as women were not allowed to work underground while pregnant or breastfeeding, and their positions were not filled by others.

In terms of age and education, it was generally noted that the older workers, being more experienced and skilled, tended to work harder and be stronger than the younger workers, who tended to be more educated than the older workers. The older workers, therefore, could be more resilient to fatigue. Some of the participating mines had a relatively high percentage of migrant labor from neighboring countries or from remote regions in South Africa; however, this percentage was decreasing, and the proportion was lower among younger workers. Migrant workers generally did not live with their families while working at the mines. Although fatigue was not generally perceived to differ between migrant and local workers, traveling times when going to rural homes could be a fatigue risk for migrant workers. For example, a participant commented:

> *"Like me, I'm from Mozambique. Let's say I have an emergency at home that I need to attend to and request three to four days off. It takes about two days for me to get home. When I get there I'll attend to what I have to do and return back to work. By the time I get back it's late already so I just leave my bag and go straight to work. I'll be very tired but I won't have a choice but to work"*.

Additional financial and social stressors could be placed on migrant workers, for example, as a result of living apart from families or having second families at the mines or because of additional household responsibilities, such as cooking or cleaning, if not living with a partner that attended to these responsibilities.

3.1.4. Socioeconomic and living conditions

Socioeconomic and living conditions were also perceived to contribute to fatigue. Income was associated with fatigue for reasons that included working excessive hours for overtime or bonus pay to supplement earnings. Participants commented, *"The salary we get is too little so we are trying to add (to) it with working overtime"* and *"People are working harder to earn better"*. Financial problems and debt were noted and were further associated with stress and sleeplessness. Contract workers were perceived to generally receive lower pay and benefits, but to work harder, than permanent employees.

Mine workers lived in a range of housing types, including formal brick houses, mine hostels, backrooms, and shacks. Mine employees usually received a living-out allowance if living outside of the mine-funded property. Fatigue could result from disturbed sleep if living in a noisy environment or if sharing a room. A worker mentioned:

"It's a challenge sometimes because we work different shifts. Sometimes you'll be trying to sleep during the day because you will be going for a night shift, and the one who is already back from his shift will be making noise or busy with other stuff while you are trying to sleep."

Poor living conditions, such as exposure to elements, crime, and a lack of amenities, were considered to contribute to poor health and fatigue. Furthermore, traveling distances and commuting time to work and home from work affected the time workers had to sleep. A worker commented, *"Some of us have to wake up at two in the morning so that you can be able reach work in time…So by the time you get to work you are tired already..."* Workers used a range of modes of transport, including taxis, buses, staff transport, cars, walking, and hitchhiking to get to work.

3.1.5. Lifestyle

Lifestyle-related factors, including activities performed outside of work, and nutrition were associated with fatigue. Workers often found it difficult to attend to family responsibilities and to rest adequately outside of work because of lack of time. Participants said, *"When you get home the kids also need attention – assistance with homework, you need to do the house chores… So we are forever tired"* and *"You don't have family time or anything. You're working in for Christmas, you're working in for Easter – you're working overtime"*. Females potentially had more household responsibilities than men because of traditional roles. A lack of recreational exercise was perceived to result from a lack of time, energy, and adequate facilities. Alcohol abuse was a reported problem that could lead to fatigue and was attributed to stress and a lack of recreational facilities. Eating unhealthy or convenience foods and irregular meal times were noted, which could result in poor health and fatigue. In addition, some workers did not eat at work because of the poor conditions and a lack of time. The rationing of food allowed underground, to prevent food being sold to illegal miners, was another concern as some mentioned that these rations were not sufficient to maintain energy levels throughout the shift.

3.1.6. Health, safety, and well-being

Health and wellness were associated with fatigue. Health problems and the use of medication could lead to drowsiness and fatigue, and conversely, fatigue could lead to poor health, psychological strain, and injuries. Examples of health problems that were mentioned were high blood pressure, diabetes, HIV/AIDS, tuberculosis, respiratory problems, sinus problems, headaches, and flu. Stress was another common concern and was considered to lead to lack of focus, absenteeism, and accidents at work, along with sleeplessness and fatigue. Participants noted, *"If you are stressed too much you can't sleep"* and *"So most of the time, your mind doesn't have the time to rest – you are always thinking. It can also cause fatigue"*. The main reported causes of stress were financial problems and indebtedness, whereas other causes were family problems, poor living conditions, transport challenges, and work-related stressors, such as working conditions, high workloads, long working hours, production pressure, and job insecurity.

3.1.7. Recommendations

Participants made recommendations to reduce fatigue and improve fatigue management at the mines. These included improved work planning and scheduling, such as reassessing the shift schedules; improved monitoring and evaluation of hours worked and leave taken; better staffing; improved infrastructure and supply of necessary equipment and materials; and revision of the current bonus system. Improved health and wellness programs, better recreational facilities, revision of the food rations allowed underground, and the provision of easily accessible midshift sustenance were recommended. Assistance with better housing and transport was also suggested. The need for improved communication between stakeholders at the mines was also highlighted, along with the need to prioritize health and safety, rather than production.

3.2. Results of data gathered using questionnaires completed by mine workers

Results of the fatigue indicators recorded in the questionnaires were as follows: (1) On the adapted Samn–Perelli fatigue scale, 14% indicated usually feeling more than "a little tired" at work; (2) more than a quarter (27%) reported usually feeling some level of sleepiness in the past year, as indicated by a score of over five on the KSS; (3) almost a quarter (24%) reported unintentionally falling asleep at work in the past year; and (4) a total of 39% did not think that they received enough sleep. A binary fatigue score was calculated based on positive responses to two or more of the four indicators, and 28% of the sample population was classified as fatigued. This score was not calculated for participants who omitted any of the four questions, which resulted in a sample size of 493 for the Chi-squared tests.

The results for the Chi-squared tests for associations between participant characteristics and fatigue are shown in Table 1. A number of variables were significantly associated with the summary fatigue score. Interestingly, younger age, higher level of education, and being a local South African worker were associated with a higher prevalence of fatigue. Those who were in debt reported being more fatigued. A lack of exercise, higher levels of alcohol use, and unhealthy diets were also statistically associated with increased fatigue. As expected, those who usually slept for fewer than six hours in the 24 hours before a work shift and those with sleeping problems were more likely to be fatigued than those who slept for more hours and had better quality sleep. Lower levels of fatigue were associated with good self-rated health, fewer than five days of sick leave taken in the previous year, higher levels of job satisfaction, and lower stress levels.

Stepwise binary logistic regression was used to assess the relationship between multiple predictor variables and fatigue. All the variables were included in the initial regression model. The criteria for inclusion of the variables into the final model were set at $p < 0.20$. A stopping criterion between 0.15 and 0.20 is recommended, with the best criteria increasing with the number of predictor variables [35]. Of the 26 predictor variables, 10 were included in the final model. Stress was the largest contributor to fatigue. Those with high levels of stress were 2.75 times more likely to be fatigued than those with low levels of stress after controlling for the variables of hours of sleep usually received before work, sleep problems, being a local versus a migrant worker, income, self-reported health, age, exercise, and work area (Table 2).

4. Discussion

The results from the questionnaires and focus group discussions were triangulated to better understand contributors to fatigue of the participating mine workers. The quantitative associations were explained by the qualitative data; these findings are discussed in the following part of the article and are compared to literature on the topic. In addition, although the focus of the study was to address the lack of knowledge about sociodemographic contributors to fatigue, information gathered in the focus group discussions

Table 2
Associations of multiple predictor variables and fatigue*

Variable (category)	Odds ratio	95% confidence interval		p†
Stress (high)	2.75	1.62	4.68	*0.000*
Sleep time before work ($\geq$6 hours)	0.39	0.23	0.67	*0.001*
Country of origin (South Africa)	2.52	1.14	5.52	*0.021*
Sleep problems (yes)	2.05	1.16	3.62	*0.013*
Salary (>R7500)	0.50	0.28	0.89	*0.018*
Health (good)	0.58	0.30	1.13	0.112
Age ($\geq$40 years)	0.56	0.32	0.99	*0.045*
Exercise (yes)	0.60	0.35	1.02	0.061
Province of origin (same as mine province)	1.59	0.89	2.84	0.117
Work area (underground)	1.67	0.79	3.52	0.182

CI, confidence interval.
* Results of stepwise logistic regression.
† Italics values indicate significance ($p < 0.05$).

provided insight into the context of the study by highlighting work-related contributors to fatigue.

In general, the findings of this study supported previous research that has found that fatigue can lead to reduced concentration or alertness, work performance, and motivation and increased health and safety risks [15–18].

