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Highlights

- Psychometric analysis of a perceptual scale for measuring workers’ heat stress impact
- CFA and invariance test were used to assess the model fit
- The Cronbach’s α for the reliability of the instrument was excellent
- The four-domain model recorded good overall fit indices
- The model was variant across gender, age, working hours, work milieu and mining type

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Insert highlights and graphical abstract here about

Abstract

Heat exposure studies over the last decade have shown little attention in assessing and reporting the psychometric properties of the various scales used to measure impacts of occupational heat stress on workers. A descriptive cross-sectional survey including 320 small- and large-scale mining workers was employed to assess the construct validity of the social impacts of occupational heat stress scale (SIOHSS) in the Western Region of Ghana in 2017. A confirmatory factor analysis (CFA) and invariance analysis were carried out using AMOS version 25 and statistical product and service solutions (SPSS) version 26 to examine the model fit and establish consistency correspondingly across multiple groups (gender, age, working hours, type of mining and workplace setting). Empirically, our results depicted that effects on health and safety, behavioural, productivity and social well-being were each found to be reliable, with Cronbach's α of 0.722, 0.807, 0.852 and 0.900 respectively. Though there were issues of insufficient discriminant validity as some average variance extract (AVE) were smaller than the corresponding maximum shared variance (MSV), the CFA showed good model fit indices (CFI = 0.856, GFI = 0.890, TLI = 0.863, SRMR = 0.08, RMSEA = 0.08). Also, the model was variant for all constrained aspects of the structural model indicating a requirement for an adaptation of the instrument across groups. The good to moderate internal consistency and construct validity of the SIOHSS is adequate evidence for the confidence required for its reliability and accuracy in measuring the social impacts of occupational heat stress on workers.

Key words: Ghana, Mineworkers, Psychometric analysis, Reliability, Work-related heat stress

1. Introduction

Global climate is experiencing escalating temperature and humidity conditions, particularly within the tropical and sub-tropical areas of the world. The intensity of rising temperature and climate change is attributed to human-induced increases in greenhouse gas (GHG) emissions (UNFCCC, 2010). From the 1850s, there has been an increase (0.6 ± 0.2 °C) in average global temperature and this is estimated to rise a further 1.4 °C - 5.8 °C by 2100 (IPCC, 2014). Africa has experienced an estimated increase in temperature (~0.7 °C) since the 1850s and this is predicted to increase more rapidly than the global average increase during the 21st Century (IPCC, 2014). From 1960-2000, Ghana has experienced a mean temperature increase (1 °C) at a mean rate of 0.21 °C per decade and by 2060 and 2090, there is likely to be an increase of between 1.0 °C-3.0 °C and 1.5 °C–5.2 °C respectively (Government of Ghana [GoG], 2013, 2015). Typically, Ghana has high temperatures and its mean annual temperature vary in the range (24 °C - 30 °C) but temperatures can fall to a low (18 °C) in the southernmost parts and rise to a high (40 °C) in the northernmost parts (Asante & Amuakwa-Mensah, 2015).

In effect, the potential impacts of a warmer climate are substantial and varied, and include increased occupational heat exposure on workers, workplaces and the economies they support (Dunne et al., 2013; Kjellstrom et al., 2016; Varghese et al., 2020; Venugopal et al., 2016). Warmer climates result in the frequent incidents, risks and impacts of heat exposure events like heatwave and heat stress severity on workers in parts of world. The cases of heatstroke-related mortality amongst South African and Qatari mine workers is exemplary of heat exposure dangers (Gibson & Pattisson 2014; Wyndham 1994). In Europe, there have been recorded incidents of morbidity and mortality related to heatwaves in 2003, which culminated in excess death of 30,000 people in France (Robine et al., 2008).

To fully understand and measure these impacts, several conceptual and empirical studies have demonstrated the risks and evaluated the impacts of excessive heat exposure on cohorts of workers in various occupational settings (e.g., construction, manufacturing, agriculture, and mining industries) across the world (Nunfam et al., 2019b; Nunfam et al., 2019c; Venugopal et al., 2016; Xiang et al., 2014). The negative repercussions of occupational heat exposure on the safety, health, productivity, and psychosocial well-being of workers have been established to be worsening with escalating global warming and climate change (Dunne et al., 2013; Kjellstrom et al., 2016; Nunfam et al., 2019a). The extent of excessive heat exposure impacts and its social impacts on workers are evident in comorbidities, mortalities, productivity loses, and poor psychosocial well-being in various occupational locations (Dunne et al., 2013; Flouris et al., 2018; Gibson & Pattisson, 2014; Kjellstrom et al., 2016; Nunfam et al., 2018; Park et al., 2017). The social impacts of heat stress on workers are also manifested in insufficient time for family care and household chores, frequent family breakdown because of tiredness, bodily harm and relational disagreements (Nunfam et al., 2018; Venugopal et al., 2016). The social implications of heat stress on workers further leads to income reduction and employment loss occasioned by heat-related illness, absence from work and loss of productivity, which affects workers' societal network connections and access to communal facilities (Nunfam et al., 2018;Venugopal et al., 2016). This has necessited the formulation and implementation of policy paradigms, such as International Standards Organisation (ISO), National Institute for Occupational Safety and Health (NIOSH), International Labour Organisation (ILO) and 2030 Sustainable Development Goals (SDGs), to safeguard workers and workplace environments (ILO, 2016; ISO, 1989; NIOSH, 2016; United Nations (UN), 2015). In the last century, several validated indices (e.g., the Wet Bulb Globe Temperature

