Assessment of the ergonomics design of self-contained self-rescuer (SCSR) devices for use by women in mining

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Research agency: CSIR
Project number: SIM 16-09-02
Date: October 2017
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3. ABBREVIATIONS AND NOMENCLATURE

- **Anthropometry**: The measurement of human body dimensions.
- **BMI**: Body mass index.
- **Ergonomics**: The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design, in order to optimise human well-being and overall system performance.
- **OEM**: Original equipment manufacturer.
- **MHSC**: Mine Health and Safety Council.
- **PPE**: Personal protective equipment.
- **RPD**: Respiratory protective device.
- **RPE**: Respiratory protective equipment, or Rating of perceived exertion.
- **SANS**: South African National Standard.
- **Self-contained self-rescuer (SCSR)**: An SCSR is a closed-circuit respiratory protection device that produces oxygen and removes carbon dioxide for a limited time, independent of the surrounding atmosphere, and provides protection by isolating the user from harmful toxic gases.
- **TTC**: Tripartite Technical Committee.
4. ACKNOWLEDGEMENTS

The authors would like to thank the following people or institutions for their valuable contributions during the research project:

- The Mine Health and Safety Council (MHSC) for sponsoring the research.
- The participating mines for their support and all of the participants for their involvement, without which the research could not have taken place.
- Prof. Hans de Ridder and his team from North-West University for conducting the anthropometric measurements for the study.
- Mines Rescue Services for the use of its services and facilities.
- The original equipment manufacturers (OEMs) for providing the self-contained self-rescuer (SCSR) devices for use in the study, for the demonstrations of donning procedures and for their involvement in discussion of the project results and recommendations.
- The Tripartite Technical Committee (TTC) for SCSRss for its involvement in study discussions.
- Ms Renee Koen for conducting statistical analyses.
- Mr Riaan Bergh for his guidance and management of the research group.
5. EXECUTIVE SUMMARY

5.1. Project aims and objectives

The aim of this project was to assess the ergonomic design of self-contained self-rescuer (SCSR) devices for use by women in the South African mining industry. This aim was achieved by conducting a review of the relevant literature, gathering and analysing anthropometric data of female mineworkers in South Africa, and conducting a practical performance assessment of SCSR devices. From the results, dimensional limitations or short-comings of current SCSRs for use by women in mining were identified. On the basis of the findings, improvements to SCSR devices were proposed and discussed with subject matter experts, stakeholders, and original equipment manufacturers (OEMs) in the mining industry.

5.2. Literature review

The employment of women in the South African mining industry is relatively recent, given the history of male dominance in the sector (Zungu, 2012a). As a result of differences in the anatomical and physiological make-up between men and women, more research on the impact of mining work on the health and safety of workers of both genders is of paramount importance. The goal is to reduce the occurrence of occupational injuries and ill-health, and promote productivity among workers in the South African mining industry (Van Aardt et al., 2008; Zungu, 2013).

The literature has shown that females generally have lower physical work capacities, physical strength and heat tolerance than their male counterparts, and that they also differ in anthropometry and body composition (Van Aardt et al., 2008). However, the design of personal protective equipment (PPE) for mineworkers has generally been based on male anthropometric dimensions (AngloAmerican, 2012; van Aardt et al., 2008; Zungu, 2013). This may compromise women’s comfort, safety and performance at work (Van Aardt et al., 2008; Zungu, 2012a).
Body-worn SCSRs are part of the PPE required in coal mines and high-risk areas in hard rock mines, and they are designed to be worn on the body for the complete duration of a working shift (SANS1737:2008; Schreiber, 1999). These devices are used in case of emergency situations, such as fires or gas inundations to protect the user from contaminants in the ambient air and to provide breathable air for a sufficient amount of time to allow the mineworker to escape from the mine (Kowalski-Trakofler et al., 2008; Sandström, 2015; Schreiber et al., 2003; Teeravarunyou, 2008). Some of the known side-effects of wearing these units include discomfort, restriction of movement and physical load (Bakri et al., 2012; Coca et al., 2011; ISO/TS 16976-8:2013).

The goal of ergonomics is to ensure that tasks, jobs, products, machines, equipment, environments and systems are suited to people in order to improve the health, safety, productivity and comfort and well-being of workers (International Ergonomics Association, 2016; ISO/TS 16976-8: 2013; Schutte, 2005; Schutte and James, 2007; Schutte and Shaba, 2003). Anthropometry is a branch of ergonomics that deals with the measurement of human body dimensions. Anthropometric data are required for the appropriate design of SCSRs (ISO/TS 16976-2: 2015). There is a need to gather current anthropometric data from women in the South African mining industry to determine whether these are compatible with the SCSR devices in use.

5.3. Anthropometric assessment

This milestone involved an anthropometric assessment of women working at mines in South Africa. Subjective ratings of the comfort of wearing an SCSR on the belt were also made.

A total of 100 female mineworkers from one coal, one platinum and one gold mine in South Africa participated in this study. Data collection took place between February and March 2017. Anthropometric measurements from 27 body sites were taken.
Questionnaires were also completed by the participants, which gathered demographic information and subjective responses relating to the comfort of SCSRs.

Almost all of the participants considered the SCSRs to be too heavy and that they disturbed their work. The majority of the participants reported discomfort while wearing SCSRs on the belt; this was mostly experienced on the body areas of the hips, lower back and stomach (abdomen). Anthropometric data, including the average, standard deviation and 5th, 50th and 95th percentiles, is provided for the 27 measurements and the derived indices of body mass index (BMI) and waist-to-hip ratio. Comparisons were made with data from reference documents and a previous study in the industry. Numerous significant differences came to light. Notably, the prevalence of obesity is higher in the study sample than the other samples, with 46% of the sample categorised as obese according to BMI.

The findings indicated the need for SCSRs to be made more ergonomic for use by women in the South African mining industry.

5.4. Practical performance assessment

This milestone involved a practical performance assessment of approved SCSRs for women in the South African mining industry. This involved an assessment of the use of the devices while worn on the belt and then while donned and in use, while navigating a route in a mine training gallery.

A total of eleven female mineworkers, who usually worked underground and were required to wear SCSRs for their daily work, formed the study sample. Of these, six of the participants worked at a metalliferous mine (platinum) and five worked at a coal mine. Data collection took place in April 2017, at Mines Rescue Services facilities in South Africa. For the testing procedures the participants were required to complete a predetermined test route that involved upright walking on level and sloped surfaces, stooped walking, crawling, and going up and down stairs. A control session involved
the participants having to navigate the route while wearing normal PPE, but without an SCSR. Testing sessions involved navigating the route wearing each of four approved SCSR models, first on the belt, and then while donned and activated. Qualitative and quantitative data were collected, including environmental temperature, body temperature, test duration, ratings of perceived exertion (RPE) and body discomfort. An ergonomic assessment questionnaire was completed, and observations and photographic recordings were made.

The average time taken to navigate the test route with the SCSR worn on the belt was 10 min 15 s, and 10 min 52 s while donned and in use. The average time to complete donning and adjusting the units was 2 min 30 s. Greater exertion was evident when an SCSR was worn on the belt than when no SCSR was worn, and the highest levels of exertion were evident when the SCSRs were donned and in use. The highest comfort ratings for wearing the units on the belt were reported for the units that were smaller, lighter and contoured to fit the wearer’s body. Larger units were observed to interfere with the participants’ movements. Discomfort while the units were worn on the belt was mainly experienced in the lower back, hips and quadriceps. When the units were donned and in use, the participants experienced discomfort mostly in the neck, shoulders, jaws, teeth, throat and chest. The participants experienced the highest levels of neck and jaw strain when the unit that was worn on the head rather than on the chest was donned. When donned, it appeared that the breathing tubes of some of the units were too short, or the adjustment limits of the straps prevented the units from resting high enough on the participants’ bodies. It appeared that participants with BMIs of 30 and above experienced slightly higher levels of discomfort during the test procedures than those with BMIs lower than 30.

Findings from this assessment will assist to inform interventions to improve the design and fit of SCSRs to be most suitable for women in the South African mining industry. As many factors highlighted in this reported appeared to be general, rather than
specific to females, recommendations made to improve the ergonomics of SCSR for women in mining, may also be expected to apply to male mineworkers.

5.5. **Recommendations**

Suggestions to improve the ergonomic design of SCSR for use by women in the South African mining industry were compiled. These recommendations were drawn from the previous milestones of this study, along with discussions with stakeholders and subject matter experts, including the Tripartite Technical Committee (TTC) for SCSR and OEMs.

The recommendations were further revised following a workshop hosted by the Mine Health and Safety Council (MHSC). In this workshop it was recommended that interventions that could bring about improvements in the shortest space of time and at relatively low costs be implemented. These included:

- Ensure the provision of specific belts recommended by the respective OEMs.
- Implement, as a matter of urgency, experiential and expectation training for the donning and use of SCSR.

Further recommendations to inform future SCSR design included:

- Make SCSR lighter and smaller, as far as practically possible.
- Shape SCSR to the contours of the body.
- Consider changes to the casing material of SCSR.
- Ensure ease of locating parts of the SCSR when donning.
- Avoid the use of head-mounted units in future developments.
- Ensure adequate length of breathing tubes.
- Ensure adequate adjustability of neck and body straps.
- Ensure optimal design of SCSR goggles.
- Consider changes to the wearing arrangement of SCSR.
Further research was also recommended, which included:

- A comparative ergonomics study of males in the South African mining industry.
- The assessment of proposed interventions and developments.
- Reassessment of the escape strategies of mines while taking female mineworkers into consideration

5.6. Conclusions

This study aimed to assess the compatibility of SCSRs with the anthropometry typical of females in the South African mining industry. Further studies should be conducted to validate the assumption that many of the findings and suggestions would also be applicable to the male workforce. Appropriate implementation of the recommendations would assist in improving health, safety and productivity in the mining industry.
6. PROJECT AIMS AND OBJECTIVES

Recently there has been an increase in the number of women entering the South African mining industry. This is a result of regulated processes, such as the Mining Charter and the Minerals and Petroleum Resources Development Act 28 of 2002, which attempt to provide opportunities for historically disadvantaged individuals, including women, to participate in the mining sector (Republic of South Africa, 2002a and 2002b). A major challenge for the mining industry has been to introduce and ensure full incorporation of women into the traditionally male-dominated sector and also to ensure the provision of appropriate PPE for them (Zungu, 2012b). Generally, PPE in the mining sector was designed based on male anthropometric measurements. As such, the redesign of current PPE, including body-worn SCSRs, to accommodate the ergonomic requirements of women in mining is essential to ensure a healthy and safe work environment. An SCSR is a portable source of oxygen to provide breathable air in emergency situations. The use of SCSRs has been associated with side-effects, including discomfort, reduced mobility and increased physical load. Ergonomics can contribute to improving the fit between SCSR devices and the people who use them.

The aim of this project was to assess the ergonomic design of SCSR devices for use by women in the South African mining industry in order to identify improvements that would make the wearing of SCSR devices more acceptable, comfortable for the wearer and not impede escape. This was achieved by conducting a review of the relevant literature and previous research (local and international perspectives) as a preliminary step, followed by gathering and analysing anthropometric data on female mineworkers in South Africa, and conducting an ergonomic practical performance assessment of SCSR devices to identify dimensional limitations of current SCSR devices. Based on the findings of the data obtained, improvements to SCSR devices were proposed and discussed with subject matter experts, stakeholders and OEMs in the mining industry.
The objectives of the project were to:

- Assess the anthropometry typical of South African female mineworkers to establish the dimensional limitations of existing SCSRs.
- Identify shortcomings or areas of improvement for current SCSRs for use by women in mining.
- Recommend measures for the improvement of existing SCSR designs to address the shortcomings identified in the current project.
- Conduct a workshop in Gauteng to present and discuss the findings with subject matter experts, stakeholders and OEMs for their inputs.

It is envisaged that the findings and recommendations emanating from this project will inform processes to improve the ergonomic design of SCSR devices for effective use by women in mining, thus contributing towards increased comfort, improved safety and better productivity among women in mining.

The project milestones were as follows:

**Milestone 1:** Project initiation
**Milestone 2:** Ethics application
**Milestone 3:** Literature review (refer to Chapter 7)
**Milestone 4:** Anthropometric assessment (refer to Chapter 8)
**Milestone 5:** Practical performance assessment (refer to Chapter 9)
**Milestone 6:** Recommendations (refer to Chapter 10)
**Milestone 7:** Draft final report
**Milestone 8:** Final report
7. LITERATURE REVIEW

7.1. Introduction

The employment of women in the South African mining industry is relatively recent, given the history of male dominance in the industry (Zungu, 2012a). The mining industry is inherently hazardous, and mineworkers face various health and safety risks, including chemical, physical, biological and psychosocial hazards (Van Aardt et al., 2008). Some of the causes of ill-health in the minerals industry are noise, dust, vibration and manual tasks (Horberry et al., 2013). The functional work capacity of workers can be affected by factors such as age, gender, injuries, health, lifestyle and anthropometrics (Hofmann and Kielblock, 2007). Owing to the physical differences between males and females, it has become important to carry out further research to determine the impact of mining work on the occupational health and safety of women and to create a safe work environment for both males and females (Van Aardt et al., 2008; Zungu, 2013).

While acknowledging that the workloads and stress imposed by mining are not unique to females, when researching women in the South African mining industry, Benya (2009, p94) observed: “In addition to the heat and humidity, workers have to carry heavy head-lamp batteries with them at all times, even while working. The head-lamp battery and rescue packs [SCSRs] are heavy and do not make it easy for women to move around and do their duties, especially when they are still new in the mine. Women often have to walk long distances carrying heavy materials and do physically demanding work with the battery and rescue packs tied around their waists.”

Body-worn SCSR are respiratory protective devices (RPDs) that are part of the PPE required in the mining industry. An SCSR is a closed-circuit respiratory protection device that produces oxygen for a limited time, independent of the surrounding atmosphere, and provides protection by isolating the user from harmful toxic gases (Sandström, 2015; Teeravarunyou, 2008). While RPDs are worn to protect against
health and safety hazards, they can also result in unintended negative effects (ISO/TS 16976-8:2013). Known side-effects of using RPDs include discomfort, hindrance of the performance of necessary activities, restricted access to working areas as a result of bulkiness, the risk of snagging on projections or other features in the work environment, and physical load (ISO/TS 16976-8:2013).

Additionally, the design of mining equipment and PPE for mineworkers has generally been based on the male physique (AngloAmerican, 2012; Van Aardt et al., 2008; Zungu, 2013). This may contribute to heightened health and safety risks for women in mining (Van Aardt et al., 2008). Hofmann and Kielblock (2007) note the importance of ensuring a fit between workers’ capacity and the physical demands of their work to ensure good health and safety. Ergonomics has much to offer in this domain (Horberry et al., 2013).