The results from the Chi-squared tests showed that lower age, higher levels of education, and being local to the country were associated with higher levels of fatigue, which were unexpected. However, previous studies have found mixed results. Some studies have linked older age and a lack of education to higher levels of fatigue, whereas other studies found that fatigue was associated with younger age and that there was no association between education and fatigue [19,21,23,36]. Di Milia et al [23] did note, however, that workers with higher socioeconomic status, which is related to educational level, could be more at risk of mental fatigue than workers with lower socioeconomic status. It was expected that the migrant workers would experience more fatigue than local workers because of factors such as long traveling distances, healthcare disruptions, and social and financial strain [37]. The Chi-square associations could be explained by the qualitative data, however, as the participants mentioned that the older workers, which included a higher proportion of migrant workers, tended to be able to handle job demands better than the younger, more educated workers. This finding also supports the "healthy migrant hypothesis," which indicates that migrants are positively selected into the workforce based on health and explains the findings of previous research, indicating that migrants are generally healthier than those from the areas to where they migrate [38,39].

A number of significant associations between lifestyle-related variables and fatigue were evident. First, a lack of recreational exercise was associated with fatigue. As mentioned in the focus groups discussions, it is possible that those who were fatigued did not have the time or energy to participate in exercise outside of work because of the long working hours, high job demands, and harsh working environment. Conversely, a lack of recreational exercise could lead to impaired health and mental well-being, which may further be associated with fatigue. Second, those who considered their diets to be healthy reported lower levels of fatigue. Poor nutrition was a noted contributor to fatigue and a lack of energy in the focus group discussions. Poor nutritional intake was also attributed to long and irregular working hours and a lack of time to prepare food and to eat. Third, fatigue was further associated with higher levels of alcohol intake. Increased alcohol use could be a cause of fatigue or a consequence of fatigue and mental strain. Participants in the focus groups also attributed alcohol abuse to stress and a lack of alternate recreational facilities. The findings that those who usually had less than six hours of sleep before a work day and those with sleep problems experienced higher levels of fatigue were expected [23]. The focus group participants commonly attributed fatigue to a lack of time to get adequate sleep—particularly because of extended working hours—and to sleep disturbances such as stress or worry and noise. Consistent with the findings from the focus group discussions, a number of authors have indicated that social activities or commitments, along with long work hours, can compete with rest and recovery [40–42].

Health-related and well-being–related variables were associated with fatigue. Lower levels of fatigue were reported by participants who considered their health to be good. The association between health and fatigue was expected as fatigue can result from poor health and disease [18,19,21]. Fatigue and circadian disruptions have also been identified as causes of health problems [17,23]. The focus group participants similarly noted that poor health could lead to, or result from, fatigue. Similarly, higher amounts of sick leave taken were associated with higher levels of fatigue; this could result from the associations with poor health. In addition, the focus group participants noted fatigue to be a cause of absenteeism from work or the "abuse" of sick leave. Åkerstedt et al [21] and Åkerstedt [43] also reported that fatigue is seen to lead to sick leave and the use of health facilities.

Higher fatigue could have been a cause or consequence of lower job satisfaction and higher stress in the participants. Halvani et al [19] found that fatigue was significantly associated with job satisfaction. In addition, fatigue and disturbed sleep have been associated with psychological disorders including depression and burnout and higher levels of stress [18,21,43,44]. Results from the logistic regression analysis indicated that stress was the variable that best explained fatigue in the participants. The focus group participants indicated that stress was a cause of sleeplessness and fatigue. A common cause of stress was financial problems, which could be a reason for the association between indebtedness and fatigue. Participants also worked excessive hours to receive bonus or overtime pay, which could result in fatigue.

Significant associations were not found between a number of the other measured variables and fatigue in the Chi-squared test results. For example, sex was not significantly associated with fatigue. More than 10% of the participants were female, which reflects the Mining Charter requirements for participation of women in mining. Some participants believed that females could experience higher levels of fatigue as a result of generally lower physical work capacities and additional household responsibilities, whereas some asserted that males experienced higher levels of fatigue as they assisted to complete the work tasks that women could not. Heavier workloads could also be experienced by the entire work team when women were absent from work while pregnant or breastfeeding. Previous literature indicates that females are generally at a higher risk of fatigue than males [23]. Significant associations between housing arrangements, overcrowding, commuting time, number of dependents, and fatigue were also not evident. Meanwhile, in the focus groups, the participants identified reasons why poor living conditions, overcrowding, long commuting times, and low salaries could lead to fatigue. Fatigue results from the combined influence of living and working environments [42].

It was surprising that work-related factors, including work area, working night shifts, work status, and length of service, were not statistically associated with fatigue. This is because the long working hours, high job demands, and work environment were noted to be major causes of fatigue by the focus group participants and in previous research [14,21,23,42]. However, fatigue was considered to affect workers across all job categories, and it is likely that participants from each category confronted different potential contributors to fatigue. For example, those who were not required to work night shifts were more likely to be required to be on standby and work more overtime. Finally, although fatigue is a known contributor to work accidents, it was not significantly associated with having been involved in an accident at work in the previous year. It is likely that there are additional contributors to accidents at work.

4.1. Limitations

The study made use of self-reported data, and as such, findings could have been influenced by aspects including personality and mood. Although many variables were considered, other unmeasured variables might contribute to fatigue. The index used to define fatigue in this study, while incorporating previously validated scales, may be limited to certain aspects of the multifaceted concept of fatigue, and there may have been differences in understanding by participants in the current context. In addition, while associations between variables were determined, the cross-sectional nature of the study precluded the analysis of cause and effect. A further limitation is the sampling method used because probabilistic sampling could not be performed for this study. Notwithstanding these limitations, the study provides insight into challenges faced by mine workers in South Africa and factors associated with fatigue in the study sample, and it contributes to the body of knowledge about sociodemographic contributors to fatigue. Further research is recommended to validate the exploratory findings of this study. Future studies could include the objective measurement of fatigue and longitudinal analyses of mine workers' fatigue.

4.2. Conclusion and recommendations

This study contributed knowledge relating to the aim of the study, which was to assess contributors to fatigue of gold and platinum mine workers in South Africa. Furthermore, the findings supported the conceptual framework that was developed from literature on the topic. Fatigue is a risk to health, safety, well-being, and productivity of mine workers in South Africa. Extended working hours were the main reported cause of fatigue identified by the participants, but fatigue was also associated with sociodemographic, lifestyle, health, and wellness characteristics. Higher levels of fatigue were associated with getting fewer hours of sleep, sleep problems, indebtedness, a lack of exercise, increased alcohol use, unhealthy diets, poor health, increased sick leave taken, reduced job satisfaction, and high levels of stress. Those with high stress levels were almost three times more likely to be fatigued than those with low levels of stress. It was surprising that lower levels of fatigue were associated with older ages, lower levels of education, and not being local to South Africa. Addressing challenges of fatigue and the many variables associated with fatigue, including stress, would result in improved health, safety, and sustainability in the SAMI. A change in the workplace culture is required to ensure safe production and to avoid risks associated with production pressure. Improved employee wellness programs are also recommended.

Conflict of interest

There is no conflict of interest to declare.

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Appendix E: Presentation 1

Pelders (Hodgskiss), J. (2017). Contributors to fatigue at four gold mines in South Africa. *Research Day 2017 – Public Health for Sustainable Development in Africa.* Wits School of Public Health. University of the Witwatersrand, Johannesburg. 27 November 2017.

CONTRIBUTORS TO FATIGUE AT FOUR GOLD MINES IN SOUTH AFRICA

Pelders, J.L. and Nelson, G.

INTRODUCTION: Fatigue is a safety hazard in the mining industry. Related research has mostly focussed on work-related causes of fatigue. However, limited research has assessed non-work contributors. The aim of this study was to assess work- and non-work contributors to fatigue across four gold mines in South Africa.

METHODS: This was a cross-sectional study, and qualitative and quantitative data were collected. Data collection took place at four gold mines in South Africa in March 2017. Questionnaires were completed by 432 mine workers. A total of 16 focus groups were held with representatives from management, unions, and mine workers (n=120).

RESULTS: Around a quarter of the participants (26%) reported usually feeling sleepy, and 50% reported some level of fatigue at work; 40% thought they did not receive enough sleep, and sleep disturbances were most commonly attributed to “stress or worries” or “noise from outside”. In the focus groups, participants attributed fatigue to long work hours, high workloads, difficult working conditions, overtime, work on standby, and understaffing. Further challenges included inadequate transport, living conditions and nutrition; a lack of time for rest and recreation; and financial difficulties.

DISCUSSION: Preliminary findings revealed that fatigue was a problem at the mines, and was primarily attributed to work-related issues. However, both work- and non-work-related factors were associated with fatigue. It is recommended that a holistic approach be taken when implementing interventions to best manage fatigue.