(WBGT), Predicted Heat Strain (PHS), and Universal Thermal Climate Index (UTCI)) have been developed to assess the magnitude of occupational heat stress hazards to various cohorts of indoor and outdoor workers (Brode et al., 2012; Lemke & Kjellstrom, 2012; Liljegren et al., 2008; Parsons, 2013). Chronic consequences of heat stress risks include comobidities (e.g., heat rash, kidney injuries, heat exhausion, and heat stroke), absenteeism, productive losses, slow work pace and mortality (Chapman et al., 2020; Glaser et al., 2016; Krishnamurthy et al. 2017; Varghese et al., 2020) These indices have been useful in empirical studies to evaluate the scope of heat stress impacts based on heat exposure risks factors including (1) environmental-related factors (e.g., temperature, air movement, humidity, and solar radiation); (2) occupational-related factors (e.g., physical workload, clothing, work-break regimes, piece rate scheme, and cooling systems); and (3) individual-related factors (e.g., age, sex, medical condition, rehydration, acclimatisation level, and metabolism rate) (Frimpong et al., 2017; Parsons, 2014; Schulte & Chun, 2009). However, these measuring devices are not able to assess workers' subjective perceptions of workplace heat stress risks and impacts on their health, productivity, behaviour and social well-being, given the conceptual and empirical understanding of heat exposure as a multifaceted phenomenon.

Special equipment (e.g. QUESTemp 34 and Lascar EL-USB-2-LCD data loggers) used in measuring heat stress indices are not only comparatively expensive, complex and need technical expertise, but they have the proclivity to interfere with workplace activities and require relatively longer periods of time in their practical use (Budd, 2008; Claassen & Kok, 2007; Gunga et al., 2008; Kenny et al., 2012). The equipment may also be restricted to assessing only heat exposure indices related to environmental and physiological risk factors but not workers' perceptions and impacts of occupational heat stress and adaptations measures (Cheung, 2007; Kenny et al., 2012). For this reason, several heat exposure-related studies have designed and used different observational, subjective judgement of heat exposure and perceptual scales (e.g., checklist, interviews and survey questionnaires) in measuring heat stress indices (Bethea & Parsons, 2002; Corleto et al., 2003; Dehghan et al., 2015; Kjellstrom et al., 2009a; Malchaire et al., 1999). Unlike heat stress monitoring equipment, observational-perceptual approaches are associated with less cost, quick response, less work interferences and they are not complex to use (Bethea & Parsons, 2002).

Extant literature based on a systematic review of 25 heat exposure-related studies (2007-2017) on social impacts of occupational heat stress and adaptation strategies of workers and further studies have shown the use of either WBGT data loggers (Ayyappan et al., 2009; Crowe et al., 2010) or observational-perceptual approach (Flocks et al., 2013; Stoecklin-Marois et al., 2013; Xiang et al., 2016) or a combination of both methods (Balakrishnan et al., 2010; Krishnamurthy et al., 2017; Hansson et al., 2019; Sett & Sahu, 2014) to assess heat stress indices (Hansson et al., 2019; Nunfam et al., 2018). An eclectic blend of these research approaches have the tendency to provide a more comprehensive view of the environmental, occupational and individual related heat stress indices as well as workers' perceptions of occupational heat stress impacts.

Within the last decade, research interests in existing literature based on heat exposure studies in Africa, which have employed either WBGT indices or observational-perceptual methods, or both, to assess occupational heat stress have increased (Frimpong et al., 2020; Frimpong et al., 2017; Ngwenya et al., 2018; Nunfam et al., 2020). However, in these studies little attention have focused on assessing and reporting the psychometric properties of scales used in measuring the impacts of occupational heat stress on workers especially in Ghana. We, therefore, fill this gap by proposing and testing a reliable and valid psychometric scale with the potential of opening a novel door in workplace heat exposure studies. This will also help in measuring workers' perceptions of occupational heat stress impacts on their health, productivity, and psychosocial well-being. Given the absence of a valid and reliable observational-perceptual scale in guaging occupational heat stress impacts, the unanswered question is, what is the extent of reliability and construct validity of the social impacts of occupational heat stress scale (SIOHSS) for small- and large-scale mining workers in the Western Region of Ghana? Hence, the significance of our research centres on providing information on the psychometric properties of the SIOHSS which could have valuable conceptual and practical implications for heat exposure research, heat stress evaluation programmes, and workplace health and safety assessment to inform policy decisions.