This literature review provides a background to women in mining, PPE design, the use of SCSRs, as well as ergonomics and anthropometric principles. This will be of use in the study of how best to design SCSRs to accommodate women in the South African mining industry.

7.2. Women in mining

The mining industry is a historically male-dominated sector and, until recently, female employees were concentrated in clerical and administrative roles (Van Aardt et al., 2008; Zungu, 2012a). Women were legally prohibited from being employed in underground operations in South Africa until the 1990s (Van Aardt et al., 2008). However, there have since been measures to integrate women into production job categories in mines. One of the objectives of the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) was to “substantially and meaningfully expand opportunities for historically disadvantaged persons, including women, to enter the mineral and petroleum industries and to benefit from the exploitation of the nation's mineral and petroleum resources” (Republic of South Africa, 2002b Section 2(d)). The
2002 Broad-Based Socio-Economic Empowerment Charter of the South African Mining Industry (the Mining Charter) of provided a framework for empowering historically disadvantaged South Africans in the mining and minerals industry (Republic of South Africa, 2002a; van Aardt et al., 2008). The Mining Charter required mining companies to ensure a baseline of 10% of women participation in the South African mining industry by 2009. By 2009 only 6% female representation had been achieved; however, this number had increased to 10.5% by 2014 (Republic of South Africa, 2015).

Various hazards face women in mining, ranging from threats to reproductive health, personal safety and security, work-life balance, to increased risk of injuries (AngloAmerican, 2012). Zungu (2012) noted that women in mining have different health and safety needs than those of their male counterparts as a result of their differing anatomical and physiological composition. If these are not catered for, women’s comfort, safety and performance in the workplace may be compromised (Zungu, 2012a). Some of the physical differences between males and females include physical work capacity, heat tolerance, and anthropometry and body composition (Van Aardt et al., 2008). This is significant as the mining industry often requires physically demanding work in demanding environments, which may involve long walking distances, restricted working postures and temperature stressors, which result in elevated heart rate, oxygen consumption and heat production (Blacker et al., 2012; Hofmann and Kielblock, 2007).

Females generally have lower physical work capacities and physical strength than their male counterparts (Van Aardt et al., 2008). Women generally have maximal aerobic capacities around 15-30% lower than those of men, and have between around 60% and 90% of men’s muscle strength and work output (AngloAmerican, 2012). Females therefore generally have to work closer to their physical work capacity than men in order to maintain the same levels of productivity, which in turn can lead to greater levels of fatigue and an increased possibility of accidents and injury than is the case for men performing the same work (Dlamini, 2016). It has also
been indicated that female mineworkers are less tolerant to heat than men (van Aardt et al., 2008). It is, however, recognised that these differences may be explained mostly in terms of body size, acquired levels of physical fitness and heat acclimatisation (Guild et al., 2001).

Men are generally taller than women, and the proportions of some anthropometric dimensions, such as hip breadth, differ between men and women (AngloAmerican, 2012; Stirling, n.d.). In terms of body composition, females have on average a lower percentage of lean body mass than males (Van Aardt et al., 2008). Higher rates of obesity are evident in females than in males in South Africa (Department of Health, 2004). In a study on women in the South African mining industry, it was found that the average BMI was 28.0, with 69.5% of the participants being classified as overweight and 18.6% as obese (Zungu, 2013).

Van Aardt et al. (2008) note that the design of mining equipment and tools does not always reflect the user population. The design of mining equipment is generally based on males from other countries (AngloAmerican, 2012). The use of work equipment, machinery and tools designed for men may contribute to accident risk and the heightened risk of musculoskeletal disorders in women (Van Aardt et al., 2008). Van Aardt et al. (2008) also note further practical difficulties involved in the integration of women into the mining industry, such as the need for infrastructure, including separate changing rooms and toilet facilities, and appropriately sized and styled clothing and PPE. The authors stated that most of the PPE used in South African mines is based on the anthropometry of male populations from Germany, France and the US, which differs significantly from that of the South African workforce (Van Aardt et al., 2008). Many mineworkers, especially women, may therefore not have adequate protection.

Zungu (2012) also notes that women in the South African mining industry face challenges related to PPE. Specific PPE for women is commonly not available in the South African mining industry, and PPE for mineworkers has generally been designed
based on the male physique (Zungu, 2013). In the study conducted by Zungu (2012) among women in mining, specifically with regard to the SCSR, lamp battery and securing belt, 95% of the participants indicated that these were “too heavy to carry and cause discomfort and chafing on the lower abdomen”, while 5% stated that they caused lower back pain (Zungu, 2012a). This subjective heavy weight and the discomfort experienced may be the result of suboptimal ergonomics of the SCSR device.

7.3. **Personal protective equipment**

In terms of the hierarchy of control of hazards prevalent in workplaces, PPE is used as a last resort to prevent, or reduce, exposure to hazards associated with mining, when all other engineering controls are inadequate or have failed (Schutte et al., 2005; Zungu, 2013). The selection of adequate PPE is essential, because if the PPE fails, the worker will be exposed to workplace hazards (Schutte et al., 2005). Thus the selection of PPE should be based on the nature of the hazard, the level of risk and the physical attributes of the wearer (Zungu, 2013). Schutte et al. (2005) note that the range of environmental conditions, PPE requirements, and anthropometric differences in the workforce population make PPE selection challenging as a “one-size-fits-all” approach is inadequate. Schutte et al. (2005) also note that PPE can create its own hazards, for example, gloves getting caught in machinery or facepieces that hinder a person’s vision.

DuPont (2016) provides a guide for PPE selection. It states that garments must be available in a full range of sizes that are suited to different physical and gender characteristics, and in addition must be of a non-restrictive, ergonomic fit compatible with other PPE items. Furthermore, garments must not be so bulky as to pose an undue risk of snagging, tearing or tripping (DuPont, 2016).

Schutte et al. (2005, p25) also list factors that should be considered when selecting PPE:
• “Results of a proper hazard identification and risk assessment survey.
• The working environment.
• The physical effort required to do the job.
• The required protection in terms of duration.
• The appropriateness of the PPE decided upon.
• The ergonomics and physical comfort of PPE.
• The need for adequate visibility and communication when wearing the PPE.
• The compatibility of equipment if more than one piece of PPE is used.
• The state of health of those who will wear the equipment.
• PPE standards and certification.”

Operator comfort and correct garment fitting is vital for health and safety compliance and the correct use of PPE (DuPont, 2016). Poor fit and discomfort are major reasons for not wearing PPE (Zungu, 2013). Zungu (2013) notes that the weight, thickness and stiffness of PPE, along with the friction it causes, can also hamper the user’s physical performance and range of motion.

Szczecińska and Łężak (2000) also note that one of the problems relating to the use of PPE is the frequent lack of acceptance by users. This is because it can cause various types of problems, such as goggles or full face masks reducing the visual field, and difficulties with heat extraction, movement restriction and dexterity when using protective clothing, shoes and gloves (Szczecińska and Łężak, 2000). Szczecińska and Łężak (2000) add that user acceptance of PPE depends on aspects such as weight, shape and size along with the elasticity and flexibility of fabrics and the comfort experienced by the users. This highlights the importance of considering ergonomic aspects that ensure that this equipment is comfortable, along with the properties that ensure optimal protection (Szczecińska and Łężak, 2000).
Graveling et al. (2009) conducted a comprehensive literature review of the use of respiratory protective equipment (RPE) in the industrial, agricultural and health care sectors. The authors noted that some of the factors relating to PPE usage in general were also relevant to the use of RPE. Barriers to RPE and PPE usage that were identified included discomfort, quality of fit, weight of the PPE, skin irritation, interference with work, fatigue, heat, difficulty breathing and interference with vision and communication. Furthermore, PPE usage was positively associated with younger workers, which may be related to increased complacency and lower risk aversion of older workers, who may not have been required to wear PPE in the past (Graveling et al., 2009). The perceived need for PPE by the users was identified as a major determinant of use, which was related to the risk of exposure and the real or perceived efficacy of the PPE. Training and education, and management and supervisory attitudes and commitment were also seen to be essential. Additionally, involving the workers in the selection process has been shown to improve acceptance and compliance. It was noted that it is important that the RPE should be compatible with work activities and other PPE worn (Graveling et al., 2009).

The wearing of PPE has been seen to increase metabolic cost and decrease performance while performing work-related tasks (DiVencenzo et al., 2014). DiVencenzo et al. (2014) assessed the differences in metabolic and perceptual responses with and without PPE required for police officers, including the duty belt, which weighs between 3.62 and 6.8 kg. During an exercise protocol, higher heart rates, oxygen consumption and perceptual responses for effort, discomfort and exertion were recorded when the participants were wearing PPE compared to the responses recorded during the non-PPE trials (DiVencenzo et al., 2014).

As a result of the differences in the anatomy and physiology between women and men, it is crucial that PPE for women in mining should be based on female anthropometric data (Schutte et al., 2005; Zungu, 2013). Owing to the considerable differences in the anthropometry of workers, more than one size of PPE may need to be provided (Schutte et al., 2005).
Furthermore, Schutte et al. (2005) note that a PPE programme is needed at mines, which requires commitment and active participation from all levels of the organisation, including senior management, supervisors and workers, during planning, development and implementation. It is important to discuss PPE needs and alternatives with manufacturer and supplier representatives (Schutte et al., 2005). The PPE should first be tested to see that it meets all the necessary criteria before it is approved (Schutte et al., 2005). The need for consultation with PPE end-users in order to gather information about fit, comfort and style preferences, and to increase acceptance of and compliance with wearing of PPE was also highlighted (Schutte et al., 2005; Zungu, 2013). The appropriateness of PPE currently in use should be assessed by means of surveys to determine its suitability and effectiveness among end-users (Zungu, 2013).

7.4. Self-contained self-rescuer devices

Respirators, or respiratory protective devices (RPDs), are types of PPE devices worn by individuals to protect them against the inhalation of potentially harmful particles in the air (Schutte et al., 2005). ISO/TS 16976-8: 2013 similarly states that the primary purpose of respiratory protection devices is to provide protection against particular inhalation hazards that cannot be eliminated or adequately reduced by other means. These devices are further classified as air-purifying, which filter contaminants from the ambient air, or air-supplied, which supply breathable air from a source other than the surrounding atmosphere (Schutte et al., 2005; Teeravarunyou, 2008). Air-supplied devices provide breathable air via an air hose or a compressed air line (not self-contained) or from a portable supply that can be carried by the person (self-contained). They are commonly referred to as self-contained breathing apparatus or SCSRs (Schutte et al., 2005; Teeravarunyou, 2008). This breathing apparatus protects the wearer against contaminants and oxygen deficiency in the ambient air (Teeravarunyou, 2008).
An SCSR may be defined as “a device that is used in the mining industry in case of fires or release of toxic gases that depletes or contaminates breathable oxygen in the surrounding atmosphere. These units are the first line of defence by providing oxygen in a closed breathing cycle, allowing personnel to get themselves to safety,” (Sandström, 2015, p3). SCSRs are important for their life-saving ability in mines’ escape and rescue strategies in the event of an emergency that results in an irrespirable atmosphere (Schreiber et al., 2003). This includes emergencies such as fires, explosions or gas inundations (Kowalski-Trakofler et al., 2008). The purpose of SCSRs is to provide breathable air in emergency situations for a sufficient amount of time to facilitate the escape from mines (Sandström, 2015). This refers to the time taken to proceed to the exit of the mine, or to reach places of safety (oxygen supply caches or a safe bunker or refuge bay). This study is limited to the assessment of body-worn SCSRs. A body-worn SCSR is an escape apparatus that is designed to be worn on the body for the complete duration of a working shift (SANS1737:2008).

Table 1: Distribution of SCSRs by commodity (adapted from Schreiber and Sehlabana, 2015)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Approximate number of SCSRs deployed</th>
<th>Number of mines or shafts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>90 000</td>
<td>47</td>
</tr>
<tr>
<td>Coal</td>
<td>30 000</td>
<td>65</td>
</tr>
<tr>
<td>Others (i.e. Cu, Mn, Cr)</td>
<td>30 000</td>
<td>37</td>
</tr>
<tr>
<td>Diamond</td>
<td>3 000</td>
<td>4</td>
</tr>
<tr>
<td>Platinum</td>
<td>67 000</td>
<td>48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>220 000</strong></td>
<td><strong>201</strong></td>
</tr>
</tbody>
</table>

In 1986 it was legislated that any person going underground in a mine in South Africa was to be equipped with a body-worn SCSR (Schreiber, 1999). This legislation was later amended to direct compulsory use in all coal mines, as well as in “high-risk areas” in hard rock mines (Schreiber, 1999). In the South African mining industry approximately 200 operations currently deploy SCSRs, with approximately 220 000
units being currently deployed (Schreiber and Sehlabana, 2015). There are four makes of SCSRs that are currently deployed in the South African mining industry. AfroxPac 35 and 35i units appear to be the most commonly used make in South Africa, followed by Dräger Oxyboks, Dezega Roxy 40 and MSA SavOx (Schreiber and Sehlabana, 2015). The distribution of SCSRs in the South African mining industry, according to commodity, is shown in Table 1. Table 2 provides a comparison of the functional duration, weight and physical dimensions of these devices (Afrox, 2014; Drägersafety, 2010; MSA, 2016; Schauenburg Lighting Technologies, 2013).