Appendix F: Presentation 2

Pelders, J. and Nelson, G. (2018). Contributors to stress of mine workers in South Africa. *6th CSIR Emerging Researchers' Symposium.* The Council for Scientific and Industrial Research (CSIR), Pretoria. 28-29 June 2018.

our future through science

Contributors to Stress of Mine Workers in South Africa

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INTRODUCTION

Stress:

- "an adaptive response, mediated by individual characteristics and/or psychological processes, that is a consequence of any external action, situation, or event that places special physical and/or psychological demands upon a person"[1]
- associated with reduced mental and physical health, safety compliance, productivity, and job satisfaction, along with increased staff turnover, absenteeism, fatigue, accidents and injuries[1-4]

Stressors in the South African mining industry include:

- high physical job demands, productivity pressures, harsh working conditions, long working hours, and a lack of resources
- psychosocial hazards, including job insecurity, strained working relationships, and working in remote locations away from families
- historically poor socio-economic and living conditions [3-7]

AIM

To examine contributors to stress of mine workers in South Africa

METHODS

- Cross-sectional, mixed methods study
- Data collection: four gold mines, one platinum mine in 2017
- 21 focus group discussions held with 154 participants, including managers, labour representatives and mine workers
- Questionnaires completed by 564 mine workers
- Qualitative data analysed, using thematic analysis
- Quantitative data analysed, using basic and inferential statistics, including Chi^2 tests ($p<0.05$)
- Ethical approval granted by the CSIR Research Ethics Committee (Reference No.: 85/2013) and the Human Research Ethics Committee of the University of the Witwatersrand (Certificate No.: M140444)

CSIR researchers at Mandela Mining Precinct

Mine worker at training facility in South Africa

RESULTS

- Participant characteristics: 87% male, average age 38 (±9) years, 86% worked in underground workplaces
- 36% usually experienced moderate to extreme levels of stress
- Variables significantly associated with stress of the participating mine workers are shownin Table 1
- Higher levels of stress associated with higher education levels, driving private vehicles, paying for housing, indebtedness, higher levels of alcohol use, sleep problems, unintentionally falling asleep at work in the previous year, higher amounts of sick leavetaken, and lower job satisfaction and quality of life

Table 1: Socio-demographic variables significantly associated with stress (N=564)

Variable	Category	Participants Number (%)	Stress: High Number (%)	Stress: Low Number (%)	p-value
Education	< Grade 7	177 (32)	50 (28)	**127 (72)**	$p < 0.05$
	Grade 8-11	163 (29)	54 (33)	109 (67)	
	Grade 12	148 (27)	59 (40)	89 (60)	
	> Grade 12	65 (12)	**39 (60)**	26 (40)	
Housing tenure	Owned and paid off	125 (23)	36 (29)	**89 (71)**	$p < 0.05$
	Owned but not yet paid off	61 (11)	**26 (43)**	35 (57)	
	Rented	270 (51)	**114 (42)**	156 (58)	
	Occupied rent-free	77 (14)	21 (27)	**56 (73)**	
Transport type	Bus	139 (26)	37 (27)	**102 (73)**	$p < 0.05$
	Private vehicle	137 (25)	**66 (48)**	71 (52)	
	Taxi	109 (20)	36 (33)	73 (67)	
	Staff transport	93 (17)	37 (40)	56 (60)	
	Walk	60 (11)	21 (35)	39 (65)	
Debt	Yes	327 (61)	**139 (43)**	188 (57)	$p < 0.05$
	No	211 (39)	61 (29)	**150 (71)**	
Alcohol use	Never	252 (46)	81 (32)	**171 (68)**	$p < 0.05$
	≤ Once a month	156 (28)	49 (31)	**107 (69)**	
	> Once a month	143 (26)	**72 (50)**	71 (50)	
Sleep problems	Yes	135 (26)	**74 (55)**	61 (45)	$p < 0.05$
	No	384 (74)	118 (31)	**266 (69)**	
Fatigue	Yes	132 (24)	**66 (50)**	66 (50)	$p < 0.05$
	No	416 (76)	137 (33)	**279 (67)**	
Sick leave	<5 days in previous year	386 (70)	124 (32)	**262 (68)**	$p < 0.05$
	≥5 days in previous year	164 (30)	**77 (47)**	87 (53)	
Job satisfaction	Satisfied	282 (51)	92 (33)	**190 (67)**	$p < 0.05$
	Not satisfied	271 (49)	**112 (41)**	159 (59)	
Quality of life	Good	199 (36)	58 (29)	**141 (71)**	$p < 0.05$
	Not good	351 (64)	**146 (42)**	205 (58)	

- The main perceived causes of stress were financial problems, e.g. difficulty affording necessities and indebtedness
- Poor living conditions, a lack of recreational facilities, and family issues, including those of migrant workers living apart from family members or having dual families, were further perceived causes of stress
- Work-related causes included high workloads, production pressure, long working hours, poor working conditions, shortages of labour and materials, job insecurity, and strained relationships with colleagues
- Stress was considered to lead to a lack of focus and a higher risk of accidents at work

CONCLUSION

- Stress in mine workers in South Africa resulted from work-related, socio-economic and personal factors, and led to reduced health and safety
- In particular, stress was associated with high job demands, socio-economic and psychosocial challenges, along with alcohol abuse, fatigue, increased absenteeism and accidents at work, and reduced job satisfaction and quality of life
- It is recommended that mines focus on culture transformation and that improved wellness programmes be implemented

ACKNOWLEDGEMENTS

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Appendix G: Presentation 3

Pelders, J. and Nelson, G. (2018). Contributors to fatigue of mine workers in South Africa. *9^{th} Wits Cross Faculty Postgraduate Symposium.* University of the Witwatersrand, Johannesburg. 29-30 October 2018.

our future through science

Contributors to fatigue of mine workers in South Africa

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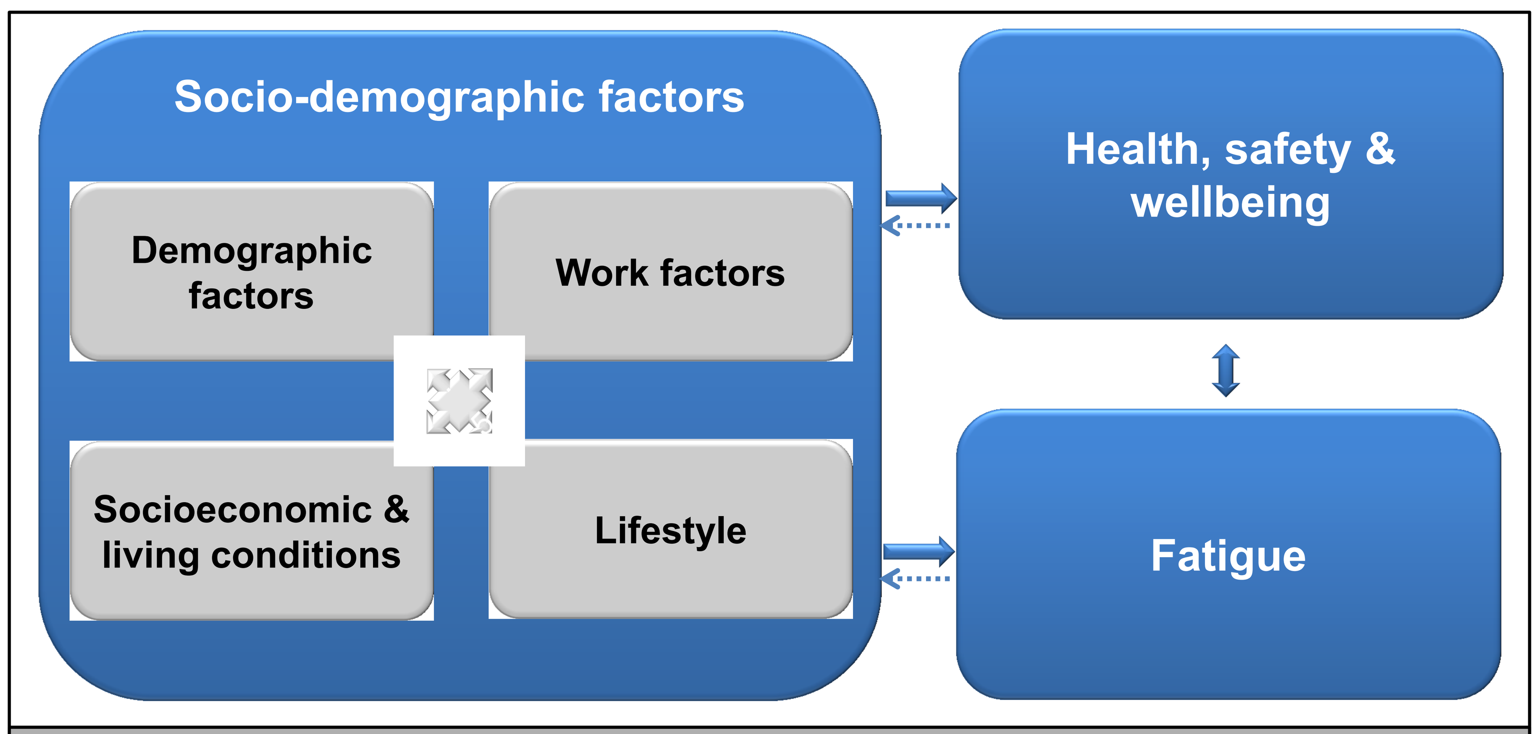
BACKGROUND

Fatigue:
- "A state of impaired mental and/or physical performance and lowered alertness arising as a result of or a combination of hard physical or mental work, health and psychosocial factors, or inadequate restorative sleep"[1]

Consequences of fatigue:
- *Reduced* vigilance, reaction time, awareness, decision-making ability, memory, motivation, mood, and health
- *Increased* errors and accidents[2-3]