2. Materials and methods

2.1 Study design, participants and sampling

Consistent with the post-positivist methodological viewpoint, this study employed a descriptive cross-sectional research design to assess the research problem at a point in time (Creswell, 2013; Sarantakos, 2012). Self-reported survey responses from small- and large-scale gold mining workers in the Western Region of Ghana were used to assess the construct validity of the SIOHSS for mining workers (Creswell & Plano Clark, 2017; Mertens, 2015). The dataset consisted of survey responses from 320 mining workers in Ghana engaged in small-scale mining (SSM) and large-scale mining (LSM). LSM is typically dominated and operated by multinational firms who use advanced technology and equipment while the SSM is usually operated by local people in the informal sector who use inadequate technology and rudimentary equipment. A response rate (83.3%) was retrieved from 384 participants who were recruited after being randomly selected from a projected population of over one million mining workers from five mining sites in the Western Region of Ghana (Nunfam et al., 2019b). Given an estimated population size (over 1,000,000) mining workers, a sample size (384) workers was determined for the study (Krejcie & Morgan, 1970). The survey participants were selected based on their literacy level (i.e. basic ability to read, write and speak English), worked for a licensed mining company for at least one year, were an adult (over 18 years), which is the youngest Ghanaian permissible working age and competent to give informed consent. However, the study excluded vulnerable working people like children under the legal employable age (under 18) years, workers of unlawful mining companies, non-gold extractive companies, and workers not able to read and write.Workers were aged between 21 and 61 (M = 35.10, SD = 8.20). However, the distribution of the 320 retrieved responses were skewed across the categories of age (92.2% younger (21-49years) vs 7.8% older (50-61years) workers), sex (80.9% males vs 19.1% females), education (2.8% no formal education vs 97.2% formal education), type of mining (50.3% SSM vs 49.7% LSM), and work setting (66% indoor vs 34% outdoor). The sampling distribution of the type of mining activity across various demographic and work characteristics are summarised in Table 1.

Insert Table 1 about here

2.2 Instruments and data collection

The study relied on primary data (mining workers' background characteristics and social impacts of heat stress on workers' health and safety, behaviour, productivity and social well-being). It also included secondary data from relevant literature based on climate change, occupational heat stress impacts, equipment for measuring heat exposure, and contruct validity and reliability of a scale. Although self-reported suvey data is associated with the tendency of non-response, measurement and common methods bias, it allows the benefit of using multiple scale items to rate multifaceted latent constructs directly (Maula & Stam, 2019). The self-reported questionnaire which comprised 25 items in two sections included a Likert scale question items for social impacts of occupational heat stress across four constructs (health and safety effects (7 items), behaviour concerns (5 items), productivity effects (5 items) and social well-being issues (8 items)) and participants' demographics and work characteristics (e.g., age, sex, education, working hours, and workplace environment) (Table 1) (Nunfam, 2019). All the items were rated on a 5-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree

(5). The questionnaire was adapted from the validated survey instruments of the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme which has been deployed in similar research studies on workers' heat exposure (Kjellstrom et al., 2009a; Kjellstrom et al., 2009b; Nunfam et al., 2019b; Xiang et al., 2015).

We subjected the modified questionnaires to peer appraisal to facilitate face and content validity for the purposes of ensuring its clarity, appropriate use of words, reducing survey bias and revision of possible ambiguities. Further procedural remedies such as informing respondents of anonymity and privacy of response as well as encouraging participants' to answer honestly assisted to lessen common methods bias (Podsakoff et al., 2003; Podsakoff et al., 2012). Pretesting of the questionnaire also resulted in additional but slight changes to few items with low internal reliability. This study had ethics endorsement from the Human Research Ethics Committee of Edith Cowan University (Project # 17487) on 16th August 2017 before the fieldwork was conducted from October 2017 to January 2018. The Ghana Mineral Commision in concurrence with the management of the mining companies also gave permission and approval for the conduct of the study in Ghana (Nunfam, 2019). The self-administered questionnaires which typically took not less than 30 minutes to complete were administered outside of the regular shift or working hours (immediately before the start, during break or after work).The responses from the participants' self-administered questionnaire were then kept safe and secure to ensure confidentiality and anonymity of respondents.

2.3 Data analysis procedure

In an exploratory factor analysis (EFA), the appropriateness of the data was assessed using the Kaiser-Meyer-Olkin (KMO) statistic and the Bartlett's test of sphericity. Common factor analysis was carried out to ascertain the factor loadings. Cronbach's alpha (α) was calculated for the items to assess their internal reliability. The structural equation model (SEM) was then used in a confirmatory factor analysis (CFA). To assess the fit of the model, appropriate indices such as comparative fit index (CFI), root mean square error of approximation (RMSEA), goodness-of-fit index (GFI), and Tucker-Lewis Index (TLI) were used. We further calculated the composite reliability (CR) statistics to establish the construct validity or otherwise of the instrument (Collier, 2020). The average variance extract (AVE) and maximum shared variance (MSV) were used to assess the discriminant validity of the instrument. The results reached statistical significance at an alpha level of 0.05. Invariance analysis was performed to assess the specification equivalence across various groupings in the dataset, namely: gender (male and female); age group (subjects above average age and subjects below average age); working hours (normal and long); type of mining activity (SSM and LSM), and; workplace environment (outdoor and indoor) for unconstrained models, models constrained on the factor loadings, structural covariance loadings, and residual covariance loadings. IBM AMOS 25 was used for the CFA, SPSS Statistic 26, for the reliability assessment.