### Table 2: Comparison of the functional duration, weight and physical dimensions of the SCSR devices currently deployed in the South African mining industry

<table>
<thead>
<tr>
<th></th>
<th>AfroxPac 35 or 35i</th>
<th>Dräger Oxyboks K35A</th>
<th>Dezega Roxy 40</th>
<th>MSA SavOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated duration (breathing rate 35 L/min)</td>
<td>30 minutes</td>
<td>25 minutes</td>
<td>40 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Approximate weight (unopened)</td>
<td>2.2 kg</td>
<td>2.1 kg</td>
<td>2.25 kg</td>
<td>2.5 kg</td>
</tr>
<tr>
<td>Approximate weight (during usage)</td>
<td>1.2 kg</td>
<td>1.2 kg</td>
<td>&gt;1.5kg</td>
<td>1.5 kg</td>
</tr>
<tr>
<td>Height</td>
<td>195 mm</td>
<td>189 mm</td>
<td>203 mm</td>
<td>220 mm</td>
</tr>
<tr>
<td>Width</td>
<td>172 mm</td>
<td>205 mm</td>
<td>202 mm</td>
<td>160 mm</td>
</tr>
<tr>
<td>Depth</td>
<td>101 mm</td>
<td>89 mm</td>
<td>116 mm</td>
<td>110 mm</td>
</tr>
<tr>
<td>Country of manufacture</td>
<td>South Africa</td>
<td>Germany</td>
<td>Ukraine</td>
<td>Germany</td>
</tr>
</tbody>
</table>

SCSRs are generally worn on the belt on a day-to-day basis, but some can also be worn over the shoulder. When in use, they are worn in varying manners. For example, the Dräger Oxyboks unit is worn with straps going over the head, while the straps for the AfroxPac 35 or 35i, Dezega Roxy 40 and MSA Savox units go around the neck.
7.4.1. Legislative framework on the use of SCSRs

The regulation that refers to the use of SCSRs is Regulation 16 of the Mine Health and Safety Act (Republic of South Africa, 1996). In terms of the issuing of SCSRs, the regulation states that:

16.2(1): "The employer of every coal mine must ensure that no person goes underground at the mine without a body-worn self-contained self-rescuer, which complies with the South African Bureau of Standards specification SANS 1737."

16.2(2): "If at any mine other than a coal mine the risk assessment in terms of Section 11 shows that there is a significant risk that employees may be exposed to irrespirable atmospheres at any area at the mine, the employer must ensure that no person goes into such area without a body-worn self-contained self-rescuer, which complies with the South African Bureau of Standards specification SANS 1737."

Additionally, various specifications also refer to the use of SCSRs. Of particular relevance is the South African National Standard (SANS) 1737. SANS1737 stipulates points that relate to the physical ergonomics of the devices, which include:

4.3.1: “The escape apparatus shall be of sound and reliable construction and shall be compact.”

4.3.2(a): “The escape apparatus shall be so designed that there are no parts or sharp edges likely to come into contact with the wearer or catch on clothing or on projections in narrow passages.”

4.4.4: “Any material that comes into direct contact with the wearer's skin and the respirable atmosphere shall not cause irritation or have any other adverse effect on the wearer's health.”
4.6: “The mass of the complete escape apparatus, including the protective casing, shall be such that it can be carried on the body for a full working shift, and that it can be donned easily and without undue exertion. The mass of the escape apparatus shall be determined and noted.”

There are a series of standards relating to elements of human factors for RPDs in general, namely ISO/TS 16976, Part 1 to Part 8. Of particular relevance to this study are Part 8 (ISO/TS 16976-8: 2013), which refers to the ergonomic factors of RPDs, and Part 2 of (ISO/TS 16976-2: 2015), which deals more specifically with the anthropometrics relating to these devices.

ISO/TS 16976-8: 2013 (p13) notes that “the ergonomic factors of RPD affect the comfort, mobility and dexterity of users, the rate at which they develop fatigue, the efficiency with which they can work in the RPD, the interaction of the RPD with other PPE, and the effectiveness of the protection provided.” The standard indicates principles relating to the biomechanical interaction between RPDs and the human body, along with the interaction between RPDs and the human senses of vision, hearing, smell, taste and touch (skin contact).

RPD can increase muscle strain or energy consumption (ISO/TS 16976-8: 2013). In ISO/TS 16976-8: 2013 it is noted that the mass and the distribution of mass of an RPD need to be considered in relation to the human body. Additional weight (i.e. from an RPD) is best worn on the trunk and as close to the body’s centre of gravity and as symmetrically as possible. ISO/TS 16976-8: 2013 also notes that working positions and movements, and the bending of joints, can be restricted by close fitting, stiff or bulky material. Additionally, abrasion or compression of the skin and underlying structures may occur as a result of the movement of the RPD against the body. ISO/TS 16976-8: 2013 further adds that RPDs may result in exacerbation of vibration, such as when wearing an RPD while travelling in a vehicle. The thermal effects of RPDs are also considered in ISO/TS 16976-8: 2013 as they may cause restrictions to heat, ventilation and moisture exchange.
Regarding the sensory effects of RPDs, if sensory signals are too weak or distorted, they may be misunderstood or not understood, whereas if they are too strong or prolonged, they may cause distraction, fatigue or pain (ISO/TS 16976-8: 2013). Furthermore, ISO/TS 16976-8: 2013 considers aspects such as the potential of RPDs to obscure the wearer’s vision, hinder the receipt or transmission of auditory signals, mask the odour or taste of a hazardous or toxic substance, cause discomfort as a result of strong odours or taste, or by undesirable effects on the sense of touch. Regarding skin contact, aspects that may cause unacceptable irritation, such as roughness, sharp edges, projections and such aspects as hot or cold surfaces, should be assessed.

ISO/TS 16976-8: 2013 states that the user group must be defined to ensure that the dimensions are specified to include the population. Adjustment systems or the provision of size ranges can be used to accommodate variations in size. The standard notes that standards writers should keep in mind that more than one essential anthropometric dimension may need to be measured to ensure adequate fit, as different body dimensions are not necessarily closely correlated. The physiological impact relating to the use of RPDs may be measured using indicators such as heart rate, oxygen consumption, alveolar gas composition, breathing rate, body temperature, sweat rate and fatigue or muscle strain (ISO/TS 16976-8: 2013). ISO/TS 16976-8: 2013 states that different tests may be conducted to verify that RPDs comply with appropriate ergonomic factors (e.g. functional performance testing, specific ergonomic testing and ergonomic practical performance testing). Whichever type of test is used, the test participants should reflect the intended wearer group.

ISO/TS 16976-8: 2013 specifies the relevant ergonomic factors that should be taken into consideration:

- Adequate fit due to adjustability and stability
- Intelligibility of instruction (donning, doffing, adjusting, controls, operating)
- Mass and mass distribution
- Essential dimensions
- Restriction and prevention of movements
- Irritation, abrasion or compression of the skin and underlying structures
- Exacerbation of vibration
- Thermal comfort
- Physiological impact
- Visual
- Auditory
- Odour or taste
- Touch or dexterity

ISO/TS 16976-8: 2013 also provides a checklist for the assessment and verification of compliance with anthropometric principles:

- Range of wearers (e.g. in terms of age, gender, physical fitness and skill at the task being simulated)
- Purpose for which the RPD is intended (e.g. activities and environment)
- Adequate fit requirements
- Anthropometric measurements of wearers to ensure adequate fit across the range of wearers
- Means of describing size categories to ensure correct selection of RPD for the wearers

Part 2 of ISO/TS 16976 (ISO/TS 16976-2: 2015) refers to the anthropometrics relating to RPD devices. The standard acknowledges that various factors need to be considered for the appropriate design, selection and use of RPDs. These include the physiological demands of the user, which are affected by factors such as the type and intensity of the work, along with the weight and the weight distribution of the device worn on the human body. This affects respiratory demands and flow rates. It is noted
that anthropometric and biomechanical data are required for the appropriate design of various components of a RPD.

The standard (ISO/TS 16976-2) includes information about anthropometric landmarks and dimensions. Detailed data for head, face and neck dimensions are provided based on international populations. Gender, age and racial/ethnic grouping are considered. ISO/TS 16976-2 notes that the data for torso dimensions provided in the standard are not appropriate for use in the design of RPDs. The standard includes a subset of data from the ADULTDATA handbook (Peebles and Norris, 1998), while noting that there was to be no test where the ergonomic features were checked by using the torso based on these data.

7.4.2. Literature findings on the use of SCSRs

Various research projects have been conducted on the ergonomics design and use of SCSRs. Some of these are described below.

In a study conducted by Bakri et al. (2012), it was found that the weight and harness design of firefighters’ self-contained breathing apparatus affected oxygen consumption and metabolic rate. Additionally, high environmental temperatures were seen to exacerbate the physiological effects of the weight and harness design of the breathing apparatus (Bakri et al., 2012). The wearing of breathing apparatus was seen to significantly increase metabolic rate, subjective muscle fatigue and thermal discomfort during the exercise protocols (Bakri et al., 2012).

Coca et al. (2011) also evaluated self-contained breathing apparatus used by firefighters. The authors noted that while providing crucial support and protection, the devices can also add to the physical work performed as they are cumbersome and heavy. The weight of self-contained breathing apparatus has been identified as a factor that most affects the physiological strain of the wearer, as heavier apparatus increases heart rate, oxygen consumption and ventilation rate (Coca et al., 2011).
Additionally, the apparatus can limit wearer mobility, range of motion and movement in confined spaces, and can change the centre of gravity of the wearer, which can impair postural balance of the body, leading to an increase in secondary hazards such as slips and falls (Coca et al., 2011). The weight, weight distribution, size and design of breathing apparatus affect user comfort as well as physical performance (Coca et al., 2011).

In the study by Coca et al. (2011), objective and subjective measures of comfort, fatigue, mobility, static and dynamic range of motion, operability, interaction with protective clothing, and time of donning and doffing the self-contained breathing apparatus during field activities were obtained. The authors noted the importance of assessing the ergonomics design features and user acceptability of PPE systems in order to better understand the suitability of the PPE being evaluated.

MacKenzie-Wood et al. (1998) conducted field trials at coal mines in Australia to gather data on the length of oxygen supply of SCSRs, time to escape, distances travelled and the average heart rate of the participants. They noted that the duration of oxygen supply was affected by personal factors, such as the wearer’s body weight and physical fitness, in addition to the work rate and the prevailing environmental conditions. In general, lower heart rates (HR) and body weights (W) were associated with lower oxygen consumption (VO₂) (MacKenzie-Wood et al., 1998). MacKenzie-Wood et al. (1998) produced the following equation, known as the “University of Wollongong model”, to predict oxygen consumption: \( VO₂ = \frac{(6.0W + 1.5HR)}{500} + 0.332 \). The authors also noted that in life-threatening underground incidents, such as an explosion or fire, mineworkers are likely to walk fast or run as a result of panic, which may result in oxygen being used more quickly or less efficiently, and hence reduce the duration of the SCSRs.

A paper by Teeravarunyou (2008) describes the importance of usability testing for self-rescue RPDs. Usability risks include errors or inappropriate actions that could decrease the effectiveness, efficiency or user satisfaction with the product
(Teeravarunyou, 2008). Emotional reactions such as stress or panic during emergency situations should also be considered (Kowalski-Trakofler et al., 2008; Teeravarunyou, 2008). The usability of the device can also be linked to the training required to activate the SCSR devices under duress.

Kowalski-Trakofler et al. (2008) highlighted the importance of expectations training for mineworkers using SCSRs in escape situations. The authors noted that, at the time, SCSR training consisted of a short demonstration of the donning procedure; however, few mineworkers had ever experienced what it was like to use the apparatus, or had an idea of what to expect when wearing the SCSR in an escape situation. The study by Kowalski-Trakofler et al. (2008) followed incidents when a number of mineworkers in emergency situations thought the devices were not working properly, and took their mouthpieces out. This can have life-threatening consequences. Areas of concern identified in their study included: 1) starting the unit, 2) unit heat, 3) induction of coughing, 4) taste of the unit, 5) resistance to breathing, 6) quality of the air supplied, 7) nose clips, 8) goggles, and 9) the behaviour of the breathing bag.

Previous research has focused on the continual improvement of SCSRs, such as that done by Schreiber et al. (2003) and Sandström (2015). This includes possible solutions to improve the ergonomic design and application of SCSRs, such as the size and weight of the units (Schreiber et al., 2003). Sandström (2015) noted that discomfort during daily wear, and complicated donning procedures (taking note of likely responses in emergency situations), were issues relating to the use of these units. Desirable design factors included comfort, wearability, durability, flexibility, adaptability, intuitiveness, safety and usability (Sandström, 2015).

7.5. Ergonomics and anthropometry

Ergonomics (or “human factors”) may be defined as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to
design, in order to optimise human well-being and overall system performance” (International Ergonomics Association, 2016). Ergonomics practitioners contribute to the design and evaluation of tasks, jobs, products, environments and systems to ensure compatibility with the needs, abilities and limitations of people (International Ergonomics Association, 2016). The goal of ergonomics is to minimise human error and occupational health and safety risks, while improving productivity and the comfort and well-being of workers (Schutte, 2005; Schutte and James, 2007; Schutte and Shaba, 2003).

The Mine Health and Safety Act (Act 29 of 1996, Section 21 (1)(c)), states that “Any person who designs, manufactures, erects or installs any article for use at a mine must ensure, as far as reasonably practicable, that ergonomics principles are considered and implemented during design, manufacture, erection or installation” (Republic of South Africa, 1996). ISO/TS 16976-8 (2013) notes that “Ergonomics involves the application of scientific methods and appropriate data to the design and specification of machines, equipment, environments, systems and the interface with the people using it. The successful use of ergonomics in designing RPD will enhance the acceptability of the RPD and through this will improve the safety, health, performance and effectiveness of the wearer.” The standard additionally notes that the application of ergonomics optimises the balance between protection and usability of RPDs.

Ergonomics promotes a holistic approach and incorporates physical, organisational and cognitive domains (International Ergonomics Association, 2016). It focuses on adapting work systems to fit people, rather than the other way around (Schutte and James, 2007; Schutte and Shaba, 2003). The focus of ergonomics is on the reduction of risk through design (or “engineering”) controls, rather than administrative controls such as training or selection (Horberry et al., 2013). The design of mining equipment should be improved from an operator-centred perspective (Horberry et al., 2013). Horberry et al. (2013) note that poor equipment design can result in safety and
performance disadvantages. In addition, the design of mining equipment can influence the tasks and behaviours of the operators (Horberry et al., 2013).

Ergonomic design criteria state that for each part of a system where there is a human element, there must be optimisation of the interaction between the person, the workspace (including machines or technology) and the environment in which they operate (RMSS, 1994; Schutte and Shaba, 2003). Further guidance notes that there should be compatibility between the workplace and the clothing and PPE to be worn by those in the workplace (RMSS, 1994). Brouwer et al. (2003) note that the effectiveness of PPE is determined by the protection aspects of the equipment as well as the suitability of the devices for actual work situations. They further add that aspects related to the individual worker (e.g. anthropometrics), the task (e.g. workload) and the work environment are often neglected in the selection of PPE, and that little attention has been given to the ergonomic and comfort aspects associated with the wearing of PPE.