Problem statement:
- Fatigue is a health and safety risk in the South African mining industry (SAMI)
- The SAMI is historically male-dominated, with poor socioeconomic and living conditions
- There is a lack of research about demographic and socioeconomic contributors to fatigue[4-5]



Conceptual framework

AIM

To assess the socio-demographic contributors to fatigue of mine workers in South Africa

METHODS

- Cross sectional, mixed methods study
- Four gold and one platinum mine in South Africa in 2017
- 21 focus group discussions with 154 participants, including managers, labour representatives, and mine workers
- Questionnaires completed by 564 mine workers
- Thematic analysis used to analyse the qualitative data
- Descriptive and inferential statistics, including Chi^2 tests, used to analyse the quantitative data ($p<0.05$)
- Ethics approval granted by the CSIR and University of the Witwatersrand research ethics committees (Reference numbers: 85/2013 and M140444)

RESULTS

Participant characteristics:
- 88% male, and 60% <40 years old
- 77% worked in the gold sector, and 86% worked underground
- 28% were classified as fatigued

Associations with fatigue:
- Extended working hours, overtime, high job demands, harsh work environment, and resource constraints
- Younger age, indebtedness, a lack of recreational exercise, greater alcohol use, worse nutrition, and less sleep
- Higher stress, poorer health, increased use of sick leave, and lower job satisfaction (Table 1)

Table 1: Variables significantly associated with fatigue

Variable	Category	Participants Number (%)	Fatigue Number (%)	p-value
Age	<40 years	286 (60)	91 (32)	< 0.05
	≥40 years	191 (40)	41 (21)	
Education	<Grade 12	299 (61)	72 (24)	< 0.05
	≥Grade 12	192 (39)	63 (33)	
Country of origin	South Africa	385 (79)	118 (31)	< 0.05
	Other	104 (21)	17 (16)	
Debt	Yes	293 (61)	93 (32)	< 0.05
	No	191 (39)	42 (22)	
Exercise	Yes	247 (50)	55 (22)	< 0.05
	No	243 (50)	81 (33)	
Alcohol use	Once a month or less	365 (74)	92 (25)	< 0.05
	More than once a month	126 (26)	44 (35)	
Diet	Healthy	350 (72)	83 (24)	< 0.05
	Not healthy	139 (28)	53 (38)	
Sleep time before work	<6 hours	218 (45)	81 (37)	< 0.05
	≥6 hours	265 (55)	51 (19)	
Sleep problems	Yes	120 (26)	53 (44)	< 0.05
	No	347 (74)	77 (22)	
Stress	Low	309 (63)	62 (46)	< 0.05
	High	181 (37)	72 (54)	
Health	Good	411 (84)	100 (24)	< 0.05
	Not good	81 (16)	35 (43)	
Sick leave (previous year)	<5 days	348 (71)	86 (25)	< 0.05
	≥5 days	141 (29)	48 (34)	
Job satisfaction	Satisfied	254 (52)	54 (21)	< 0.05
	Not satisfied	239 (48)	82 (34)	

CONCLUSION AND RECOMMENDATIONS

- Demographic, work, socioeconomic, lifestyle, and wellness factors are associated with fatigue of mine workers in South Africa
- A change in workplace culture and improved employee wellness programmes are recommended
- Improved fatigue management would help to improve health, safety, and productivity in the SAMI

CSIR researchers in a test stope

Mine worker at a training facility

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Appendix H: Presentation 4

Pelders, J. and Nelson, G. (2018). Socio-demographic contributors to fatigue of mine workers in South Africa. *Wits Integrated Mine Health and Safety Research Group – Postgraduate Research Seminar.* University of the Witwatersrand, Johannesburg. 21 August 2018.

WITS INTEGRATED MINE HEALTH AND SAFETY RESEARCH GROUP
POSTGRADUATE RESEARCH SEMINAR – 21 AUGUST 2018

Socio-demographic contributors to fatigue of mine workers in South Africa

Pelders, J.L. and Nelson, G.

Fatigue is a safety hazard in the mining industry. Most related research has focussed on work-related causes, while limited research has assessed demographic and socio-economic contributors to fatigue. With increased scrutiny placed on socioeconomic and living conditions in the South African mining industry, and demographic changes, such as increasing numbers of women in mining, it is valuable to consider the impact of these factors on fatigue. The aim of the research was to assess socio-demographic contributors to fatigue of mine workers in South Africa.

This was a cross-sectional, mixed methods study. Data collection took place at 12 mines and one platinum smelter in South Africa from 2014 to 2017. Data were obtained from questionnaires, interviews and focus groups to gain an understanding of fatigue and its contributors at the study sites. Questionnaires were completed by 1515 mine workers, and interviews and focus group discussions were held with 391 participants, representing management, labour and workers. Thematic analysis was used to analyse the qualitative data, while the quantitative data were analysed using descriptive and inferential statistics ($p<0.05$). Ethical approval for the research was obtained from the CSIR Research Ethics Committee and the Human Research Ethics Committee of the University of the Witwatersrand.

Fatigue was associated with work-related factors, demographic and socioeconomic characteristics, living conditions, lifestyle, and health, safety and wellness. Contributors to fatigue included extended working hours, harsh working conditions, high workloads, and production pressures, along with younger age, longer commuting times, poor living conditions, a lack of access to amenities, low income, a large number of dependants, indebtedness, stress, lack of exercise, household responsibilities, poor nutrition, poor health, less sleep received, and sleep problems. Higher fatigue was also associated with higher levels of sick leave taken and accidents experienced in the previous year, and poorer job satisfaction and quality of life. Work and socio-demographic factors should be addressed in fatigue management plans. Reduced fatigue will contribute to improved health, safety, and sustainability of the industry.

Appendix I: Presentation 5

Pelders, J., Nelson, G. and Magweregwede, F. (2019). Shift cycles and fatigue in the South African mining industry. *International Mine Health and Safety Conference 2019.* The Southern African Institute for Mining and Metallurgy. Johannesburg. pp. 81-88.

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Shift cycles and fatigue in the South African mining industry

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Shift work and fatigue are health and safety risks in industry. The aim of this research was to assess contributors to fatigue of workers in the South African mining industry (SAMI), including shift cycles, commuting times and lifestyle factors. This paper summarises past and current research conducted by the Council for Scientific and Industrial Research (CSIR) on the topic. The research employed mixed methods, as both qualitative and quantitative data were collected. Numerous factors were associated with fatigue, including work, demographic characteristics, socioeconomic and living conditions, and lifestyle factors. Current research conducted at the Mandela Mining Precinct (MMP) involves the development of a framework for optimising shift cycles in the SAMI, which will consider aspects such as travelling times, working conditions, fatigue and productivity. A holistic approach to shift scheduling, and fatigue management, should be applied to improve worker health, safety and wellbeing, and industry sustainability.

INTRODUCTION

Fatigue is a health and safety risk, and contributes to accidents, injuries and fatalities in the mining industry (Schutte, 2010; Theron, 2014). Fatigue results in impaired performance, productivity, alertness, motivation and mood, increases the risk of error, and can lead to health problems, including mental illness, and increased use of sick leave (Åkerstedt et al., 2014; Bates 2009; Pfeifer, 2017; Schutte, 2010; South Africa, 2014; Theron, 2014). Shift cycle arrangements, job demands and conditions, commuting times, and individual and lifestyle factors all contribute to fatigue (Schutte, 2010; South Africa, 2014). Shift work is required in mining and many other industries, and refers to "an organisation of work where workers succeed each other at the same workplace while performing similar operations at different times of the day thus allowing longer hours of operation than feasible for a single worker" (South Africa, 2014, p. 36). Shift work has negative effects on social and domestic activities, and can lead to occupational incidents and long-term physical or psychological health impairments, including cardiovascular disease and diabetes (Baulk et al., 2009; Härmä et al., 2018). Numerous factors are associated with accident and fatigue risk during shift work, including night or early morning work, backward-rotating shifts, extended shift lengths, excessive overtime, inadequate shift breaks and high job demands (Härmä et al., 2018; South Africa, 2014; Spencer et al., 2006; Theron, 2014).

The mining industry is a significant contributor to employment and the economy in South Africa but faces sustainability challenges, including increased operational costs, decreased production, and health, safety, environmental and social issues (Chamber of Mines of South Africa, 2018; Singh, 2017). South African narrow-reef hard-rock underground mines are deepening, and distances to the work faces are increasing, which result in increased travelling times to and from the workplace, shorter time available at the rock face ('face times'), increased health and safety challenges, reduced production, and increasing costs (Minerals Council South Africa, 2018; Rupprecht, 2018a). Activities undertaken during the mining cycle, such as safety meetings and re-entry examinations, further shorten the available face times (Rupprecht, 2018a). As a result, the traditional shift lengths of 8 hours and 20 minutes might not support a daily conformant blast (Rupprecht, 2018a; 2018b). For the purpose of this research, a conformant blast was defined as a blast which conformed to the minimum standards of a particular mine, while assessing parameters such as safety, face advances, fragmentation, and rock removal. The effects of long commutes between home and work are also not well understood (Gumbie, 2018). Further research has been recommended to assess the total time taken from when a mine worker leaves home for work until returning home afterwards, and to better understand the impacts of the work cycle on workers (Gumbie, 2018; Rupprecht, 2018b).