3. Results

3.1 Exploratory factor analysis

A KMO score of 0.889 indicated that the sample size was adequate. The Bartlett's test of sphericity further produced a p-value < 0.001, indicating that the dataset diverges significantly from the identity matrix, making the dataset suitable for data reduction. The Cronbach's α for the reliability of the instrument was 0.905. The internal consistency of the extracted domains was good with Cronbach's α statistics lying between $0.7 \leq \alpha < 0.9$. Table 2 presents the Cronbach's α and the item-delete Cronbach's α for the four-domain. Based on the item-delete Cronbach's α internal reliability assessment, 6 items were deleted.

Insert Table 2 about here

3.2 Confirmatory factor analysis

From the CFA, the four-domain model recorded good overall fit indices: (CFI = 0.856, GFI = 0.890, TLI = 0.863, SRMR = 0.08, RMSEA = 0.08). Figure 1 presents the standardised factor loadings from the structural model and as well indicates construct validity since all composite reliability (CR) test values for the various constructs are correspondingly above the 0.7 threshold. All the regression weights for the items were statistically significant ($p < 0.001$) (see Table 3). In terms of convergent and discriminant validity, the social well-being effect domain measured adequately (AVE = 0.644, MSV = 0.366). However, the average variance extract (AVE) were smaller than the maximum shared variance (MSV) for the productivity effect (AVE = 0.536, MSV = 0.774), health and safety effect (AVE = 0.320, MSV = 0.378) and behavioural effect (AVE = 0.583, MSV = 0.774). Additionally, the health and safety domain did not achieve convergent validity (AVE < 0.5).

Insert figure 1 about here

Insert Table 3 about here

3.3 Invariance analysis

A multi-group analysis was carried out to assess whether the four domains from the CFA were invariant across gender, age, number of working hours, type of mining engaged and workplace environment. Gender was categorised as male (*n = 259*) or female (*n = 61*), age was treated as a binary variable, with the dataset divided into those below (*n = 167*) or above (*n = 153*) the mean of 35.10. Workplace environment was also treated as a binary variable, with the dataset split into outdoor (*n = 211*) and indoor (*n = 109*). There were two types of mining activities, namely, SSM (*n = 161*) and LSM (*n = 159*). Table 4 displays the fit indices for the multi-group analyses. Constrained models were compared to the baseline model where no constraints were placed on all aspect of the four-factor structural model across multi-groups. Across multi-groups, the four-factor model was variant when the factor loadings, structural covariance loadings, and residual covariance loadings were constrained (*$p < 0.05$*). This implies that responses to the measures of the concept of heat stress across the four-domains differ among groups.

Insert Table 4 about here

4. Discussion

To the best of our knowledge this is the first study to assess the psychometric properties of the SIOHSS beyond content validity to establish its reliability and construct validity. The vulnerability principle indicates that the extent of severity related to occupational heat stress risk and impact explains the degree of susceptibility and risk of workers, and the scope of adaptation strategies to work-related heat stress determines the level of vulnerability (Ford et al., 2006; Kelly & Adger, 2000). Therefore, the degree to which workers' vulnerability is reduced and their adaptation strategies and adaptive capacity optimised hinges on how heat exposure indices are measured effectually using a robust instrument characterised by adequate construct validity and reliability.

Fundamentally, our findings demonstrate the suitability of the sample and dataset for factor analysis. The EFA showed that the internal consistency of the instrument's overall scale is excellent with Cronbach's α (0.905) and the sub-scales are good to moderately consistent (Nunnally, 1994), confirming the reliability of the SIOHSS instrument. The goodness-of-fit indices based on the CFA indicated good model fit between the theoretical and empirical models (CFI = 0.856, GFI = 0.890, TLI = 0.863, SRMR = 0.08, RMSEA = 0.08) (Collier, 2020), which confirms the construct validity of the SIOHSS instrument (Bentler & Bonett, 1980; Hu & Bentler, 1999). However, aside from the social well-being effect, the other domains showed inadequate evidence of convergent and discriminant validity. Our model did not achieve measurement invariance for all restricted aspects of the structural model across all the groups, signifying a condition for adapting the instrument across different socio-economic, cultural and demographic groups (Chen, 2008; Schmitt & Ali, 2014; Vandenberg & Morelli, 2016).