**Anthropometry** is a branch of ergonomics which deals with the measurement of human body dimensions (Schutte and Shaba, 2003). The aim of anthropometry is to accommodate as much of the user population as possible in design (Stirling, n.d.). Systems, equipment and facilities should be designed to optimise human performance, and design and sizing should ensure accommodation, compatibility and maintainability by the user population (RMSS, 1994). The RSA Military Standards Steering Committee (RMSS, 1994) notes that the following attributes should be considered with use of anthropometric data:

- “Dimensional differences between males and females
- Dimensional differences between ethnic groups
- Anthropometric data should be continuously updated to monitor for secular changes that may take place in the dimensions
- The nature, frequency, safety and difficulty of the related tasks to be performed by the operator or wearer of the equipment
• Mobility or flexibility requirements imposed by these tasks
• Increments in the design – critical dimensions imposed by the need to compensate for obstacles, projections, etc.
• Increments in the design – critical dimensions imposed by protective clothing or equipment, packages, lines, padding, etc.

Several types of anthropometric measures can be taken, including static (e.g. stature, weight, breadth, length and circumference), functional, and strength measures (Stirling, n.d.). For all body dimensions, the 5th percentile value indicates that 5% of the population will be equal to or smaller than that value, and 95% will be larger, while the 95th percentile values indicate that 95% of the population will be equal to or smaller than that value and 5% will be larger (RMSS, 1994; Schutte and Shaba, 2003). Clothing and personal equipment (including protective or specialised equipment) worn or carried by the individual should be designed and sized to accommodate at least the 5th to the 95th percentile values of body dimensions (RMSS, 1994). This would indicate that 90% of the population would be accommodated for that dimension (Schutte et al., 2007). Design for essential or critical equipment (e.g. oxygen masks) may be based on the 1st to 99th percentile values for the pertinent dimensions (RMSS, 1994; Schutte et al., 2007). In addition, in instances where two or more dimensions are used simultaneously as design parameters, the appropriate multivariate data and techniques should be utilised (RMSS, 1994). Schutte and Shaba (2003, p8) noted the following four related ergonomic design principles:

• “Design for the smallest: This principle applies primarily to forces and reach distances.
• Design for the largest: This principle applies primarily to clearances, such as escape hatches, walkways and ceiling heights.
• Design for the average: This principle applies to operator positions that are not adjustable (e.g. fixed-height tables and work surfaces).
• **Design for the range**: This principle is applied to determine the amount of adjustability that should be built into such things as variable workstation seats (forward-aft and up-down).

In a study by Schutte and Shaba (2003), the observed health and safety risks resulting from ergonomics-related factors were predominantly ascribed to workstation designs based on anthropometric data that were not completely suited to the South African user population. The authors further noted that at the time of the study, the anthropometric data of South African mineworkers were dated and only incorporated male mineworkers (Schutte and Shaba, 2003).

An anthropometric survey in the South African mining industry was conducted by Schutte *et al.* (2007). As a result of the low availability of female participants at the mines where the survey was conducted, the sample consisted of 42 female mineworkers and 1,485 male mineworkers. Owing to secular changes among populations, anthropometric data should be updated regularly (Schutte *et al.*, 2007). Furthermore, sample sizes should be based on recent labour statistics of the study population (Schutte *et al.*, 2007).

An initiative known as African Body Dimensions (ABD), as described in a document by MacDuff and Smith (n.d.), was in the process of being established with the aim of creating, maintaining and managing an anthropometric database representative of the South African population. Three-dimensional whole-body scanners were the technology of choice over traditional hand measurements alone. However, the results of the initiative do not yet appear to be available. MacDuff and Smith (n.d.) noted that the South African National Defence Force (SANDF) database was the largest South African anthropometric database at the time. As a result of the relatively small sample of females in the anthropometric survey by Schutte *et al.* (2007), it was not possible to make statistical comparisons between women in the South African mining industry and those in the SANDF database.
ISO/TC 159: 2013 was intended to be the single source of anthropometric data for equipment design guidance in standards. It contains worldwide and regional design ranges for 56 variables based on member body data. However, it was noted that the data it contained could change at any time as new data emerged, while taking into consideration that variations in body sizes and populations occur over time. It was also evident that data from African countries were not included in the document at the time.

7.6. Conclusions of literature review

The review of literature confirmed the value of this study to assess the ergonomics of SCSRs for women in the South African mining industry. This is because it is evident that the design of PPE is currently not based on female anthropometric data and because, as noted in the literature, SCSR devices may potentially have comfort and performance shortcomings. Ergonomic compatibility between SCSRs and mineworkers is important to contribute to optimal occupational health and safety in the South African mining industry.

7.7. Next milestones

The findings from the review of literature provided direction for the current research that will inform improved design of SCSRs for women in the South African mining industry. This involved an anthropometric assessment of women in the South African mining industry, as well as practical ergonomic performance testing of SCSRs that are currently in use.

Anthropometric data are seen to vary according to factors such as gender, ethnic grouping, and secular changes. From the review of literature, it was apparent that there is a dearth of comprehensive and current anthropometric data for women in the South African mining industry. It is not certain whether the anthropometrics used to design and test SCSRs is matched to this population. As such, this study will
contribute towards creating an appropriate database relating to the design of SCSRs for use by women in the South African mining industry. The anthropometric dimensions selected for measurement in this study were informed by the reviewed literature on the topic, including standards, specifications and previous studies.

Practical ergonomic performance testing of SCSRs by women in mining was also conducted. The SANS1737 specification reviewed provided pivotal guidance into the procedures to be followed for the practical ergonomic performance testing. Additionally, the literature reviewed included previous studies assessing the use and comfort of PPE generally and SCSRs specifically. The tools and methodologies employed in these studies also informed the current study design. This testing provided information on the ergonomic compatibility of the units with the wearers, which will further inform interventions to improve the comfort and fit of the units. The ultimate aim of this study was to bring about improved health, safety and productivity in the mining workforce.
8. ANTHROPOMETRIC ASSESSMENT

8.1. Introduction

For this milestone, anthropometric assessments of women working at mines in South Africa were conducted. Data collection took place at three mines between 27 February and 24 March 2017. Questionnaires relating to the use and comfort of SCSR devices were also completed by the participants.

8.2. Methods

Mines that were invited to participate in this study included coal and metalliferous mines. Three volunteering mines were selected for this study, which included one coal, one platinum and one gold mine. These mines were located in the provinces of Mpumalanga, Limpopo and Gauteng, respectively. Each mine made use of a different make of SCSR.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Location</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Mpumalanga</td>
<td>27</td>
</tr>
<tr>
<td>Platinum</td>
<td>Limpopo</td>
<td>26</td>
</tr>
<tr>
<td>Gold</td>
<td>Gauteng</td>
<td>47</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Participants were recruited from the three study sites. Those who were invited to participate were women in mining. The focus of the study was on women who normally worked underground, but not necessarily those who were required to wear SCSRs on a daily basis. A total of 100 participants volunteered to take part in the study. There were two participants who completed questionnaires, but did not have their body measurements taken. In addition, the sample included four new recruits and five surface employees, and as these participants were not required to wear an
SCSR on a daily basis, they did not answer the questions in the questionnaire that related to the use of SCSRs. As such, anthropometric assessments were obtained from 98 participants, and questionnaires were completed by 91 participants. See Table 3 for a breakdown of the number of participants by commodity and location.

Body measurements, as relevant to the design and wearability of SCSRs, were taken. A total of 27 different measurements were taken. See Table 4 for the list of measurements taken and the equipment that was used to obtain these. In addition, BMI and waist-to-hip circumference were calculated using the stature and weight, and waist and hip circumference measurements, respectively. BMI was calculated by dividing the weight of the participant, in kilograms, by the square of their stature, in metres \((\text{BMI} = \frac{\text{weight}}{\text{stature}^2})\). Waist to hip ratio was calculated by dividing the waist girth by the hip girth. The identified measurements were selected primarily with reference to the following documents: 1) ISO/TS 16976-2: Respiratory protective devices – Human Factors. Part 2: Anthropometrics; and 2) ISO/CD 16900-5.2: Respiratory protective devices – Methods of test and test equipment – Part 5: Breathing machine/metabolic simulator/RPD headforms/torso, tools and transfer standards. See Appendices A and B for diagrams of torso dimensions, and basic headform measurements from these documents.

Measurements were taken by post-graduate students trained and supervised by a Level 4 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist and according to international ISAK standards. Two measurements were taken at each body site. If there was a difference of more than 5% between the two measurements, then a third measurement was taken. The median value for each participant per site was used. All measurements were taken on the right-hand side of the body. Measurements were taken while the participants were wearing minimal clothing for increased accuracy of the measurements. However, some measurements were taken over a layer of clothing, to prevent unease of the participants. Relevant landmarks were located for each of the body sites prior to the
measurements being taken. Some of the participants did not have all of their measurements taken.

In addition to the anthropometric measurements, the participants were asked to complete short questionnaires. These questionnaires gathered information about participant demographics, and posed closed- and open-ended questions relating to the design and fit of SCSR devices. Researchers fluent in local languages were available to assist the participants.

Data were captured electronically, and descriptive and comparative statistical analyses were performed. For the anthropometric variables, averages, standard deviations, minimum and maximum values, and percentiles were determined for each variable. The anthropometric data gathered in this study were compared against ISO reference values and data collected from previous studies in the South African mining industry, using the one-sample Median Test. Statistical significance was set at 95% (p<0.05).

Ethical approval to conduct this study was obtained from the CSIR Research Ethics Committee (REF: 179/2016). Necessary permission was gained from the study sites. Participation was voluntary and informed consent forms were signed by each of the participants.
Table 4: Measurement definitions, landmarks and equipment used

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Definition</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stature</td>
<td>Distance between the vertex and the inferior aspects of the feet. Stretch stature.</td>
<td>Stadiometer</td>
</tr>
<tr>
<td>2 Weight</td>
<td>Body weight. Measured while wearing minimal clothing.</td>
<td>Electronic scale</td>
</tr>
<tr>
<td>3 Sitting height</td>
<td>Distance between the vertex and the inferior aspects of the buttocks when seated. Stretch stature.</td>
<td>Stadiometer and anthropometric box</td>
</tr>
<tr>
<td>4 Head circumference</td>
<td>Circumference of the head immediately above the glabella and perpendicular to the long axis of the head.</td>
<td>Anthropometric tape</td>
</tr>
<tr>
<td>5 Neck circumference</td>
<td>Circumference of the neck on the Adam's apple and perpendicular to the long axis of the neck.</td>
<td>Anthropometric tape</td>
</tr>
<tr>
<td>6 Head length</td>
<td>Maximum distance between the glabella and the most posterior point on the head with the person sitting.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>7 Maximum head breadth</td>
<td>Maximum horizontal breadth of the head above the level of the ears with the person sitting.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>8 Menton-sellion length</td>
<td>Distance between the bottom of the chin (menton) and the sellion (the point of the deepest depression of the nasal bones at the top of the nose).</td>
<td>Bone calliper</td>
</tr>
<tr>
<td>9 Interpupillary distance</td>
<td>Distance between the centres of the right and left pupils.</td>
<td>Bone calliper</td>
</tr>
<tr>
<td>10 Eye-to-nose diagonal</td>
<td>Distance between the right pupil and the right alare (lateral points on the flare or wing of the nose).</td>
<td>Bone calliper</td>
</tr>
<tr>
<td>11 Nose breadth</td>
<td>Distance between left and right alare (lateral points on the flare or wing of the nose).</td>
<td>Bone calliper</td>
</tr>
<tr>
<td>12 Top of breastbone to centre of mouth</td>
<td>Distance between the most superior point on the sternum to the opening of the mouth (centre).</td>
<td>Bone calliper</td>
</tr>
<tr>
<td>13 Height of prominent neck vertebra, sitting</td>
<td>Distance from the 7th cervical vertebra to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>14 Shoulder (acromion) height, sitting</td>
<td>Distance from the acromiale landmark to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>15 Mid-shoulder height, sitting</td>
<td>Distance from the mid-acromiale-radiale to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>16 Shoulder breadth (deltoid)</td>
<td>Maximum breadth of the deltoids with the person sitting.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>17 Chest breadth, at level of nipples</td>
<td>Breadth of the thorax at the level of the nipples.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>18 Chest depth</td>
<td>Anterior-posterior depth of the thorax at the level of the nipples. The calliper must be perpendicular to the long axis of the thorax.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>19 Chest circumference</td>
<td>Circumference of the chest at the level of the nipples. The tape must be perpendicular to the long axis of the thorax.</td>
<td>Anthropometric tape</td>
</tr>
<tr>
<td>20 Trunk height to the top of the breastbone, sitting</td>
<td>Distance between the most superior point of the sternum to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>21 Height of maximum lumbar curvature, sitting</td>
<td>Distance between the maximum lumbar curvature to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>22 Sitting hip height</td>
<td>Distance between the most superior point on the iliac crest to the inferior aspects of the buttocks when seated.</td>
<td>Segmometer</td>
</tr>
<tr>
<td>23 Lower abdominal depth</td>
<td>Horizontal linear distance between the point on the skin surface of the abdomen immediately inferior to the omphalion and the corresponding dorsal surface of the torso. Subject is standing.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>24 Waist breadth</td>
<td>Breadth of the waist at the level of the navel.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>25 Hip breadth</td>
<td>Maximum linear breadth between the most lateral points of the hips.</td>
<td>Large sliding calliper</td>
</tr>
<tr>
<td>26 Waist circumference – natural indentation</td>
<td>Circumference of the abdomen at the narrowest point between the lower costal border and the top of the iliac crest. The tape must be perpendicular to the long axis of the trunk.</td>
<td>Anthropometric tape</td>
</tr>
<tr>
<td>27 Mid-hip circumference</td>
<td>Circumference of the buttocks at the level of their greatest posterior protuberance, perpendicular to the long axis of the trunk.</td>
<td>Anthropometric tape</td>
</tr>
</tbody>
</table>
8.3. Results

8.3.1. Participant demographics

The average age of the participants was 35 (±8) years, ranging from 19 to 57. The average length of service was 5 (±4) years, ranging from 0 to 15 years. Most of the participants were blacks (98%); 2% were white. A breakdown of the areas where the participants were from is illustrated in Figure 1. As anthropometric characteristics have been found to vary according to demographics, including age, ethnicity, geographic location and secular changes, these factors should be taken into consideration.