Not enough research has focused on the associations between demographic characteristics and socioeconomic conditions, including commuting times, and fatigue. Further research on the impact of current conditions in the South African mining industry (SAMI), on shift cycles and fatigue, is also warranted. Better understanding of this will assist mining companies to select the most appropriate shift cycles in terms of health, safety and productivity.

The aim of the research summarised in this paper was to assess the effects of factors including shift cycles, commuting times and lifestyle factors, on fatigue in workers in the SAMI.

This work draws on research conducted by the Council for Scientific and Industrial Research (CSIR) over the past five years. Findings related to shift cycles and fatigue from four research projects are described. The findings from three of the studies have been published in scientific peer-reviewed journals (Pelders and Nelson, 2019a; 2019b; 2019c), and were included in a PhD thesis at the University of the Witwatersrand. The fourth study is ongoing and is being conducted as part of the Longevity of Current Mines (LoCM) programme of the South African Mining Extraction Research, Development and Innovation (SAMERDI) strategy at the Mandela Mining Precinct (MMP).

METHODS

The studies were cross-sectional and used mixed methods – both quantitative and qualitative data were collected from questionnaires, semi-structured interviews and focus group discussions. The research took place across 12 mines and one platinum smelter in South Africa. Participants were selected, using purposive and convenience sampling, and included management and labour representatives, and workers. The interviews and focus groups were audio-recoded, and the qualitative data were transcribed and then analysed using thematic analysis. The quantitative data from the questionnaires were analysed using basic and inferential statistics, at a 95% significance level. The results were verified using methodological triangulation. Research assistants, fluent in local languages, translated information and assisted workers to complete the questionnaires, where required.

The research was approved by the CSIR Research Ethics Committee (reference numbers: 85/2013 and 239/2017) and the University of the Witwatersrand Human Research Ethics Committee (clearance certificate number: M140222).

RESULTS

Study 1: Socioeconomic contributors to health and safety of mine workers in South Africa
The Mine Health and Safety Council (MHSC) commissioned a project titled 'Health and safety impacts of socioeconomic conditions and other matters relating to living conditions in the South African mining industry' (project number: SIM 13-09-01) (Hodgskiss et al., 2015). Data collection for this project took place in 2014 at three platinum, two gold, one coal, one diamond and one manganese mine in South Africa. Data were collected from interviews and focus group discussions with mine workers (n=120), labour representatives (n=18) and individuals in mine management (n=67), and from questionnaires completed by mine workers (n=875). Fatigue was identified as a safety-related concern, and the related data were further assessed, and described in a paper accepted for publication in *Work* (Pelders and Nelson, 2019c).

From the interviews and focus group discussions, it was ascertained that fatigue resulted from various factors, including physical job demands, harsh working conditions, long working hours, shift configurations, and long commuting times. Additional aspects associated with fatigue were poor health, the use of medication, inadequate nutrition, alcohol use or abuse, insufficient sleep, poor sleeping conditions, and psychological problems. Data from the questionnaires revealed that 16% of the participating mine workers usually felt 'very sleepy' at work. As shown in Table 1, higher subjective fatigue was statistically significantly associated with lower incomes, living in hostel accommodation or informal housing, lack of exercise, fewer hours of sleep, and poorer quality of life.

Table 1. Statistically significant associations of sociodemographic characteristics with fatigue – Study 1.*

Variable	Category	Number of participants	% participants	Fatigue (% yes)	Fatigue (% no)
Average monthly income	≤ R 5 000	247	29	24	76
	R 5 001 – R 7 500	256	30	17	83
	R 7 501 – R 10 000	139	16	12	88
	> R 10 000	212	25	10	90
House type	Formal brick dwelling	317	39	10	90
	Flat/townhouse/cottage	100	12	18	82
	Hostel	126	15	24	76
	Shack/informal housing	116	14	20	80
	Backroom	161	20	18	82
Sleep received	< 6 hours	449	52	23	77
	≥ 6 hours	409	48	9	91
Exercise	Never	393	46	21	79
	Once a week or less	237	28	11	89
	More than once a week	229	27	14	86
Quality of life	Good	432	51	8	92
	Not good	421	49	24	76

*Chi-square tests performed ($p<0.05$)

Study 2: Contributors to fatigue at a platinum smelter in South Africa
The CSIR conducted fatigue-related research at a platinum smelter in South Africa in 2016. Selected data from this research were analysed and the findings regarding the associations between demographic characteristics, work, living and socioeconomic conditions, and lifestyle characteristics, and fatigue were published in the March 2019 edition of *The Journal of the South African Institute for Mining and Metallurgy (SAIMM)* (Pelders and Nelson, 2019a).

Qualitative and quantitative data were collected from eight interviews with management representatives, two focus groups discussions with workers (n=24), and 75 questionnaires completed by workers.

Causes of fatigue mentioned during the interviews and focus group discussions included shift work, overtime, and work that was monotonous, repetitive or required high levels of concentration. Household responsibilities and social activities outside of working hours were also perceived to contribute to fatigue. Additionally, fatigue was perceived to be associated with age, sleep and stress. Data from the questionnaires showed that factors statistically associated with higher self-reported fatigue included younger age (≤35 years), renting or paying for housing, unhealthy diet, sleep disorders, higher stress, and lower job satisfaction (Table 2). More than half of the participants (52%) admitted to having unintentionally fallen asleep at work in the previous year, and 21% were usually 'moderately tired' to 'completely exhausted' when at work.

Table 2. Statistically significant associations of sociodemographic characteristics with fatigue – Study 2.*

Variable	Category	Number of participants	% participants	Fatigue (% yes)	Fatigue (% no)
Age	≤35 years	36	51	58	42
	>35 years	34	49	29	71
Housing tenure	Owned and paid off	6	9	17	83
	Owned by not yet paid off	25	36	40	60
	Rented	33	48	58	42
	Occupied rent-free	5	7	0	100
Healthiness of diet	Healthy	56	77	38	63
	Not healthy	17	23	65	35
Sleep disorder	Yes	11	16	73	27
	No	58	84	36	64
Stress	None/a little	48	68	27	73
	High	23	32	78	22
Job satisfaction	Good	39	55	67	33
	Not good	32	45	16	84

*Chi-square and Fisher's exact tests performed ($p<0.05$)

Study 3: Contributors to fatigue of mine workers in the South African gold and platinum sector
Further research relating to fatigue of mine workers was conducted by the CSIR in 2017 at four gold mines and one platinum mine in South Africa. The findings have been published in *Safety and Health at Work* (Pelders and Nelson, 2019b). Data were collected from 21 focus groups with individuals in mine management (n=48), union representatives (n=23), and mine workers (n=83), and questionnaires completed by 564 mine workers.

Table 3. Statistically significant associations of sociodemographic characteristics with fatigue – Study 3.*

Variable	Category	Number of participants	% participants	Fatigue (% yes)	Fatigue (% no)
Age	<40 years	286	60	32	68
	≥40 years	191	40	21	78
Debt	Yes	293	61	32	68
	No	191	39	22	78
Exercise	Yes	247	50	22	78
	No	243	50	33	67
Alcohol use	Once a month or less	365	74	25	75
	More than once a month	126	26	35	65
Diet	Health	350	72	24	76
	Not healthy	139	28	38	62
Sleep time before work	<6 hours	218	45	37	63
	≥6 hours	265	55	19	81
Sleep problems	Yes	120	26	44	56
	No	347	74	22	78
Health	Good	411	84	24	76
	Not good	81	16	43	57
Sick leave	<5 days	348	71	25	75
	≥5 days	141	29	34	66
Job satisfaction	Satisfied	254	52	21	79
	Not satisfied	239	48	34	66
Stress	Low	309	63	20	80
	High	181	37	40	60

*Chi-square tests performed ($p<0.05$)

Participants in the interviews and focus group discussions attributed fatigue to extended working hours, harsh working conditions, high job demands, and resource constraints. Aspects relating to demographic characteristics, socioeconomic and living conditions, lifestyle, health and wellness, were also associated with fatigue. Information collected from the questionnaires showed that higher fatigue was significantly associated with younger age, being in debt, a lack of recreational exercise, unhealthy diet, increased alcohol consumption, and a lack of sleep. Furthermore, higher levels of fatigue were associated with poor self-rated health, increase in sick leave taken, higher levels of stress, and lower job satisfaction (Table 3). Close to half of the participants (45%) usually received less than six hours of sleep before a work shift, and 14% usually felt more than 'a little tired' at work.