The good to moderate internal consistency and construct validity of the instrument is adequate proof of confidence required for its reliability and accuracy in measuring the social impacts of occupational heat stress on workers (Bentler & Bonett, 1980; Hu & Bentler, 1999; Nunnally, 1994). The probability of cross-cultural studies using this instrument to reliably measure with accuracy the effects of occupational heat stress on workers' health, productivity, behaviour and social lives in other settings is promising, though with caution (Chen, 2008). Special equipment such as QUESTemp 34 and Lascar data loggers are often complex and more appropriate for calculating physiological and environmental-related heat stress indices (Hansson et al., 2019; Kenny et al., 2012; Venugopal et al., 2016). Comparatively, the SIOHSS is less costly, easy to use in a short time, and does not require technical expertise, however its use with trained questioners is critical (Bethea & Parsons, 2002; Budd, 2008; Claassen & Kok, 2007; Gunga et al., 2008). It can also serve as a supplementary method for heat exposure researchers, occupational hygienists, and policy makers interested in evaluating workers' perceptions of workplace heat stress risks and impacts, perceived or otherwise, on their health, safety, productivity, behaviour and social well-being across various occupational settings (Nunfam et al., 2019a; Nunfam et al., 2018). However, it is essential to recognise and minimise the instrument's inherent limitations (e.g., skewed sample of workers and study location and inadequate multi-group measurement invariance). Thus, the actualisation of the instrument's potential requires further adaptation and reassessment across different workers, cultures and settings for its standardisation and efficient functioning (Chen, 2008).

The insufficient evidence of convergent and discriminant validity of the extracted domains except for social well-being effect, may be attributed to issues of conceptual misunderstanding of the multifaceted phenomenon of occupational heat stress among the sampled Ghanaian mining workers, in relation to their health and safety, productivity, behaviour and social well-being. Similarly, the evidence of inconsistency for all the constrained characteristics related to the structural model across the multi-groups may be related to differences in the workers' conceptual and language interpretation of the constructs for assessing the impacts of occupational heat stress on their health and safety, productivity, behaviour and social well-being (Chen, 2008; Schmitt & Ali, 2014). The observed lack of convergent and discriminant validity, and the inadequate measurement equivalence implies a significant conditional requirement for adapting this instrument across various groups in other locations. There are genuine concerns among measurement-oriented researchers regarding the internal consistency and construct validity of instruments which are used with several groups in various settings. Thus, the extent to which convergent and discriminant validity is achieved and an instrument measuring similar constructs across many groups can be influenced by differences in culture (e.g., clothes, architectural style, policies, procedures, traditions and values), conceptual understanding, and language interpretation (Chen, 2008; Schmitt & Ali, 2014).

Even though our study demonstrated significant contributions as evident in the adequacy of the reliability and construct validity of the instrument, it is not without limitations. Firstly, the study relied on recollections of participants' perceptions and experiences of occupational heat stress effects on workers' health and safety, productivity, behaviour and social well-being; however, this may be linked to the possibility of reminiscence bias (Nunfam, 2019). Secondly, the participants in this study were sampled from mining sites located in only one region of Ghana (Nunfam et al., 2020). The participants did not include vulnerable populations such as children under required working age, workers who could not read and write, and those not part of the formal mining sector and mining other minerals except gold. This raises concerns of representativeness of the relatively adequate sample size to the population of mining workers including other cohort of workers (e.g., construction, manufacturing, and agriculture) exposed to the risk and impact of heat stress. Therefore, it is important to proceed with caution in generalising the outcome of this study until it is replicated among such categories of workers. Lastly, the study could not achieve multi-group measurement invariance and the sub-scales showed inadequate attributes of convergent and discriminant validity due to response bias (e.g. cultural difference, memory recall and conceptual understanding), which would have served as a supplementary measure of an enhanced and more robust scale.

5. Conclusion and implications

The study holds adequate promise to provide unequivocal evidence to uphold the rigorousness, reliability and construct validity of the SIOHSS in measuring workers' perceptions of occupational heat stress risks and impacts on their health and safety, productivity, behaviour and social well-being. Beyond the use of specialist equipment in heat exposure studies, this study provides an innovative alternative and/or supplementary method for gauging the impacts of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being. Though this preliminary evidence appears encouraging, similar and further studies on the psychometric properties of the SIOHSS amongst other cohort of workers, cultures and various settings is warranted for adequate standardisation. Further research has the potential of determining whether the SIOHSS is affected by response biases akin to social desirability response set, consistency motif and cultural differences. The outcome of such studies is essential to ensure the potential of sustaining its usefulness in measuring the risks and impacts of occupational heat stress on workers' health and safety, productivity, behaviour and social well-being. The instrument has the potential of being useful in the practices of hygienists and occupational health and safety officers, as well as adequately informing policy decisions by reducing vulnerabilities, improving adaptive capacity, and strengthening adaptation strategies of workers to occupational heat stress in the context of global warming and climate change. Researchers and other stakeholders interested in occupational heat stress evaluation are encouraged to participate in this ongoing effort in the development and adaptation of this instrument to fulfil its potential.

Credit authorship contribution statement

The paper was conceived and designed (Nunfam, V.F., Adusei-Asante, K., van Etten, E., Frimpong, K., & Oosthuizen, J.); data collected (Nunfam, V.F.); data analysed and interpreted (Nunfam, V.F., & Afrifa-Yamoah, E.); paper first drafted (Nunfam, V.F., & Afrifa-Yamoah, E.); paper reviewed for critical inputs (Adusei-Asante, K., van Etten, E., Frimpong, K., Mensah, I. & Oosthuizen, J.); and paper edited and approved for final version (all authors).