![Figure 1: Participants’ area of origin (N=97)](image)

<table>
<thead>
<tr>
<th>Area</th>
<th>Percentage of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limpopo</td>
<td>26%</td>
</tr>
<tr>
<td>Eastern Cape</td>
<td>18%</td>
</tr>
<tr>
<td>Gauteng</td>
<td>16%</td>
</tr>
<tr>
<td>Mpumalanga</td>
<td>16%</td>
</tr>
<tr>
<td>Free State</td>
<td>7%</td>
</tr>
<tr>
<td>North West Province</td>
<td>6%</td>
</tr>
<tr>
<td>Outside South Africa</td>
<td>5%</td>
</tr>
<tr>
<td>KwaZulu Natal</td>
<td>4%</td>
</tr>
<tr>
<td>Northern Cape</td>
<td>1%</td>
</tr>
<tr>
<td>Western Cape</td>
<td>0%</td>
</tr>
</tbody>
</table>

8.3.2. Comfort of SCSRs

Figure 2 indicates how frequently participants felt pain or discomfort because of their SCSR when wearing it. Most of the participants (68%) reported that this occurred
most or all of the time. Figure 3 indicates the level of discomfort reported because of the SCSR. The average rating was that of moderate discomfort.

Figure 2: Frequency of pain or discomfort when wearing an SCSR (N=91)

Figure 3: Level of discomfort when wearing an SCSR (N=87)
The participants were also asked to indicate where on their bodies they felt pain or discomfort while carrying an SCSR on the belt. The main areas of the body where
pain or discomfort was experienced were the hips, lower back and stomach (abdomen). Each of these areas was indicated as a source of pain or discomfort by between a third to over a half of the participants (see Figure 4). The area of “hips” was not indicated as an option in the questionnaire, but a number of participants indicated this in the “other” option. It is expected that the number of participants indicating pain or discomfort in the hips would be higher if this area was included as a specific selection choice in the questionnaire.

Almost all (99%) of the participants indicated that they considered SCSRs to be too heavy. The majority (92%) also indicated that wearing an SCSR disturbed their work. When asked when the SCSRs disturbed their work, over half of the respondents indicated that this occurred when sitting or stooping (bending forward), and between a third and a half indicated that this occurred when walking, standing or crawling (see Figure 5).

![Bar chart showing frequency of pain or discomfort when wearing an SCSR per mine](chart.png)

*Figure 6: Frequency of pain or discomfort when wearing an SCSR per mine (N=91)*
Comparisons of comfort when wearing SCSRs between participants from the three different mines were also made. The participants from the gold and coal mines appeared to report the highest frequency of pain and discomfort while wearing an SCSR on the belt, compared with the platinum mine (Figure 6). The participants from the gold and platinum mines were marginally more likely to report that the SCSRs were too heavy for them (Figure 7).

Figure 8 illustrates the activities at the different mines during which the participants experienced disturbance from the SCSRs. These are probably related to the required job tasks. At the coal mine, the greatest disturbances were reported while the participants were standing and sitting, and for the gold and platinum mines, while sitting and stooping. The ceiling heights of the mines would have an effect on these findings, as gold and platinum mines have lower ceiling heights than those of coal mines, which would result in a higher frequency of restricted work postures such as stooping and crawling (Schutte et al., 2003).
The participants were also asked open-ended questions about the main problems that they experienced with using an SCSR, if applicable, along with recommendations that they would make to improve the SCSR.

A total of 85 participants made comments regarding the main problems they faced with using an SCSR. Most of these comments indicated that the participants felt the SCSRs were too heavy and that the devices caused pain on their bodies. The comments were classified into categories of 1) weight, 2) size, 3) pain or discomfort and 4) effect on work. Some of the comments included aspects from different categories.

In terms of weight, 54% of the comments made stated that the SCSRs were too heavy. This was a cause of pain or discomfort or difficulty performing work. Gender was also indicated as a factor, for example, with the comment, “It’s heavy for us as women.” The size of the SCSR was associated with weight, and 5% of the participants indicated that the devices were too big.
Around 65% of the comments indicated that the participants experienced pain or discomfort when wearing an SCSR. The participants indicated that it caused pain in the back (particularly the lower back), stomach, waist, hips and buttocks. A few participants also mentioned that it was worse during menstruation, or that it exacerbated this discomfort. It was also noted that the SCSR becomes more uncomfortable as time goes on (i.e. cumulative pain or discomfort).

Some (21%) of the participants indicated that the SCSR affected their work. A number indicated that it made it difficult to operate machinery, lift objects, shovel, and get between small spaces. Movement of the SCSR around the waist was also a concern.

A total of 82 comments were made with regard to what the participants would suggest to improve SCSRs. A number of participants suggested that the SCSRs be changed, and this would be particularly by reducing the size and weight of them. Size and weight were associated and 52% of the comments suggested that they should be made lighter, and 47% suggested that they should be made smaller. A number of the comments (36%) also referred to the design or function of the SCSR. This referred to changes to make them more comfortable or usable. Some of these suggestions included changing it to fit better against the waist, making it flatter or shorter, making the casing of light plastic, changing the wearing position or making it easier or more comfortable to carry.

8.3.3. Anthropometric variables

Table 5 contains the results for the anthropometric measurements, including the average, standard deviation, minimum and maximum (range) and the 5th, 50th and 95th percentile values.
Table 5: Anthropometric data for the study sample

<table>
<thead>
<tr>
<th>Measurement</th>
<th>N</th>
<th>Average</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>5th percentile</th>
<th>50th percentile</th>
<th>95th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stature (cm)</td>
<td>98</td>
<td>160.2</td>
<td>5.6</td>
<td>147.1</td>
<td>172.4</td>
<td>150.8</td>
<td>160.4</td>
<td>168.4</td>
</tr>
<tr>
<td>2 Weight (kg)</td>
<td>98</td>
<td>76.3</td>
<td>15.3</td>
<td>49.2</td>
<td>121.2</td>
<td>52.8</td>
<td>75.9</td>
<td>101.5</td>
</tr>
<tr>
<td>3 Sitting height (cm)</td>
<td>93</td>
<td>81.6</td>
<td>3.1</td>
<td>74.9</td>
<td>90.3</td>
<td>77.0</td>
<td>81.5</td>
<td>86.9</td>
</tr>
<tr>
<td>4 Head circumference (cm)</td>
<td>90</td>
<td>58.2</td>
<td>3.3</td>
<td>52.0</td>
<td>69.5</td>
<td>53.6</td>
<td>57.7</td>
<td>63.7</td>
</tr>
<tr>
<td>5 Neck circumference (cm)</td>
<td>90</td>
<td>33.2</td>
<td>1.9</td>
<td>29.0</td>
<td>38.4</td>
<td>29.9</td>
<td>33.2</td>
<td>36.2</td>
</tr>
<tr>
<td>6 Head length (cm)</td>
<td>91</td>
<td>19.1</td>
<td>2.0</td>
<td>12.7</td>
<td>23.2</td>
<td>14.0</td>
<td>19.4</td>
<td>21.5</td>
</tr>
<tr>
<td>7 Maximum head breadth (cm)</td>
<td>92</td>
<td>13.7</td>
<td>1.7</td>
<td>8.9</td>
<td>17.1</td>
<td>9.8</td>
<td>14.0</td>
<td>15.7</td>
</tr>
<tr>
<td>8 Menton-sillon length (cm)</td>
<td>88</td>
<td>11.0</td>
<td>0.6</td>
<td>9.5</td>
<td>12.4</td>
<td>10.1</td>
<td>11.0</td>
<td>11.9</td>
</tr>
<tr>
<td>9 Interpupillary distance (cm)</td>
<td>92</td>
<td>6.2</td>
<td>0.5</td>
<td>4.6</td>
<td>7.5</td>
<td>5.3</td>
<td>6.2</td>
<td>6.8</td>
</tr>
<tr>
<td>10 Eye-to-nose diagonal (cm)</td>
<td>91</td>
<td>4.5</td>
<td>0.9</td>
<td>2.8</td>
<td>7.6</td>
<td>3.4</td>
<td>4.4</td>
<td>6.0</td>
</tr>
<tr>
<td>11 Nose breadth (cm)</td>
<td>91</td>
<td>4.0</td>
<td>0.3</td>
<td>3.0</td>
<td>4.7</td>
<td>3.4</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>12 Top of breastbone to centre of mouth (cm)</td>
<td>91</td>
<td>13.0</td>
<td>1.7</td>
<td>8.4</td>
<td>16.8</td>
<td>10.4</td>
<td>13.0</td>
<td>16.0</td>
</tr>
<tr>
<td>13 Height of prominent neck vertebra, sitting (cm)</td>
<td>87</td>
<td>60.4</td>
<td>2.7</td>
<td>55.2</td>
<td>66.6</td>
<td>55.9</td>
<td>60.2</td>
<td>64.6</td>
</tr>
<tr>
<td>14 Shoulder (acromion) height, sitting (cm)</td>
<td>87</td>
<td>53.9</td>
<td>2.8</td>
<td>48.4</td>
<td>62.2</td>
<td>49.8</td>
<td>53.8</td>
<td>59.3</td>
</tr>
<tr>
<td>15 Mid-shoulder height, sitting (cm)</td>
<td>87</td>
<td>39.6</td>
<td>3.2</td>
<td>33.9</td>
<td>55.7</td>
<td>35.1</td>
<td>39.8</td>
<td>44.8</td>
</tr>
<tr>
<td>16 Shoulder breadth (deltoid) (cm)</td>
<td>87</td>
<td>42.3</td>
<td>3.0</td>
<td>36.3</td>
<td>51.9</td>
<td>37.5</td>
<td>42.2</td>
<td>46.7</td>
</tr>
<tr>
<td>17 Chest breadth, at level of nipples (cm)</td>
<td>87</td>
<td>29.5</td>
<td>2.9</td>
<td>22.9</td>
<td>37.2</td>
<td>25.6</td>
<td>29.2</td>
<td>35.4</td>
</tr>
<tr>
<td>18 Chest depth (cm)</td>
<td>87</td>
<td>23.0</td>
<td>3.6</td>
<td>17.2</td>
<td>33.6</td>
<td>17.8</td>
<td>23.0</td>
<td>29.4</td>
</tr>
<tr>
<td>19 Chest circumference (cm)</td>
<td>87</td>
<td>99.9</td>
<td>11.2</td>
<td>78.6</td>
<td>126.5</td>
<td>85.0</td>
<td>99.8</td>
<td>120.2</td>
</tr>
<tr>
<td>20 Trunk height to the top of the breast bone, sitting (cm)</td>
<td>92</td>
<td>54.4</td>
<td>2.9</td>
<td>48.5</td>
<td>61.8</td>
<td>49.4</td>
<td>54.3</td>
<td>59.2</td>
</tr>
<tr>
<td>21 Height of maximum lumbar curvature, sitting (cm)</td>
<td>92</td>
<td>21.4</td>
<td>5.2</td>
<td>11.2</td>
<td>34.1</td>
<td>13.3</td>
<td>20.8</td>
<td>29.2</td>
</tr>
<tr>
<td>22 Sitting hip height (cm)</td>
<td>92</td>
<td>22.1</td>
<td>2.5</td>
<td>13.5</td>
<td>29.1</td>
<td>18.7</td>
<td>21.8</td>
<td>26.6</td>
</tr>
<tr>
<td>23 Lower abdominal depth (cm)</td>
<td>92</td>
<td>25.3</td>
<td>5.2</td>
<td>15.9</td>
<td>37.7</td>
<td>17.8</td>
<td>24.3</td>
<td>33.2</td>
</tr>
<tr>
<td>24 Waist breadth (cm)</td>
<td>92</td>
<td>30.5</td>
<td>4.5</td>
<td>20.1</td>
<td>43.2</td>
<td>24.2</td>
<td>30.0</td>
<td>38.3</td>
</tr>
<tr>
<td>25 Hip breadth (cm)</td>
<td>92</td>
<td>33.9</td>
<td>5.8</td>
<td>22.9</td>
<td>63.3</td>
<td>26.0</td>
<td>33.8</td>
<td>41.5</td>
</tr>
<tr>
<td>26 Waist circumference – natural indentation (cm)</td>
<td>96</td>
<td>84.7</td>
<td>11.8</td>
<td>52.5</td>
<td>107.6</td>
<td>67.1</td>
<td>84.8</td>
<td>103.0</td>
</tr>
<tr>
<td>27 Mid-hip circumference (cm)</td>
<td>96</td>
<td>110.5</td>
<td>11.9</td>
<td>83.1</td>
<td>145.0</td>
<td>92.2</td>
<td>110.5</td>
<td>130.3</td>
</tr>
<tr>
<td>28 BMI (kg/m²)</td>
<td>98</td>
<td>29.8</td>
<td>5.8</td>
<td>19.9</td>
<td>43.7</td>
<td>21.4</td>
<td>29.6</td>
<td>39.9</td>
</tr>
<tr>
<td>29 Waist-to-hip ratio</td>
<td>96</td>
<td>0.77</td>
<td>0.07</td>
<td>0.42</td>
<td>0.94</td>
<td>0.67</td>
<td>0.77</td>
<td>0.88</td>
</tr>
</tbody>
</table>
The current data gathered can be compared with reference values, or those recorded from previous studies. Table 6 shows a comparison of the data with torso reference values from ISO/CD 16900-5.2 and ISO/TS 16976, and with values recorded from a previous study conducted in the South African mining industry (Schutte et al., 2007). A number of differences in the measurements recorded in the different documents should be noted. Some of the measurements taken in the current study were not recorded in the other documentation. In addition, the landmarks used in the current study for measuring hip breadth were different from those indicated in the ISO documents. In the current study, the most lateral points of the iliac crests were used as landmarks. Only the values for female mineworkers for the current study and for the study by Schutte et al. (2007) are presented in Table 6, whereas the ISO values are derived from both male and female dimensions.