Current study: Development of a framework to optimise shift cycles in the SAMI

Current research commissioned by SAMERDI's LoCM programme aims to develop a framework to optimise shift cycles in the SAMI, while considering factors including productivity and fatigue. The need for this research was identified by the programme in 2017 and 2018 (Gumbie, 2018; Rupprecht, 2018b), in which key issues that constrain conventional narrow-reef underground gold and platinum group metals (PGM) mines from meeting their productivity and occupational health and safety (OHS) targets were identified. Both technical and people-centred issues were identified as constraints to zero harm production. Conventional mines are still highly labour-intensive, and are highly dependent on people to deliver on productivity, quality and OHS targets. Thus, the mines are vulnerable to negative people-centred issues such as non-conformance with mine standards and lack of a high-performance work culture. On the technical side, bottlenecks were identified in mining cycle activities, such as cleaning, support, drilling and blasting. The aforementioned inefficiencies are worsened by the limited available face time, which is no longer adequate for various production-related tasks to be completed, as a significant part of the shift time is consumed by travelling to and from the work place, and by completing other OHS obligations. The mines are getting deeper and mining activities have progressed further from the shafts, which has resulted in serious challenges in logistics (transportation of man, material and ore) and the management of OHS. To this end, a study was commissioned to develop a framework to optimise shift cycles for OHS and productivity in South African underground narrow-reef hard-rock underground mines.

Numerous off-mine and in-mine considerations need to be made when designing shift cycles. Off-mine considerations include social and economic factors such as living conditions, family responsibilities, and worker commuting times to and from work, which have an impact on fatigue, and the physical and mental well-being of the workforce. In-mine factors include prevailing mine environmental conditions (temperature, humidity, air quality etc.), travelling times within the mine, and ancillary activities that impact on available face times in underground work environments. Other factors such as maintenance, logistics, availability of resources, quality of supervision, work-life balance, absenteeism and workplace culture, should also be considered when designing shift cycles. The resulting framework is envisaged to assist the mining industry to use a holistic approach to develop appropriate shift cycles. Changing shift cycles at any workplace is a fundamental change, requiring a proper change management process. Some key elements of a structured change management process include management and workforce buy-in, commitment and support, mitigation of potential adoption constraints, adequate communication, engagements and feedback with all the stakeholders.

DISCUSSION

Fatigue is a health and safety challenge in the SAMI, and the findings from the three completed studies showed that many workers experience high levels of fatigue at work. It is evident that fatigue is associated with numerous factors, including work-related factors, demographic characteristics, socioeconomic and living conditions, lifestyle, health, safety and wellness. The focus of the research was on sociodemographic contributors to fatigue, as this was identified as a research gap. However, during the course of the research, numerous work-related contributors to fatigue were identified. These contributors included extended working hours, overtime, shift configurations, labour-intensive work, work that was monotonous, repetitive, or required high levels of concentration, production pressure, a lack of resources, and harsh working conditions, including heat and humidity in underground workplaces, and those requiring long travelling distances. Similar findings relating to shift work and fatigue in the SAMI have been reported in literature (Härmä et al., 2018; South Africa, 2014; Spencer et al., 2006; Theron, 2014). Fatigue was more prevalent in younger workers, which could be a consequence of a lack of experience, participating in age-related social activities, or because workers that are least able to cope with the job demands may not stay for long (or grow older) in the job (the 'healthy worker effect').

Fatigue was also associated with socioeconomic and living conditions, and lifestyle factors. These factors included lower incomes and indebtedness, paying for accommodation, not living in formal houses, poor nutrition, lack of recreational exercise, increased alcohol use, insufficient sleep and sleep problems. Workers with financial problems might work extended hours in order to receive bonus or overtime pay, which could cause fatigue. Financial problems were also a major reported cause of stress which, in turn, was a primary cause of sleeplessness, leading to fatigue. Housing and sleeping conditions, including noise, exposure to adverse weather, and limited access to services and amenities are also likely to result in fatigue as they impact on health, and the amount and quality of sleep received. Lifestyle factors such as diet, exercise and alcohol use, might be causes or effects of fatigue. Longer commuting times to and from work were also suggested as contributors to fatigue: long commutes reduce the amount of time available to attend to household responsibilities and to sleep (Pfeifer, 2017).

Fatigue was also associated with higher stress, lower job satisfaction, lower quality of life, increased use of sick leave and poorer self-rated health. These findings support and bolster those reported in the literature, which have highlighted impacts of fatigue on absenteeism, and impaired OHS and wellness (Åkerstedt et al., 2014; Baulk et al., 2009; Härmä et al., 2018; South Africa, 2014).

Research currently underway at the MMP focuses on the development of a framework to optimise shift cycles in the SAMI, to maximise productivity, while minimizing worker fatigue. Numerous factors need to be considered when assessing shift cycles, including worker commuting times and ancillary activities that impact face times in underground work environments. Impacts of shift cycles on workers include health, safety and social factors. Factors such as maintenance, logistics, stope heat and humidity, resources, supervision, absenteeism and workplace culture should also be considered. The resulting framework intends to provide industry stakeholders with a holistic approach to ascertain the most appropriate shift cycles for each operation. Related change processes and stakeholder engagements should also be carefully managed.

Limitations

The use of purposive and convenience sampling can result in bias, and the findings might not fully represent the SAMI. However, participants from a range of workplaces and job positions were selected to improve the generalisability of the findings. The use of self-report data can be a limitation as differences in understanding, personality and mood can affect responses. The complexity of fatigue and its measurement is also a challenge but validated tools were used to measure fatigue to minimise this bias. The cross-sectional nature of the studies prevented the assessment of cause and effect of fatigue, but data from the interviews and focus group discussions provided insight into reasons for associations between the different variables and fatigue. We believe that, despite the limitations, the findings from this research provide valuable information about, and insight into fatigue in the mining industry.

CONCLUSION

Numerous factors including work-time arrangements, job demands, work conditions, and demographic-, socioeconomic-, living condition-, or lifestyle-related factors can contribute to fatigue. Fatigue management and shift schedule arrangements in the South African mining sector need to be holistically assessed to ensure optimal productivity and to minimize health and safety risks. Changing shift cycles would require a structured change management process for successful implementation. Reduced fatigue and optimal shift scheduling will contribute to the sustainability of the mining industry.

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Appendix J: Deviations from study protocol

Deviations from study protocol

The original title of the PhD was "The association between living conditions and fatigue of mine workers in South Africa". The proposed objectives were:

- To describe the living conditions of mine workers employed at nine mines in South Africa;
- To determine the demographic, work, living condition, lifestyle, and psychosocial risk factors for fatigue of mine workers employed in these nine mines;
- To make an assessment of the housing of mine workers at a specific mine in South Africa and to gain an understanding of the perspectives of those living in this housing about living conditions and fatigue; and
- To make an in-depth assessment of fatigue and its association with the living conditions of mine workers at the same specific mine in South Africa.

These objectives were proposed to be fulfilled following the completion of two study phases. The first planned phase entailed conducting fieldwork at nine mines from a range of commodities in South Africa. The second planned phase comprised a more detailed assessment at one of the nine mines. The first phase of the study linked to Objectives 1 and 2, while Objectives 3 and 4 were further informed by the second phase. However, the project plan was adapted as the study progressed.

The first phase of the study was completed as planned at eight mines. Data collection was not completed at the ninth mine, as it was indicated that sufficient data was gathered at eight mines. Time constraints and difficulties in gaining access to mines also contributed to this decision. Data collected in this first study phase was completed as part of a larger project. In the project contract signed at the onset of the study, it was stipulated that papers may be published using data from the study, subject to review by the funder. However, upon completion of the project, the study funder requested that no papers be published with the use of study data, as a result of the sensitivity of the findings at the time. This resulted in an adaptation of the original project plan.

It was decided that further data collection take place at other mines that did not take place in the first phase of the study. It was uncertain at the time whether the funder would review the decision of refusal to publish at a later stage. Furthermore, following the analysis of data gathered in the first phase of the study, it was evident that various demographic and non-work factors, in addition to living conditions, had important influences on worker fatigue. As such, the scope of the next phase of the study was broadened to incorporate a range of contributors to fatigue, rather than living conditions alone. Further data were collected at a platinum smelter, one platinum mine, and four gold mines.

Three phases of fieldwork were ultimately conducted, namely:

- At eight mines (3 platinum, 2 gold, 1 coal, 1 diamond and 1 manganese) in South Africa between June and November 2014;
- At a platinum smelter in March 2016; and
- At five mines (4 gold and 1 platinum) in March 2017.

Papers were drafted based on data collected during first phase of the study, in the hope that the funder would condone publication after sufficient time had passed. The funder eventually reviewed and permitted the publication of the first paper in March 2017. The second paper was completed after this time.

The objectives of the study were refined accordingly, as follows:

- To describe the living conditions of mine workers at eight mines in South Africa;
- To determine associations between demographic, work, living condition, lifestyle, and psychosocial variables with health, safety and wellbeing of workers at these eight mines;
- To assess contributors to fatigue of workers at a platinum smelter in South Africa; and
- To assess contributors to fatigue of workers in the South African gold and platinum sector.