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Conflict of interest

None

Declaration of competing interest

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

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Figure

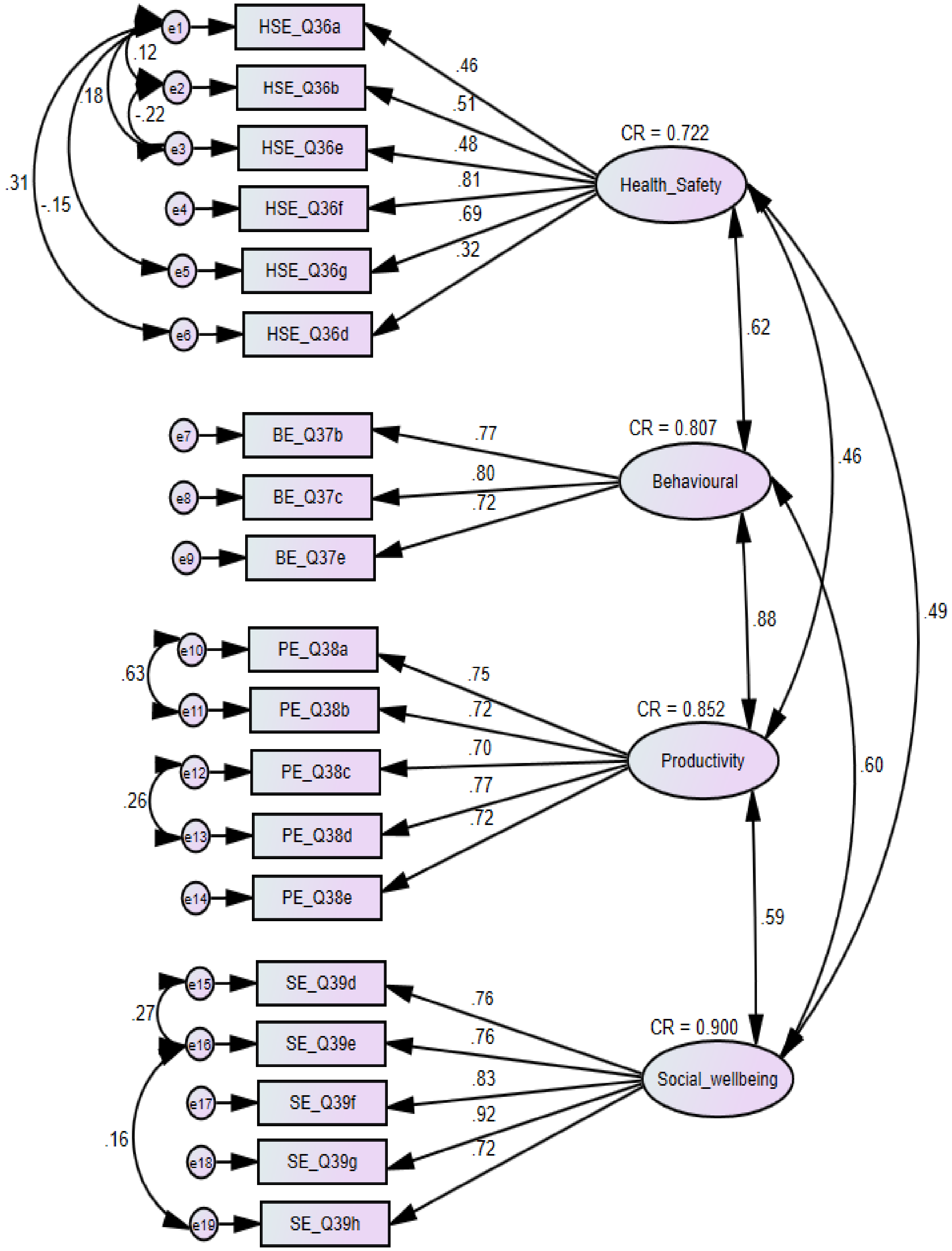
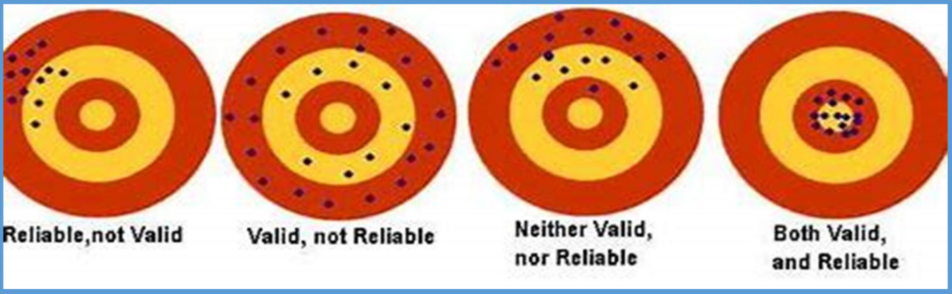


Figure 1: Confirmatory factor model showing the standardized factor loadings for the four-domain structure of the 19-item instrument.