The current data were compared with ISO reference data (male and female) in order to determine whether the data used for the design and testing of SCSRs is suited to women in the South African mining industry. As expected, most of the reference values from the ISO documents are larger than the average measurements from the participants in the current study, as our study included only female participants, whereas the ISO data are derived as an average of male and female data. The measurements for which the study sample had higher averages than the ISO reference values were for head circumference, nose breadth, chest circumference, waist breadth, waist circumference and hip circumference, along with BMI and waist-to-hip ratio. It is likely that the current sample had higher values for head circumference and head length as a result of hairstyles and hair extensions, which increased the measurements. The participants in the current sample tended to have higher levels of obesity than the ISO reference sample, which were reflected in the higher waist, hip and BMI indices. High levels of obesity have been recorded among South African women (Puoane et al., 2002). When the current data were compared with only the female data from ISO documentation, similar trends were evident (see Table 6).
Table 6: Comparisons of current data with reference and previous study data
Highlighted values indicate significance (p<0.05)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Current data 50th percentile (females)</th>
<th>ISO data 50th percentile (males and females)</th>
<th>ISO data 50th percentile (females only)</th>
<th>Schutte et al. (2007) 50th percentile (females)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stature (cm)</td>
<td>160.4</td>
<td>169.1</td>
<td>162.7</td>
<td>160.8</td>
</tr>
<tr>
<td>2 Weight (kg)</td>
<td>75.9</td>
<td>80.3</td>
<td>72.1</td>
<td>68.0</td>
</tr>
<tr>
<td>3 Sitting height (cm)</td>
<td>81.5</td>
<td>-</td>
<td>-</td>
<td>83.3</td>
</tr>
<tr>
<td>4 Head circumference (cm)</td>
<td>57.7</td>
<td>56.5</td>
<td>55.5</td>
<td>-</td>
</tr>
<tr>
<td>5 Neck circumference (cm)</td>
<td>33.2</td>
<td>36.9</td>
<td>33.5</td>
<td>-</td>
</tr>
<tr>
<td>6 Head length (cm)</td>
<td>19.4</td>
<td>19.2</td>
<td>18.7</td>
<td>19.3</td>
</tr>
<tr>
<td>7 Maximum head breadth (cm)</td>
<td>14.0</td>
<td>15.0</td>
<td>14.6</td>
<td>15.0</td>
</tr>
<tr>
<td>8 Menton-sellion length (cm)</td>
<td>11.0</td>
<td>11.8</td>
<td>11.3</td>
<td>11.1</td>
</tr>
<tr>
<td>9 Interpupillary distance (cm)</td>
<td>6.2</td>
<td>6.35</td>
<td>6.2</td>
<td>-</td>
</tr>
<tr>
<td>10 Eye-to-nose diagonal (cm)</td>
<td>4.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11 Nose breadth (cm)</td>
<td>4.0</td>
<td>3.45</td>
<td>3.3</td>
<td>-</td>
</tr>
<tr>
<td>12 Top of breastbone to centre of mouth (cm)</td>
<td>13.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13 Height of prominent neck vertebra, sitting (cm)</td>
<td>60.2</td>
<td>64.8</td>
<td>62.8</td>
<td>61.4</td>
</tr>
<tr>
<td>14 Shoulder (acromion) height, sitting (cm)</td>
<td>53.8</td>
<td>58.7</td>
<td>56.9</td>
<td>51.5</td>
</tr>
<tr>
<td>15 Mid-shoulder height, sitting (cm)</td>
<td>39.8</td>
<td>60.6</td>
<td>57.9</td>
<td>-</td>
</tr>
<tr>
<td>16 Shoulder breadth (deltoid) (cm)</td>
<td>42.2</td>
<td>43.7</td>
<td>41.6</td>
<td>-</td>
</tr>
<tr>
<td>17 Chest breadth, at level of nipples (cm)</td>
<td>29.2</td>
<td>30.6</td>
<td>28.2</td>
<td>-</td>
</tr>
<tr>
<td>18 Chest depth (cm)</td>
<td>23.0</td>
<td>25.0</td>
<td>25.1</td>
<td>-</td>
</tr>
<tr>
<td>19 Chest circumference (cm)</td>
<td>99.8</td>
<td>91.9</td>
<td>92.1</td>
<td>-</td>
</tr>
<tr>
<td>20 Trunk height to the top of the breastbone, sitting (cm)</td>
<td>54.3</td>
<td>58.5</td>
<td>57.3</td>
<td>-</td>
</tr>
<tr>
<td>21 Height of maximum lumbar curvature, sitting (cm)</td>
<td>20.8</td>
<td>23.7</td>
<td>23.2</td>
<td>-</td>
</tr>
<tr>
<td>22 Sitting hip height (cm)</td>
<td>21.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23 Lower abdominal depth (cm)</td>
<td>24.3</td>
<td>26.7</td>
<td>25.0</td>
<td>24.9</td>
</tr>
<tr>
<td>24 Waist breadth (cm)</td>
<td>30.0</td>
<td>26.2</td>
<td>26.4</td>
<td>26.2</td>
</tr>
<tr>
<td>25 Hip breadth* (cm)</td>
<td>33.8</td>
<td>32.4</td>
<td>32.1</td>
<td>36.2</td>
</tr>
<tr>
<td>26 Waist circumference – natural indentation (cm)</td>
<td>84.8</td>
<td>80.4</td>
<td>76.9</td>
<td>-</td>
</tr>
<tr>
<td>27 Mid-hip circumference (cm)</td>
<td>110.5</td>
<td>105.8</td>
<td>105.6</td>
<td>-</td>
</tr>
<tr>
<td>28 BMI (kg/m²)</td>
<td>29.6</td>
<td>23.7</td>
<td>22.2</td>
<td>21.1</td>
</tr>
<tr>
<td>29 Waist-to-hip ratio</td>
<td>0.77</td>
<td>0.76</td>
<td>0.73</td>
<td>-</td>
</tr>
</tbody>
</table>

*Please note: Different anthropometric landmarks were used between studies for measuring hip breadth.
A comparison with data from Schutte et al. (2007) was made in order to assess possible changes that may have occurred in the study population over the past decade. Comparisons between 12 of the recorded measures could be made. Upon inspection, it appears that the participants from the current sample have higher body weights and greater associated dimensions than the participants in the 2007 study. This is expected as obesity rates have increased substantially in South Africa over the past few years.

### 8.3.4. BMI and comfort

Waist girth, waist-to-hip ratio and BMI can be used as health risk indicators. For females, weight girths of over 88 cm, and waist-to-hip ratios of over 0.85 are associated with increased health risks such as high blood pressure, diabetes and heart disease (McArdle et al., 2001; Puoane et al., 2002). BMI may be classified into the categories of underweight (below 18.5), normal (18.5–24.9), overweight (25.0–29.9) and obese (30 and above). Obesity may further be classified into categories of class 1 (30.0–34.9), class 2 (35.0–39.9) and class 3 (≥40.0) obesity.

![BMI classifications](image)

**Figure 9: BMI classifications (N=98)**
The average waist girth for the sample was 85 (±12) cm, and 43% of the sample had waist girths of more than 88 cm. The average waist-to-hip ratio was 0.77 (±0.07), and 11% of the sample had waist-to-hip ratios of above 0.85. The average BMI for the sample was 30 (±6), and 46% of the sample had BMIs of over 30. This indicates that the average participants’ weight was higher than recommended for their stature and 46% of the sample was therefore classified as obese. See Figure 9 for the BMI distribution of the participants.

![BMI Distribution](image)

**Figure 10: Frequency of pain or discomfort when wearing an SCSR according to BMI (N=89)**

Comparisons of self-reported data on the use of SCSRs were made between different BMI groups, in order to see whether the BMI of participants was having an impact on the level of comfort of SCSRs. Categories for BMI for this analysis include those that were considered obese (BMI≥30) versus those with BMIs of less than 30. It appeared that those with higher BMIs reported a slightly higher frequency of discomfort and higher levels of discomfort when using an SCSR than those with lower BMIs (see Figures 10 and 11). Those with lower BMIs were slightly less likely to report that the SCSRs were too heavy or disturbed their work (Figure 12).
8.4. **Conclusions of anthropometric assessment**

- An assessment of the anthropometry of women in the South African mining industry, relating to the design and use of SCSR devices, was conducted.
- Data were collected for a total of 29 dimensions for the sample of 100.
- A number of significant differences between the data collected and reference and historical data were found.
- The differences in data collected versus reference data indicates that the dimensions used in the design of such equipment may not be appropriate for the assessed population.
- Subjective discomfort was experienced by women in mining while wearing SCSRs on the belt at work.
- The SCSRs were reported to cause pain in the hips, lower back and stomach.
- Almost of (99%) of the participants considered the SCSRs to be too heavy, while 92% indicated that the devices disturbed their work.
- Participants hoped that the devices could be made smaller and more ergonomic for daily use.

8.5. **Next milestone**

The next milestone for this project involved a practical ergonomics assessment of SCSR devices while worn on the belt and while donned and used by women in the South African mining industry. Recommendations for the improvement of existing SCSRs to address the identified shortcomings will be discussed with subject matter experts, stakeholders and OEMs. The recommendations are reported in Chapter 10.
9. PRACTICAL PERFORMANCE ASSESSMENT

9.1. Introduction

A practical performance assessment was done, in which the effect of SCSRs on women’s ability to walk erect, stoop or crawl was analysed through observation as well as the participants’ self-reported experiences and responses. This was done with the SCSR worn on the belt and while donned and in use. The functionality of the units when deployed was considered, as was the functionality during use of different makes of SCSRs.

9.2. Methods

A mixed methods study was carried out as both quantitative and qualitative data were gathered. Data collection took place over one week in April 2017, at Mines Rescue Services facilities. The study was undertaken in a simulated underground mining environment. This setting is as per sub clause 5.2.9.1 of SANS1737. The controlled environment was necessary to ensure consistency for each test, to enable accurate comparisons.

Female mineworkers who were required to wear SCSRs during their daily work formed the sample population. The final sample comprised of six participants from a platinum mine and six participants from a coal mine. The participants had a range of job positions and demographic and anthropometric characteristics. The participants had undergone an annual medical examination to ensure that they were fit to undertake the test procedures.

Before testing started, the participants were informed of the study aims and procedures. The participants’ demographic information was gathered, they completed a “comfort questionnaire”, and their anthropometric measurements were taken (see Chapter 8 for details).
Each of the participants was required to attend two consecutive days of testing. Six participants were tested at a time, and the participants from the coal and platinum mines were tested on separate days at the Mines Rescue Services facilities located nearest to their place of work for practical purposes.

One control and eight testing sessions were completed by the participants. Each session required the participants to navigate a test route that was approximately 400 m long, and involved crawling, stooping and walking upright. In the control sessions the participants were required to navigate the mine training gallery test route while wearing full PPE (overalls, boots, hard hats, cap lamps, gloves and knee guards), without an SCSR device. For the testing sessions the participants were required to navigate the route while wearing an SCSR unit on the belt and while the unit was donned and activated. Four different models of SCSRs were used, with two models being used on each day. The order in which the different models were used differed between the two testing venues to minimise the effect of ordering.

On the first day of the study the participants were first familiarised with the test route and completed the control session. Following this, the first four testing sessions were completed. The final four testing sessions were completed on the second day of the study. For these testing sessions, each SCSR was first tested while worn on the belt, and then while donned and in use. Prior to testing, the correct procedures for opening, donning and using each make of escape apparatus were demonstrated in accordance with the manufacturer’s instructions for use.

The participants were asked to navigate the test route in single file at a comfortable pace that the whole group could maintain. The testing sessions were to continue until the participants had completed the test route, or if the observers or the participants judged it unsafe to continue. Safety procedures were followed during testing, including physiological monitoring and close supervision by trained, experienced staff,
and voluntary withdrawal was permitted at any time. A period of approximately 30 minutes was provided for rest and recovery between tests.

Qualitative and quantitative data were collected, which included both subjective and objective responses and outcomes. Environmental temperatures (dry and wet bulb) were also monitored. Prior to starting each test, the participants were asked to sit and rest. The participants' body temperatures were measured orally before the exercise began on each day. During each of the sessions, the information that was recorded included the time to don the apparatus (when applicable), the test duration, and the reason for ending the test. Photographs were taken and video recordings and observations were made. Immediately after the test, the following measurements were taken: body temperature (oral), ratings of perceived exertion (RPE), body discomfort ratings and an ergonomic assessment questionnaire.

Body temperatures were recorded using oral thermometers. The RPE scale developed by Borg (1962) consists of a scale from 6 (“very, very light”) to 20 (“very, very hard”). The participants were asked to rate their level of exertion on this scale for both central (heart and lung) and peripheral (muscular) RPE. A body discomfort map was used on which the participants were asked to indicate where they felt discomfort, along with the level of discomfort experienced for each area, on a scale from 1 (“very slight discomfort”) to 10 (“extreme discomfort”) (Corlett and Bishop, 1976). The ergonomic assessment questionnaire was taken from SANS1737 according to the procedures for practical ergonomics testing of body-worn escape type breathing apparatus. See Appendices C – E for the RPE scale, body discomfort map and ergonomic assessment questionnaire, respectively.

Comparisons were made of the responses obtained during the control session, with the units worn on the belt and with the units donned and in use. Comparisons between the responses while using different SCSR models were also made. Recommendations may be drafted from these comparisons.
Ethical approval to conduct this study was received from the CSIR Research Ethics Committee (Ref: 179/2016). Informed consent forms were signed by each of the participants.

9.3. Results

9.3.1. Participant characteristics

One of the participants only attended one day of the study and, therefore, her data has been excluded from the results. The total sample size was 11, of which 6 were from the platinum sector and 5 from the coal sector. All of the participants were female. The average age of the participants was 31 (±4) years, ranging from 26 to 41. The average length of time the participants had been working at the respective mines was 3.5 (±4) years, ranging from 0 to 10 years. Most (91%) of the participants were black Africans, while 1 (9%) was white.

Table 7: Anthropometric characteristics of the participants

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature (cm)</td>
<td>164</td>
<td>4</td>
<td>157</td>
<td>171</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77</td>
<td>17</td>
<td>62</td>
<td>121</td>
</tr>
<tr>
<td>Body mass index</td>
<td>29</td>
<td>6</td>
<td>23</td>
<td>44</td>
</tr>
<tr>
<td>Waist girth (cm)</td>
<td>80</td>
<td>9</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Hip girth (cm)</td>
<td>111</td>
<td>14</td>
<td>102</td>
<td>145</td>
</tr>
</tbody>
</table>

Basic anthropometric data of the participants is given in Table 7. The average BMI for the participants was in the overweight category according to World Health Organization guidelines. Furthermore, 36% of the participants were considered to have a “normal” weight, 36% were “overweight”, and 27% were “obese”. For women, having a waist girth of above 88 cm is considered to be a health risk factor as it is indicative of central obesity, and 9% of the sample fell into this category (McArdle et al., 2001).
There was a range of job positions among the participants, namely: belt attendant; fitter; general assistant; loco operator; multi-skilled operator; pipes, tracks and ventilation; general worker; long Airdox operator (x2); miner; roof bolt operator.

All of the participants were required to wear SCSRs on the belt when at their normal place of work, although none had ever deployed an SCSR (e.g. in an emergency situation or for training). In terms of reported comfort while wearing an SCSR during daily work, all of the participants considered the SCSRs to be too heavy, and that the devices disturbed their work. Higher percentages of participants reported disturbance while sitting (82%), stooping (73%) and walking (64%), compared to standing (36%) and crawling (36%); this is likely related to job tasks performed.

9.3.2. Practical ergonomics assessment

Environmental temperatures

The average wet bulb temperature measured during the testing sessions was 13 °C (±4 °C), ranging from 9 °C to 20 °C. The average dry bulb temperature was 22 °C (±2 °C), ranging from 19 °C to 24 °C.