Appendix K: Interview and discussion guide on the effects of socioeconomic and living conditions on health and safety

Participant ID: ____________
Date: ____________

Stakeholder interview / focus group

1. What are the main issues about the socioeconomic conditions of workers at this mine? (e.g. income, employment, education)
   ____
   ____

2. What are the main issues about the living conditions (and housing) of workers at this mine?
   ____
   ____

3. What community services and facilities are available to workers at this mine? (E.g. education, healthcare services, crèches, recreational facilities, religious centres, transport and shops)? Are these adequate?
   ____
   ____

4. As far as you know, what social development plans is the mine involved with? Are these helping?
   ____
   ____

5. What are the main health challenges faced by workers at this mine?
   ____
   ____

6. What are the main safety challenges faced by workers at this mine?
   ____
   ____

7. How do you think that the socioeconomic conditions and the living conditions of the workers at this mine affect their health, if at all?
   ____
   ____

8. How do you think that the socioeconomic conditions and the living conditions of the workers at this mine affect their safety at work, if at all?
   ____
   ____

9. What changes need to be made to improve the socioeconomic and living conditions of workers at this mine?
   ____
   ____

10. What changes need to be made to improve the health and safety of workers at this mine?
    ____
    ____

Additional comments regarding this interview:

____

____

____

____

Appendix L: Interview and discussion guide on contributors to fatigue

Question guide

1. What do you think about fatigue at the mine (e.g. about the extent and risk of it)?

2. What do you think the main causes of fatigue are?

3. Do you think the following factors result in fatigue at the mine and, if so, how?

    3.1. Work-related causes (e.g. shift work, overtime, job demands, work environment, understaffing)
    3.2. Worker demographics (e.g. gender, age, education, migrant/local workers, contract/permanent workers)
    3.3. Lifestyle-related factors (e.g. diet, alcohol use, exercise, family responsibilities)
    3.4. Living or socioeconomic conditions (e.g. housing, indebtedness, access to services and amenities)
    3.5. Health and wellness (e.g. diseases or stress)

4. What would you recommend to reduce fatigue here?

Appendix M: Mine worker questionnaire

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Questionnaire for mine workers:
Non-work contributors to fatigue

Date: -----------------------------------

Workplace: -----------------------------------

Participant number: -----------------------------------

Demographics

1. Are you male or female?	Male ☐	Female ☐
2. How old are you?	☐ years	
3. What is your home language?	English ☐ Afrikaans ☐ IsiZulu ☐ IsiXhosa ☐ Setswana ☐ Xitsonga ☐ Southern Sotho ☐	Northern Sotho ☐ SiSwati ☐ Tsivenda ☐ IsiNdebele ☐ Other ☐ If other, then what? ________________
4. What is your race?	Black/African ☐ Coloured ☐ Indian/Asian ☐ White ☐	Other ☐ If other, then what? ________________
5. What is your marital status?	Married ☐ Engaged ☐ Unmarried but living with partner ☐	Single ☐ Divorced ☐ Widowed/widowered ☐
6. What area do you come from?	Eastern Cape ☐ Free State ☐ Gauteng ☐ KwaZulu Natal ☐ Limpopo ☐	Mpumalanga ☐ North West Province ☐ Northern Cape ☐ Western Cape ☐ Outside South Africa ☐
7. What is your highest level of education?	No schooling ☐ Some primary (Grade 1 – 6) ☐ Completed primary (Grade 7) ☐ Some secondary (Grade 8 – 11) ☐ Completed secondary (Grade 12) ☐	Higher than secondary ☐ Other ☐ If other, then what? ________________
8. What is your job title? Please write this down	Job title: ☐ *(E.g. Team Leader, Rock Drill Operator, Artisan etc.)?*	
9. Where do you work?	Surface ☐ Underground ☐	Other ☐ If other, then what? ________________
10. What shifts do you work?	Day shifts only ☐ Day and night shifts ☐	Night shifts only ☐
11. Are you a permanent or a contract employee?	Permanent ☐	Contract ☐
12. How long have you been working at this mine?	Less than 1 year ☐ 1 – 5 years ☐ 5 – 10 years ☐ 10 – 15 years ☐	15 - 20 years ☐ 20 - 25 years ☐ More than 25 years ☐

Living and socioeconomic conditions

13. What housing arrangement do you have with the mine?	Mine accommodation ☐ Living out allowance ☐ Bond repayment subsidy ☐ Housing capital subsidy ☐ None ☐	Other ☐ If other, then what? ________________
14. What type of house do you live in between work shifts?	Formal brick house (non-RDP) ☐ RDP house ☐ Flat/townhouse/cottage ☐ Shack/informal dwelling ☐ House/room in backyard ☐ Hostel/mine residence (high density) ☐	Other ☐ If other, then what? ________________
15. Where do you live?	Mine premises ☐ Suburban area ☐ Rural area ☐ Township ☐ Informal settlement ☐	Other ☐ If other, then what? ________________
16. What is your housing payment status?	Owned and fully paid off ☐ Owned but not yet paid off ☐ Rented ☐ Occupied rent-free ☐	Other ☐ If other, then what? ________________
17. How far away from the mine do you live?	Less than 10km ☐ Between 10km and 29km ☐	Between 30km and 49km ☐ 50km or more ☐
18. How many people do you share a room with?	0 (no one else) ☐ 2 ☐ 4 ☐ 1 ☐ 3 ☐ More than 4 ☐ 2 ☐	
19. Do you have electricity in your house?	Yes ☐	No ☐
20. Do you have piped water in your house?	Yes ☐	No ☐
21. Do you have a flush toilet in your house?	Yes ☐	No ☐
22. Do you trust the people living in your community?	Yes ☐ Sometimes ☐ No ☐	
23. How do you usually get to or home from work?	Staff transport ☐ Bus ☐ Taxi ☐ Private vehicle – driving ☐ Private vehicle – lift club ☐	Walk ☐ Other ☐ If other, then what? ________________
24. How long does it usually take you to get to or home from work?	Less than 15 minutes ☐ 15 - <30 minutes ☐ 30 minutes - <1 hour ☐	1 - <1 ½ hours ☐ 1 ½ - <2 hours ☐ 2 hours or more ☐
25. Do you consider your house near the mine to be your permanent home?	Yes ☐	No ☐

26. What is your average monthly salary (after deductions and including bonuses)?	Less than or equal to R5 000 ....☐ R5 001 – R7 500........☐ R7 501 – R10 000........☐ R10 001 – R12 500........☐ R12 501 – R15 000........☐ R15 001 – R17 500........☐ R17 501 – R20 000........☐ More than R20 000 ....☐
27. How many people depend on this income?	1 ....☐ 2 ....☐ 3 ....☐ 4 ....☐ 5........☐ 6........☐ 7........☐ 8........☐ 9........☐ 10........☐ More than 10 ....☐
28. Do you find it difficult to pay for all the things that you need?	Always........☐ Often ....☐ Sometimes........☐ Occasionally........☐ Never........☐
29. Do you owe money to anyone (e.g. a loan shark)?	Yes ....☐ No........☐

Lifestyle, health and wellness

30. How often do you exercise in your free time (e.g. play soccer or jog)?	Never........☐ Once a week or less ....☐ 2 – 3 times a week........☐ 4 – 5 times a week ....☐ Every day ....☐
31. Do you smoke?	Yes ....☐ No........☐
32. On average, how often do you drink alcoholic drinks?	Never........☐ Occasionally (once a month or less) ....☐ Sometimes (once a week or less) ....☐ Moderately (a few drinks every week)........☐ Frequently (more than one drink every day) ....☐
33. How healthily do you usually eat?	Very healthily ....☐ Healthily ....☐ Neither healthily or unhealthily ......☐ Unhealthily ....☐ Very unhealthily ....☐
34. How is your health?	Very good........☐ Good ....☐ Neither good nor bad........☐ Bad........☐ Very bad........☐
35. Do you take any medication?	Yes ....☐ No........☐ If yes, then what? ____________________
36. How many days of sick leave did you take in the last year?	None at all........☐ 1-4 days ....☐ 5-9 days ....☐ 10-14 days ....☐ 15-19 days ....☐ More than 20 days ....☐
37. Have you been in an accident at work in the last year?	Yes ....☐ No........☐
38. How satisfied are you with your job?	Very dissatisfied........☐ Dissatisfied........☐ Neither satisfied or dissatisfied.... .☐ Satisfied ....☐ Very satisfied........☐