Graphical abstract



EFA: Reliability
Cronbach's α:
Overall scale: 0.905
HSE=0.722, PE=0.807, BE=0.852, SE=0.900

CFA: Construct validity
Good overall fit indices:
CFI = 0.856, GFI = 0.890, TLI = 0.863, SRMR = 0.08, RMSEA = 0.08

Social impacts of occupational heat stress scale (SIOHSS)

Multi-group invariance analysis:
The 4-factor model was variant across multi-groups for all restricted aspects of the structural model ($p<0.05$)

Tables

Table 1: Background characteristics of the mining workers

Characteristics	Type of mining activity		
	SSM	LSM	Total
	F(%)	F(%)	F(%)
Sex			
Male	144(89.4)	115(72.3)	259(80.9)
Female	17(10.6)	44(27.7)	61(19.1)
Age group (*M* = 35.1; *SD* = 8.20)			
< 25	16(9.9)	11(6.9)	27(8.4)
25-34	72(44.7)	68(42.8)	140(43.8)
35-44	52(32.3)	57(35.9)	109(34.1)
45-54	18(11.2)	17(10.7)	35(10.9)
55+	3(1.9)	6(3.7)	9(2.8)
Level of education			
No formal education	9(5.6)	0(0.0)	9(2.8)
Basic education	79(49.1)	22(13.8)	101(31.6)
Secondary education	52(32.3)	69(43.4)	12137.8)
Tertiary education	21(13.0)	68(42.8)	89(27.8)
Years of working experience (*M* = 7.71; *SD* = 4.434)			
<5	67(41.6)	67(42.1)	134(41.8)
5-9	44(27.3)	57(35.9)	101(31.6)
10+	50(31.1)	35(22.0)	85(26.6)
Workload			
Light	8(5.0)	13(8.2)	21(6.6)
Medium	39(24.2)	59(37.1)	98(30.6)
Heavy	114(70.8)	87(54.8)	201(62.8)
Working hours			
8-10	124(77.0)	32(20.1)	156(48.8)
11-13	34(21.1)	127(79.9)	161(50.3)
14-16	3(1.9)	0(0.0)	3(0.9)
Workplace environment			
Outdoor	94(54.8)	117(73.6)	211(66.0)
Indoor	67(41.8)	42(26.4)	109(34.0)
Work around heat sources			
Yes	149(92.5)	130(81.8)	279(87.2)
No	12(7.5)	29(18.2)	41(12.8)
Frequency of work around heat sources			
Never	14(8.8)	41(25.7)	55(17.2)
Sometimes	26(16.1)	49(30.8)	75(23.4)
Often	109(68.8)	42(26.5)	151(47.2)
No response	12(7.5)	27(17.0)	39(12.2)

Note: n = 320; SSM, LSM, F, M and SD correspondingly represents Small-scale mining; Large-scale mining, frequency, mean and Standard deviation.

Source: Field survey, 2017

Table 2: Internal consistency of the four-factors structure (Cronbach's α if item is deleted)

Domain	Label	Item	Cronbach's α	Cronbach's α (if deleted)
Health & safety effect (HSE)	HSE_Q36a	Intensive physical mining work in hot weather conditions results in excessive sweating, headaches, and dizziness	0.722	0.686
	HSE_Q36b	Doing mining work in hot weather conditions increases the risks of tiredness, weakness, and muscles cramps or body pains		0.709
	HSE_Q36d	Excessive sweating due to heat exposure increases the risk of extreme thirst		0.713
	HSE_Q36e	Intensive work in hot weather conditions enhance the risk of injuries such as heat burns from the sun or hot surfaces		0.687
	HSE_Q36f	Fatigue, confusion and lack of concentration due to heat exposure during heavy mining work leads to heat-related injuries likes skin burns, bruises and cuts		0.622
	HSE_Q36g	Loss of grip and control of mining equipment due to sweaty hands results in heat-related injuries like skin burns, bruises, and cuts		0.676
Behavioural effect (BE)	BE_37b	Physical fatigue and excessive sweating due to heat exposure affects the attentiveness and judgement of mining workers	0.807	0.719
	BE_37c	Thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increase the fear and anxiety of mining workers		0.683
	BE_37e	Mistakes/errors during work in hot weather conditions are due to lack of training and information on risk of heat exposure		0.780
Productivity effect (PE)	PE_38a	Tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduces productive capacity of mining workers	0.852	0.834
	PE_38b	Lack of concentration, confusion and coordination as result of heat exposure leads to loss of productive efficiency of mining workers		0.838
	PE_38c	Heat-related illness and injuries increase the risk of absenteeism of mining workers		0.847
	PE_38d	Absenteeism of mining workers due to heat-related illness and injuries result in loss of income and employment opportunities		0.844
	PE_38e	Work-rest regimes due to excessive heat exposure increase the risk of reducing productivity of mining workers		0.860
	SE_39d	Erosion of income due to increased medical expense as a result of heat-related illness and injuries of mining workers increase the risk of family education, health and cohesion	0.900	0.885
	SE_39e	Increased medical costs due to heat-related illness and injuries affect the social health and cohesion of mining workers and their family		0.877

Social well-being effect (SE)	SE_39f	Increase irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increase the risk of poor interpersonal relationship with co-workers, family and community	0.876
	SE_39g	Heat-related illness and loss of productivity due to workplace heat exposure influence the social well-being and cohesion of mining workers, their families, co-workers, and communities	0.855
	SE_39h	Workplace stress and frustration due to heat-related tiredness and illness influence alcoholism, smoking, substance abuse, and workplace and domestic violence	0.893