Test durations

None of the participants had to withdraw from any of the sessions as they were able to complete the test routes. The participants were encouraged to keep a consistent pace while navigating through the different sessions, and were asked to stick together as a team while going single file through the route. The time taken to complete the route was not a performance outcome as such, although some observations were made in this regard.
The average time taken to complete each test route was 10 min 34 s. The average time taken to complete the route while wearing an SCSR on the belt was 10 min 15 s, and when donned it was 10 min 52 s. The increased time taken to complete the route while the unit was donned and in use could be a result of the increased physical stress placed on the participants, as they may have slowed down when experiencing tiredness.

![Figure 13: Time taken to complete the test using SCSRs on the belt and while donned and in use](image)

Some comparisons of times taken to complete the route while wearing different SCSRs are illustrated in Figure 13. The participants appeared to complete the route faster with models 1 and 2 worn on the belt than models 3 and 4. It can also be seen that the biggest difference in time taken to complete the route when wearing the unit on the belt and when donned was for SCSR model 2. This model was the only unit that was worn on the head and had a head rather than a neck strap, which could result in higher strain while the unit is donned.
Donning time was also measured. Average donning time was recorded at 2 min 32 s from when the participants were instructed to start the procedure until they were completely fitted with the device and had refitted their PPE including hard hats and gloves, and were ready to continue with the route. As such, the time for when the participants started breathing oxygen from the devices was shorter than the total donning time. Donning time varied between participants, but the average time for each unit is illustrated in Figure 14. The participants took the longest time to don model 3. This was the only model that included goggles, and putting them on would have added to the total donning time. Training and familiarity with the units may also have a role to play in the time taken to don.

![Figure 14: Average time taken to don SCSRs](image)

The time taken to complete the test routes once the units were donned was roughly extrapolated to an estimate of 20 minutes to reach a refuge bay of 750m away if moving at the average pace maintained during the testing sessions. As such, the rated durations of the four SCSRs in use, which range from 25 to 40 minutes, were longer than this time. However, the length of time to reach a place of safety could be extended in an emergency situation where visibility may be hampered and where more extreme environmental conditions may be evident.
Observations

Basic observations were made while the participants were undergoing the test procedures, and after analysing the photographs taken and the videos made. See Figures 15 to 24 for pictures of the SCSRs while worn on the belt and while donned and in use.

Control session

The participants navigated the test routes while wearing full PPE except for an SCSR. This involved walking on level and sloped surfaces, stooping, climbing up and down stairs, and crawling. The participants did not appear to experience difficulty with this.

Model 1

This unit had a protective metal casing. It appeared to be longer than it was wide, and was contoured to fit the user’s body. The belt loops looked relatively long, and were located fairly near to the top of the unit. It was observed that the participants wore model 1 on the belt at the side or towards the back of their bodies. Some of the participants wore the unit on the left side and others on the right side. The units appeared to rest quite low on the body, touching the side of the widest part of the hip or buttocks. A number of the units slipped to the front of the belt when the participants were crawling.

During donning, the participants had to exert some force to lift the opening lever from the left to the right, after which the front cover of the unit came off. This appeared to be more difficult for left-handed users. The participants continued to don the inner (operational) units with some guidance from the instructors. Once donned, the side of the metal casing of the unit facing the body of the user remained on the participants’ belts. The inner unit appeared to rest on the chest. The participants were encouraged to tighten the neck straps to increase the “goose neck” of the breathing tube, which would allow them to lift their heads and look from side to side. This helped particularly when crawling because of the body and head position. When the units were donned
and in use, it could be seen that some of the participants held the inner units against their bodies while stooping. This was to prevent the inner units falling forward, and could be an indication that the participants felt that the inner units were too loose or that the body straps were not fitted tightly enough.

Figure 15: Picture of model 1 while worn on the belt

Figure 16: Picture of model 1 being donned
Figure 17: Picture of model 1 when donned

Model 2
This unit had a relatively soft protective Kevlar cover over its outer casing and a metal lid. It appeared wider than it was long, and was contoured to fit the user's body. The participants' belts fitted through belt loops in the protective cover, which were located slightly above halfway up the unit. The participants wore the units on their belts, towards the side or back of their hips, either on the left or right side. Some of the participants' units slipped to the front of their bodies when crawling. This could be a result of the tightness of the belt on the wearer, rather than the attachment of the unit onto the belt.

The participants donned the inner units under the guidance of the supervisors. Donning these units required the participants to lift an opening lever from left to right. After this had been done, the metal lid of the protective casing was lifted off the unit and the inner unit was removed. Some of the participants experienced some difficulty removing the metal lid.
The inner unit had head straps rather than neck and body straps. The head straps were adjusted according to head size. The hairstyles of the participants appeared to affect the fit of the unit. These units did not incorporate a breathing tube and the mouth piece was connected directly to the inner unit. The weight of the inner unit appeared to be borne by the necks and jaws of the participants. It looked as though
increased strain on the head and neck was experienced by the participants while crawling or bending forward as the packs fell forward. Some of the participants supported the weight of the pack with their hands while stooping.

This model had an automatic oxygen starter, so the participants did not have to blow into the unit to initiate the chemical reaction to produce oxygen. It was evident, however, that a few of the units did not self-inflate. As a result, normal breathing was not possible, the participants needed to stop and inflate the units by removing the nose clip and blowing air into the units.

*Model 3*
This unit had a plastic casing and appeared rather bulky when worn on the belt. It had fairly short but wide belt loops that were located around half to two-thirds of the way to the top of the unit. The unit appeared to rest relatively high up on the body when worn, and the participants’ elbows were seen to touch the unit. It did not appear to be contoured to the user’s body. The participants wore the unit on their left or right hips towards the back of the body, as with the other models. These units, as with the other models, often slipped to the front of the body while the participants were crawling.

*Figure 20: Picture of model 3 while worn on the belt*
During donning of the inner unit, the casing lid was removed, and the belt loop clips fell away. It appeared that some of the participants found it difficult to lift the opening lever. There was some delay in adjusting the fit of the inner unit after the mouthpieces and nose clips had been fitted. Some of the belt loop clips did not fall away and remained attached to the belt; these had to be manually detached from the unit for it to fit properly. This unit had a neck and a body strap. The body strap was attached using a clip, and could then be adjusted to size. The unit was designed so that, when donned, the bottom part of the casing of the unit remains attached to the inner unit. The casing appeared to rest below the participants’ chests. It also appeared that the neck straps were too long, which resulted in a shortened “goose neck” of the breathing tube, which could prevent the participants from looking fully up or to the side. It appeared that the participants experienced neck strain when using this unit. The participants were observed to support the weight of the units with their hands when walking or to hold the units against their bodies when stooping.

Figure 21: Picture of model 3 while donned
Goggles were provided with this unit. These had an elastic strap which stretched according to head size in order to fit properly. During navigation of the test route, it was observed that some of the goggles misted up. A few of the participants took the goggles off, as they said that they could not see through them.

**Model 4**  
This unit had a metal casing and elongated belt loops. The belt loops appeared to be fairly close to the top of the unit. The unit appeared to be longer than it was wide, and was flat at the back, and not contoured to the body shape. The unit looked relatively bulky when worn on the belt, and some of the participants’ elbows made contact with the top of the unit during normal movements. Some of the participants had difficulty attaching the units to the belts that they were wearing. When worn on the belt, the unit appeared to hang quite loosely, as it moved around and slipped to the front while the participants were crawling. They frequently held it to keep it in place or to bear some of the weight.

The neck and body straps of the unit appeared to become entangled for some of the participants during the donning of the unit. When donned, the back cover of the metal casing remained on the participants’ belts. Some of the participants started coughing
when breathing from the unit. It appeared that as a result of the design of the unit, the neck strap could not be sufficiently adjusted, and some of the participants reached the adjustment limit. This prevented the unit from hanging higher up on the body. There was no adjustment clip on the body strap of this model; instead the participants used a knot to attach it. As with the other units, the participants sometimes held and supported it against their chests when stooping or bending forward.

Figure 23: Picture of model 4 worn on the belt

Figure 24: Picture of model 4 while donned
General considerations

It is possible that in the case of an emergency, users may panic, and not fit the SCSRs as well as they would in a controlled environment under the guidance and supervision of training personnel. It is likely that the wearers would be more methodical and less hasty during test procedures. The participants expressed concern over the relatively long time taken to don some of the units, as this could be life-threatening factor in an emergency situation.

Body temperature

Body temperature was recorded before starting with testing each day and following each testing session. The average body temperature at the start of day 1 was 36.5 °C (±0.5 °C) and at the start of day 2 it was 36.7 °C (±0.6 °C). The average temperature after the control sessions was 36.7 °C (±0.6 °C), after wearing the units on the belt was it 36.5 °C (±0.5 °C), and after donning and using the units it was 36.5 °C (±0.4 °C). Figure 25 shows the average body temperature of the participants following the testing sessions.

Figure 25: Body temperature following testing
The sessions did not appear to influence body temperature to any great extent. This is likely because the duration of the exercise combined with the workload was not high enough to cause any great change in body temperature. Time of day and order of testing may also have affected the results, as these differed between the two groups of participants – body temperatures are seen to fluctuate over a 24-hour cycle. It should also be noted that body temperatures were measured orally, which may not be as accurate as core body temperature measurements.

**Ratings of perceived exertion**

Average central (heart and lung) and peripheral (muscular) RPEs were generally lowest following the control session, higher when wearing an SCSR on the belt, and highest when donning and using an SCSR (see Figure 26). This was expected, as the lowest levels of exertion were anticipated during the control route navigation and the highest while donning and using an SCSR. During the control and on-the-belt sessions, central RPE was generally observed to be higher than peripheral RPE, which meant that the participants generally felt that their hearts and lungs were working harder than their muscles. Average central and peripheral RPEs were similar when the units were donned and in use, as this condition placed higher demands on both the circulatory and muscular systems of the body.

Figures 27 and 28 show the participants’ average central and peripheral RPEs, respectively, for the participants for each SCSR model while worn on the belt and while donned and in use. When the units were worn on the belt, the participants reported the highest levels of central and peripheral exertion for model 3. When the SCSRs were donned and in use, model 4 appeared to cause the lowest reported levels of exertion.
Figure 26: Central and peripheral RPE

Figure 27: Central RPE following testing
Body discomfort

Body discomfort was assessed after completion of the test routes. Following the control routes, none of the participants reported experiencing discomfort in any parts of their bodies. However, the participants experienced discomfort after navigating through the test route while the SCSR was on the belt, and when donned and in use, respectively.

The areas of the body where the participants reported discomfort while wearing the SCSR on the belt were predominantly the lower back, hips, buttocks and the front of the thighs (see Figure 29). The average discomfort rating for the combined area of the lower back, hips and buttocks was 5, and 4 for the thighs, on a scale from 1 (very slight discomfort) to 10 (extreme discomfort). While discomfort was reported while wearing each of the units, model 3 was rated as causing slightly greater average discomfort than the other SCNRs.

The participants reported discomfort in a number of areas of the body after completing the route with the SCSR donned (see Figure 30). The main areas of discomfort that were reported were the neck or shoulders, throat, and jaws or teeth.
Meanwhile, the highest average pain ratings for the areas that experienced discomfort were reported for the chest, jaws or teeth and the neck or shoulders.

**Figure 29: Body discomfort while wearing SCSRs on the belt**

**Figure 30: Body discomfort while SCSRs were donned an in use**
Some differences in the discomfort ratings between the different models while donned were evident (see Figures 31 – 34). The highest number of reports of discomfort was recorded for models 2 and 3. For model 1, the highest levels of discomfort were reported for the neck and shoulder area. For model 2, a high frequency of discomfort was reported for the jaws and teeth, and for the neck and shoulder area. When model 3 was donned and used, discomfort was primarily reported in the neck and shoulders,
the throat and the chest. The participants who experienced pain in the chest reported high levels of discomfort. For model 4, the highest pain ratings were for the lower back and hip area.

![Figure 33: Body discomfort while model 3 was donned and in use](image)

![Figure 34: Body discomfort while model 4 was donned and in use](image)
Ergonomics questionnaire

The participants rated each of the four SCSR models on various aspects on a scale of 0 (totally unacceptable) to 10 (highly acceptable). A score of 5 indicates acceptability. The average results for each SCSR model are shown in Figure 35. More detailed responses are shown in Tables 8 – 10. The participants also made related comments about each of the devices, and a summary of these responses is given below.

![Figure 35: Assessment of ergonomic design of four SCSR models](image)

It can be seen that models 1 and 2 were rated most highly with regard to ergonomic design for normal wearing, i.e. wearing the SCSR on the belt, while the other two models were, on average, rated as slightly below acceptable. Model 4 was rated highest in terms of acceptability of donning the unit and wearing it while donned and in use.

Table 8 shows ratings by the participants relating to while the units were worn on the belt. It should be noted that the suitability of the belts that the participants were
wearing appeared to have a major influence on this, as they wore the same type of belts and PPE for all of the tests. Differently designed belts would be better suited to some SCSR models than to others. On average, the weight of the SCSRs received the lowest ratings, along with their shape, which received lower than “acceptable” average ratings. Models 1 and 2 were rated higher (better) for shape, size, mass, wearing arrangement and daily affixing of the SCSR to the belt than models 3 and 4, which generally received lower than acceptable ratings for normal (on the belt) wearing.

Table 8: Ratings of ergonomic design of four SCSR models for normal wearing

<table>
<thead>
<tr>
<th>Category</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Shape of escape apparatus (shaped to body contours, comfort)</td>
<td>5.3</td>
<td>6.5</td>
<td>3.9</td>
<td>3.1</td>
<td>4.7</td>
</tr>
<tr>
<td>b) Size of escape apparatus (too bulky for routine work, or only if in confined spaces; bruising, bumping, catching)</td>
<td>6.7</td>
<td>6.1</td>
<td>3.4</td>
<td>4.2</td>
<td>5.1</td>
</tr>
<tr>
<td>c) Mass of escape apparatus (are you aware of the mass of the escape apparatus, and if so how would you rate it?)</td>
<td>4.2</td>
<td>5.5</td>
<td>2.8</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>d) Wearing arrangement – belt and suspension to belt (comfort in negating the effect of mass?)</td>
<td>6.5</td>
<td>6.7</td>
<td>4.6</td>
<td>4.7</td>
<td>5.6</td>
</tr>
<tr>
<td>e) Daily affixing of escape apparatus to the body (cumbersome?)</td>
<td>6.2</td>
<td>6.2</td>
<td>4.5</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>f) Prevention of accidental opening of escape apparatus</td>
<td>7.8</td>
<td>5.7</td>
<td>6.9</td>
<td>7.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

The participants made varying comments about the units. In terms of shape, some found particular units to be more comfortable or acceptable, while others declared that they were not comfortable, were not shaped to the body, and some were too big or too high, which resulted in disturbance to movements or discomfort on the body.
For the size of the units, the participants preferred the smaller units, and some noted that some of the units were a bit too big or bulky. Mass appeared to be the main concern for normal on-the-belt SCSR wearing, with participants commonly reporting that the units were too heavy.