39. How stressed (anxious, worried) do you usually feel?	Not at all stressed .... ☐ A little stressed.............................. ☐ Moderately stressed .... ☐	Very stressed .... ☐ Extremely stressed .... ☐
40. What is the main thing that makes you feel stressed (e.g. money, relationships, work etc.)? Please write this down	______________________________ ______________________________	
41. How would you rate your quality of life?	Very poor .... ☐ Poor.. ☐ Neither poor nor good................. . ☐	Good .... ☐ Very good...................................... ☐
42. Do you think that you get enough sleep?	Yes .... ☐	No... ☐
43. How many hours of sleep do you usually get each day (24 hours) when you are working?	Less than 4 hours .... ☐ 4 - <5 hours.................................. ☐ 5 - <6 hours.................................. ☐ 6 - <7 hours.................................. ☐	7 - <8 hours.................................. ☐ 8 - <9 hours.................................. ☐ 9 hours or more............................ ☐
44. How many hours of sleep do you usually get each day (24 hours) when you are not working?	Less than 4 hours .... ☐ 4 - <5 hours.................................. ☐ 5 - <6 hours.................................. ☐ 6 - <7 hours.................................. ☐	7 - <8 hours.................................. ☐ 8 - <9 hours.................................. ☐ 9 hours or more............................ ☐
45. How well do you usually sleep?	Very badly .... ☐ Fairly badly.................................... ☐ Moderately .... ☐	Fairly well .... ☐ Very well.. ☐
46. Do you have problems sleeping?	Yes .... ☐	No .... ☐
47. What is the main disturbance you have when you are trying to sleep?	Light from outside .... ☐ Noise from outside.......................... ☐ People that I live with..................... ☐ Uncomfortable bed .... ☐ Sleep disorder................................ ☐ Stress or worries............................ ☐	Physical pains .... ☐ None.. ☐ Other .... ☐ If other, then what? ____________________
48. How sleepy have you usually felt in the past year?	Extremely alert.. ☐ Very alert.. ☐ Alert... ☐ Rather alert .... ☐ Neither alert nor sleepy.. ☐ Some signs of sleepiness .... ☐ Sleepy, no effort to stay awake .... ☐ Sleepy, some effort to stay awake.. ☐ Very sleepy, great effort to stay awake .... ☐	
49. Have you fallen asleep by mistake at work in the last year?	Yes .... ☐	No... ☐
50. How fatigued (tired, weary) do you usually feel when you are at work?	Fully alert, wide awake .... ☐ Very lively, but not at peak .... ☐ Okay, somewhat fresh .... ☐ A little tired, less than fresh .... ☐ Moderately tired, let down .... ☐ Extremely tired, very difficult to concentrate........................... ☐ Completely exhausted, unable to function effectively .... ☐	

Thank you for completing this questionnaire!

Please write down any comments that you have:

Appendix N: Ethics approval from the CSIR Research Ethics Committee

CSIR Research Ethics Committee
PO Box 395 Pretoria 0001 South Africa
Tel: +27 12 841 4060
Fax: +27 12 841 2476
Email:R&DEthics@csir.co.za

30 January 2014

Dear: Ms Jodi Hodgskiss

Approval of Protocol: **Health and safety impacts of socioeconomic conditions and other matters relating to living conditions in the South African mining industry.**

This is to confirm that your Protocol reviewed by the CSIR REC has been approved. The reference number of this research project is REF: 85/2013.This approval is granted under the condition that:

1. The researcher remains within the procedures and protocols indicated in the proposal, as well as the additions made to the procedures and protocols as indicated in the responses submitted to the questions of the REC, particularly in terms of any undertakings made and guarantees given.
2. The researcher notes that the research must be submitted again for ethical clearance if there is substantial departure from the existing proposal.
3. The researcher remains within the parameters of any applicable national legislation, institutional guidelines and scientific standards relevant to the specific field of research.
4. This approval is valid for one calendar year from the date of this letter.
5. The researcher submit bi-annual progress reports to the REC
6. The researcher immediately alert the REC of any adverse events that have occurred during the course of the study, as well as the actions that were taken to immediately respond to these events.
7. The researcher alert the REC of any new or unexpected ethical issues that emerged during the course of the study, and how these ethical issues were addressed. If unsure how to respond to these unexpected or new ethical issues as they emerge, the researcher should immediately consult with the REC for advice.
8. The researcher submit a short report to the REC on completion of the research in which it is indicated (i) that the research has been completed; (ii) if any new or unexpected ethical issues emerged during the course of the study; and if so, (iii) how these ethical issues were addressed.

We wish you all of the best with your research project.

Kind regards

Dr Mongezi Mdhluli

(CSIR REC Chair)

Dr Sandile Ncanana

(CSIR REC Secretariat)

Appendix O: Ethics clearance certificate from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand

M140444

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M140444

NAME:
(Principal Investigator) Ms Jodi Hodgskiss et al

DEPARTMENT: School of Public Health
Centre for Scientific and Industrial Research

PROJECT TITLE: Living Conditions and Fatigue in the South African Mining Industry

DATE CONSIDERED: 25/04/2014

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Gill Nelson

APPROVED BY: ________________________
Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 28/05/2014

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned researcl and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from th research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

________________________ 28/5/2014
Principal Investigator Signature M140444Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix P: Plagiarism declaration

Declaration: Student's contribution to article(s) and agreement of co-author(s)

I, Jodi Lyndall Pelders, student number 583086, declare that this thesis is my own work and that I contributed adequately towards research findings published in the articles stated below, which are included in my Thesis.

Signature of Student..**Date**...19/11/2019...............

Name of Primary Supervisor: Professor Gill Nelson

Signature of Primary Supervisor ....**Date**.........19/11/2019.......

Agreement by co-authors

By signing this declaration, the co-authors listed below agree to the use of the articles by the student as part of her thesis. In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Paper 1:

Title: Living conditions of mine workers from eight mines in South Africa

Journal name, year, volume and page numbers: Development Southern Africa, 2019, 36(3): 265-282. https://doi.org/10.1080/0376835X.2018.1456909.

Authors	Name	Signature	Date
1st author	Jodi Pelders		19/11/2019
2nd author	Gill Nelson		19/11/2019

Comments by primary supervisor:

Contributions by authors Jodi Pelders (JP) and Gill Nelson (GN) to the paper, based on ICMJE recommendations on criteria for authorship, as follows:

- Substantial contributions to the conception of the work: JP and GN
- Substantial contributions to the design of the work: JP
- Acquisition of data: JP
- Analysis of data: JP
- Interpretation of data: JP and GN
- Drafting the work or revising it critically for important intellectual content: JP and GN
- Final approval of the version to be published: JP and GN

Paper 2:

Title: Socio-demographic contributors to health and safety of mine workers in South Africa

Journal name, year, volume and page numbers: Work, 2019, 64: 67-76. http://doi.org/10.3233/WOR-192969.

Authors	Name	Signature	Date
1st author	Jodi Pelders		19/11/2019
2nd author	Gill Nelson		19/11/2019

Comments by primary supervisor:

Contributions by authors Jodi Pelders (JP) and Gill Nelson (GN) to the paper, based on ICMJE recommendations on criteria for authorship, as follows:

- Substantial contributions to the conception of the work: JP and GN
- Substantial contributions to the design of the work: JP
- Acquisition of data: JP
- Analysis of data: JP
- Interpretation of data: JP and GN
- Drafting the work or revising it critically for important intellectual content: JP and GN
- Final approval of the version to be published: JP and GN

Paper 3:

Title: Contributors to fatigue at a platinum smelter in South Africa

Journal name, year, volume and page numbers: The Journal of the Southern African Institute of Mining and Metallurgy, 2019, 199: 313-319. http://dx.doi.org/10.17159/2411-9717/2019/v119n3a11.

Authors	Name	Signature	Date
1st author	Jodi Pelders		19/11/2019
2nd author	Gill Nelson		19/11/2019

Comments by primary supervisor:

Contributions by authors Jodi Pelders (JP) and Gill Nelson (GN) to the paper, based on ICMJE recommendations on criteria for authorship, as follows:

- Substantial contributions to the conception of the work: JP and GN
- Substantial contributions to the design of the work: JP
- Acquisition of data: JP
- Analysis of data: JP
- Interpretation of data: JP and GN
- Drafting the work or revising it critically for important intellectual content: JP and GN
- Final approval of the version to be published: JP and GN

Paper 4:

Title: Contributors to fatigue of mine workers in the South African gold and platinum sector

Journal name, year, volume and page numbers: Safety and Health at Work, 2019, 10: 188-195. https://doi.org/10.1016/j.shaw.2018.12.002.

Authors	Name	Signature	Date
1st author	Jodi Pelders		19/11/2019
2nd author	Gill Nelson		19/11/2019

Comments by primary supervisor:

Contributions by authors Jodi Pelders (JP) and Gill Nelson (GN) to the paper, based on ICMJE recommendations on criteria for authorship, as follows:

- Substantial contributions to the conception of the work: JP and GN
- Substantial contributions to the design of the work: JP
- Acquisition of data: JP
- Analysis of data: JP
- Interpretation of data: JP and GN
- Drafting the work or revising it critically for important intellectual content: JP and GN
- Final approval of the version to be published: JP and GN

Appendix Q: Turnitin report

583086:JPelders_-_PhD_(25_Nov_19)_-_for_Turnitin.docx

ORIGINALITY REPORT

16%	9%	12%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Jodi Pelders, Gill Nelson. "Contributors to fatigue of mine workers in the South African gold and platinum sector", Safety and Health at Work, 2018 Publication	3%
2	www.tandfonline.com Internet Source	1%
3	www.scielo.org.za Internet Source	1%
4	researchspace.csir.co.za Internet Source	1%
5	www.hse.gov.uk Internet Source	<1%
6	repository.up.ac.za Internet Source	<1%
7	Di Milia, L.. "Demographic factors, fatigue, and driving accidents: An examination of the published literature", Accident Analysis and Prevention, 201103	<1%