- Cronbach's α greater than or equal to 0.7 is acceptable

Source: Field survey, 2017

Table 3: Regression weights for the fit of the four-domain structural model

Items		Domains	Estimate	Standard error	Critical Ratio	P-value
HSE_Q36a	<---	Health and Safety	1.000			
HSE_Q36b	<---	Health and Safety	1.443	.230	6.281	***
HSE_Q36e	<---	Health and Safety	1.668	.262	6.357	***
HSE_Q36f	<---	Health and Safety	2.898	.421	6.890	***
HSE_Q36g	<---	Health and Safety	3.055	.475	6.435	***
HSE_Q36d	<---	Health and Safety	.752	.145	5.195	***
BE_Q37b	<---	Behavioural	1.000			
BE_Q37c	<---	Behavioural	1.095	.077	14.183	***
BE_Q37e	<---	Behavioural	1.119	.089	12.620	***
PE_Q38a	<---	Productivity	1.000			
PE_Q38b	<---	Productivity	.974	.048	20.485	***
PE_Q38c	<---	Productivity	.928	.080	11.637	***
PE_Q38d	<---	Productivity	1.056	.082	12.880	***
PE_Q38e	<---	Productivity	.994	.081	12.307	***
SE_Q39d	<---	Social wellbeing	1.000			
SE_Q39e	<---	Social wellbeing	1.032	.063	16.436	***
SE_Q39f	<---	Social wellbeing	1.377	.089	15.464	***
SE_Q39g	<---	Social wellbeing	1.506	.088	17.187	***
SE_Q39h	<---	Social wellbeing	1.242	.095	13.107	***

*** values are significant at p-value < 0.001.

Note: HSE-Health and safety effects; BE- Behavioural effect; PE- Productivity effect; SE-Social well-being effect

Source: Field survey, 2017

Table 4: Multi-group analysis of fit indices by gender, age group and number of working hours for four-factor unconstrained model, model constrained on factor loadings, models constrained on structural covariance loadings and models constrained on residual covariance loadings

Model	χ^2	df	RMSEA	90% CI	SRMR	CFI	GFI	TLI	p-value
Unconstrained									
Across gender	885.79	274	0.084	[0.078, 0.090]	0.082	0.835	0.793	0.794	-
Across age group	783.60	274	0.075	[0.070, 0.083]	0.097	0.858	0.804	0.822	-
Across working hours	809.46	274	0.083	[0.077, 0.090]	0.109	0.831	0.787	0.789	-
Across mining type	939.89	274	0.087	[0.081, 0.094]	0.091	0.822	0.775	0.778	-
Across workplace environment	904.54	274	0.085	[0.079, 0.091]	0.081	0.830	0.785	0.788	-
Measurement weights									
Across gender	63.46	15	0.085	[0.078, 0.091]	0.082	0.822	0.775	0.789	<0.001
Across age group	36.87	15	0.076	[0.070. 0.082]	0.093	0.851	0.792	0.824	<0.001
Across working hours	49.57	15	0.084	[0.078, 0.090]	0.104	0.821	0.771	0.788	<0.001
Across mining type	43.14	15	0.087	[0.081, 0.093]	0.099	0.815	0.763	0.781	<0.001
Across workplace environment	43.03	15	0.085	[0.079, 0.091]	0.123	0.822	0.778	0.790	<0.001
Structural covariance									
Across gender	80.02	25	0.084	[0.078, 0.090]	0.083	0.820	0.775	0.794	<0.001
Across age group	56.04	25	0.075	[0.069, 0.081]	0.097	0.849	0.789	0.827	<0.001
Across working hours	93.34	25	0.084	[0.078, 0.090]	0.109	0.812	0.761	0.785	<0.001
Across mining type	93.21	25	0.088	[0.082, 0.094]	0.110	0.804	0.756	0.776	<0.001
Across workplace environment	64.54	25	0.084	[0.078, 0.090]	0.134	0.819	0.774	0.793	<0.001
Measurement residuals									
Across gender	178.39	53	0.084	[0.079, 0.090]	0.082	0.801	0.755	0.792	<0.001
Across age group	160.21	53	0.077	[0.071, 0.083]	0.097	0.828	0.774	0.820	<0.001
Across working hours	194.08	53	0.085	[0.079, 0.091]	0.108	0.812	0.740	0.782	<0.001
Across mining type	187.07	53	0.088	[0.082, 0.093]	0.112	0.787	0.733	0.777	<0.001
Across workplace environment	172.59	53	0.079	[0.079, 0.091]	0.133	0.798	0.748	0.788	<0.001

(df = Degrees of freedom; RMSEA = Root mean square error of approximation, CI = Confidence interval; SRMR = Standardized root mean square residual; CFI = Comparative fit index; GFI = Goodness-of-fit index; and TLI = Tucker-Lewis index: Acceptable thresholds – RMSEA < 0.08, SRMR < 0.05, CFI, GFI, TLI > 0.9)