The wearing arrangement would also be affected by the belt worn. Comments relating to this indicated that some were comfortable, but others noted that the SCRs were too loose and moved around on the belt or did not fit properly. Some also felt that the units pulled their belts down. Similarly, with daily affixing of the apparatus to the belt, the participants felt that some units were easier to attach than others. The participants generally thought that the prevention of accidental opening of the SCRs was acceptable. However, there were some concerns about this, for example some of the participants reported that their elbows made contact with the top of the SCRs during daily movements, which could potentially by accident lift the opening lever; other participants were concerned about the units slipping around on the belt, and yet others expressed concerns about the possible abrasion of the protective casing.

The average rating of the ergonomic design of the SCRs for donning was at least acceptable, with some variation according to the participant and the different models of SCSR (see Table 9). In general, the participants found it easy to manoeuvre the SCRs into donning position. Some of the participants experienced difficulty in opening the protective casing of the SCSR, and noted that they needed to apply force, which could make it difficult in an emergency situation. Some of the models (1 and 3) were also designed with an opening lever that was most easily lifted with the right hand; however, as some people are left-handed, this could make it awkward for them. In terms of handling the breathing tube, mouthpiece and nose clip, and the fitting of the head, shoulder and waist straps, most of the comments dealt with comfort during use, which is discussed below. Many of the participants did not report difficulties with donning, but some concerns were raised, such as difficulty locating and adjusting the straps, and some participants noted a preference for body straps.
that had an adjustment mechanism to secure them rather than a tie, as in model 4, and that the strap was potentially too short to fit all users.

Table 9: Ratings of ergonomic design of four SCSR models for donning

<table>
<thead>
<tr>
<th>Category</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Ease of manoeuvring escape apparatus into donning position</td>
<td>6.5</td>
<td>7.3</td>
<td>6.0</td>
<td>8.4</td>
<td>7.1</td>
</tr>
<tr>
<td>b) Ease of opening the container</td>
<td>5.0</td>
<td>6.1</td>
<td>4.8</td>
<td>8.5</td>
<td>6.1</td>
</tr>
<tr>
<td>c) Ease of handling essential parts:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) breathing tube</td>
<td>5.0</td>
<td>6.2</td>
<td>5.0</td>
<td>7.7</td>
<td>6.0</td>
</tr>
<tr>
<td>2) insertion of mouthpiece</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) fixing of nose clip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Ease of affixing and adjusting of ancillary webbing/equipment:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) head strap</td>
<td>6.5</td>
<td>4.7</td>
<td>5.5</td>
<td>7.2</td>
<td>6.0</td>
</tr>
<tr>
<td>2) bag strap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) body strap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Ratings of ergonomic design of four SCSR models for negotiating escape routes

<table>
<thead>
<tr>
<th>Category</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Accommodation for different torso lengths and sizes in respect of breathing tube and ancillary webbing, etc.</td>
<td>5.8</td>
<td>4.8</td>
<td>4.1</td>
<td>8.5</td>
<td>5.8</td>
</tr>
<tr>
<td>b) Comfort</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) nose-clip</td>
<td>3.9</td>
<td>5.3</td>
<td>3.7</td>
<td>5.9</td>
<td>4.7</td>
</tr>
<tr>
<td>2) mouthpiece</td>
<td>6.0</td>
<td>4.3</td>
<td>3.8</td>
<td>7.4</td>
<td>5.4</td>
</tr>
<tr>
<td>3) physical contact of set with body – too hot?</td>
<td>6.1</td>
<td>3.7</td>
<td>4.4</td>
<td>8.4</td>
<td>5.7</td>
</tr>
<tr>
<td>4) breathing resistance</td>
<td>5.4</td>
<td>6.7</td>
<td>4.4</td>
<td>8.5</td>
<td>6.3</td>
</tr>
<tr>
<td>5) breathing temperature</td>
<td>6.0</td>
<td>6.7</td>
<td>4.0</td>
<td>8.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Participants also commented on the use of the SCSRs while donned and during navigation through the test routes (see Table 10). In terms of the fit of the SCSR to the human body and comfort, participants showed a preference for model 4. Some
participants, particularly for model 1, noted that the breathing tube appeared to be too short. On the unit with a head strap (model 2) the participants noted that they experienced jaw, tooth, neck and shoulder strain, while some reported neck strain while donning the models with neck straps, as a result of the weight of the containers. In general, the participants showed a preference for units with neck straps rather than head straps, as the weight of the unit would then rest on the chest, rather than being borne by the neck and jaw.

Some participants also noted that the SCSRs obscured their vision, and were distracting, including the unit with the head strap, as a result of its positioning on the face. Additionally, model 3 provided goggles to protect the user’s eyes from toxic gases. However, the participants often felt that these goggles were uncomfortable and that they could not see clearly through them, and some of them misted up while the participants were wearing them. Some also noted that the SCSRs were a bit loose on the body. This could be the result of how well the SCSR fitted and how the straps were adjusted. One participant also noted that heat from the unit could burn the chin, when wearing the unit secured with a head strap.

In terms of comfort of the nose clip, a number of participants noted that it was uncomfortable or painful, and the lowest ratings were given for models 1 and 3. One of the participants also noted that the nose clip slipped off. With regard to the mouthpiece, some participants said that the mouthpiece was not comfortable, or felt too big, and some noted that they experienced jaw pain from having to bite it to keep it in place. The lowest ratings for the mouthpiece were given for models 2 and 3. However, it should be noted that all four units, in fact, had the same nose clip and that models 1 and 3 incorporated the same mouth piece.

Some of the participants noted increases in breathing resistance and breathing air temperature when using the SCSRs. This was especially evident for model 3. A few noted burning sensations in the throat during use. Some also commented that some units caused saliva to be produced in the mouth or that the mouth became dry,
particularly for model 4, but also for model 1. Irritation of the throat sometimes caused coughing while the unit was in use. Some of the participants noted that the units with an automatic self-starter (model 2) did not self-inflate at an adequate flow rate when donned, resulting in excessive breathing resistance levels. In general, it was likely that the breathing air temperature and breathing resistance would have increased further if the test duration had been longer (i.e. until the SCSRs had expired). A few of the participants experienced headaches when the units were donned.

BMI and practical performance

The weight-to-height ratio, BMI, may be used to provide an indication of health and fitness for duty of the participants. Comparisons between BMI and practical performance outcomes were made. Eight of the participants had BMIs of lower than 30, and three were classified as obese according to their BMIs (BMI ≥30). As a result of the small number of participants in each group, the results for this analysis should be interpreted with caution.

Figures 36 and 37 illustrate comparisons of central and peripheral RPE, respectively, between participants with BMIs under 30 and those with 30 and above. On average,

![Figure 36: Central RPE according to BMI](image)
those with higher BMIs had slightly higher levels of perceived exertion during the control sessions and when the SCSRs were donned and in use, than those with lower BMIs. When the participants wore the SCSRs on their belts, those with higher BMIs reported slightly higher average central RPEs and slightly lower peripheral RPEs, than the participants with lower BMIs.

**Figure 37: Peripheral RPE according to BMI**

**Figure 38: Assessment of ergonomic design of four SCSR models according to BMI**
A comparison of average results from the ergonomic assessment questionnaire according to BMI category is shown in Figure 38. In general, those that were classified as obese tended to report slightly lower levels of acceptability of SCSRs for normal wearing, donning and negotiating escape routes than the lower-BMI group.

**Overview of findings**

The practical performance assessment revealed a number of challenges relating to the use of SCSRs, as well as user preferences regarding specific features of various SCSR models. While the scope of this study was limited to female mineworkers in South Africa, it is anticipated that the majority of the factors identified would also apply to broader populations, including male mineworkers. It is therefore anticipated that proposed interventions to improve the ergonomics of SCSRs for women in mining would benefit the mining workforce as a whole. However, differences between males and females, including anthropometric characteristics, should also be taken into consideration.

Results of this study highlighted a number of factors that could be addressed to improve the ergonomics of SCSRs, presumably for both male and female mineworkers. These findings include a preference for smaller, lighter, contoured SCSRs when these are worn on the belt. As donning time for all units was relatively high, the need exists for interventions to reduce this time, in order to optimise the utility of these units in life-threatening situations. Challenges relating to donning of the units included difficulties for left-handed users to raise opening levers designed to be lifted with the right hand, and locating and positioning the parts of the inner units correctly. When the SCSRs were donned, the head-worn unit was seen to result in increased strain, and the lighter units were preferred. Some of the goggles provided were seen to mist up, and this result is also likely to occur in a male sample. Body discomfort experienced during testing – such as neck/shoulder, jaw, throat, chest,
nose and leg pain – is also likely to reflect discomfort that would be experienced in a male sample.

Differences between males and females include body composition and strength and anthropometric characteristics. Because females, on average, have lower levels of physical strength and lower work capacities than males, these disadvantages could result in greater difficulty in opening the SCSR levers, and higher levels of physical demands on the female’s body as a result of the weight of the SCSRs. Females tend to be shorter than males, which could result in higher levels of disturbance from the units than the levels males experience. For example, when the units are worn on the belt, shorter heights may increase the likelihood of participants’ elbows touching the unit. Additionally, a higher prevalence of obesity exists among females than males in South Africa. Findings from this study suggested slightly higher levels of exertion and lower levels of acceptability of SCSRs among those that are obese.

9.4. Conclusions of practical performance assessment

Practical ergonomic assessments of SCSR devices were made for a sample of women in the South African mining industry. These assessments were made while the devices were worn on the belt and while donned and in use. The participants experienced the least strain while navigating the test route without wearing an SCSR, and the strain increased while wearing an SCSR on the belt, and increased further when the unit was donned and in use.

The participants mostly reported body discomfort in their lower backs and hips from navigating the test route while wearing the SCSRs on the belt. When wearing the unit on the belt, the participants reported a preference for models 1 and 2. This is likely because these units were less bulky and felt lighter than models 3 and 4, and were contoured to fit the wearer’s body.

The participants showed a preference for model 4 for donning and negotiating the test route while donned and in use. The participants took the longest time to don model 3.
When navigating the test route while the units were donned, the participants experienced strain in body areas including the neck and shoulders, jaw, throat and chest. The participants experienced a high level of body discomfort while navigating the test route when the unit with head straps (model 2) was donned, as the weight of the unit was carried by the head, rather than the body of the wearer. However, the highest chest discomfort was reported for model 3, and the goggles supplied with model 3 tended to obscure the vision of the wearers.

The findings of this assessment helped to identify features of different SCSR devices in use in the mining industry which are most ergonomic for use by female mineworkers in South Africa. This could assist OEMs to improve the design of SCSR models in the future to ensure optimal compatibility with the wearer, which would contribute to improved acceptability and comfort for the wearer, and enhanced health, safety and productivity in the South African mining industry.

9.5. **Next milestone**

The following milestone involved an assessment and comparison of findings from the previous and current milestones. Following this, discussions with subject matter experts, the TTC for SCSR devices, and OEMs were held to discuss findings of the study and the feasibility of SCSR redesign and implementation. These discussions informed and confirmed recommendations from the results of this research.
10. RECOMMENDATIONS

10.1. Introduction

The aim of this milestone was to compile recommendations to improve the ergonomic design of SCSRs for use by women in the South African mining industry. Comparisons were made between literature reviewed on the topic, SCSR specifications, and results from the anthropometric and practical performance assessments conducted for this study. From the findings shortcomings and areas of improvement for SCSRs were identified. Results of the study and provisional recommendations were discussed further with stakeholders and subject matter experts, including the TTC for SCSRs and OEMs. The resulting draft recommendations were further revised following a workshop hosted by the MHSC. During this workshop the study results and draft recommendations were presented and discussed with the stakeholders present. A feedback session following the workshop was also held with tripartite stakeholders and women in mining. The recommendations for potential interventions to improve the ergonomic design of body-worn SCSRs are given in this report. General recommendations are first provided, followed by more specific guidance that may be implemented in the South African mining industry.

The recommendations include suggestions for improvements that are likely to benefit wearers of SCSRs including, but not limited to, women in the South African mining industry. Subject matter experts were of the opinion that it would not be feasible or necessary to design different SCSR devices for males and females. Results of this study can be used to help the relevant stakeholders to ensure that SCSRs are designed to cater for the entire range of wearers. It should also be noted that while findings from specific SCSR models were compared in this study, the aim was not to identify a particular unit that would be most suitable for women in the South African mining industry. It was rather to gain an understanding of aspects of each model that were most favourable to the study sample, to inform any future SCSR design.
10.2. **Observations and recommendations**

10.2.1. **Mass, shape and size**

**Overview of study findings**

In the user comfort questionnaires completed during this study relating to wearing SCSRs on the belt, the participants indicated that they considered SCSRs to be too heavy, that they disturbed their work, and that they caused discomfort. The participant group represented wearers of the three most commonly used models of SCSRs in the country (models 1 to 3) and from the mines with the highest numbers of labour in the industry (gold, platinum and coal), and similar results were found across all groups. The majority of suggestions that the participants made for improving SCSRs to make them easier and more comfortable to carry was to reduce the size and weight of these devices. Some suggested making the SCSRs fit better against the body, making them flatter, shorter, changing the material of the protective casing or changing the wearing position.

Findings from the practical performance assessment similarly showed that the average ratings for the shape and mass of SCSRs for normal wearing were below “acceptable”. Many participants also considered the units to be too bulky. The participants showed a preference for models 1 and 2 when wearing the units on the belt, and reported higher acceptability scores in terms of shape, size and mass for these models than for models 3 and 4. These findings can be compared with the specifications of these models. As can be seen in Table 11, models 1 and 2 are slightly lighter and smaller than models 3 and 4. It can be observed that models 1 and 2 are contoured to fit the user’s body, while models 3 and 4 are not (see Table 12). In terms of weight of the units when donned and in use, the participants experienced more strain when using model 3 than the other models as a result of the heavier weight of this model. However, the longer functional duration of this model and the benefits in terms of the safety margin that this provides should not be overlooked.
Table 11: Comparison of the functional duration, weight and physical dimensions of the SCSR devices

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated duration</td>
<td>30 minutes</td>
<td>25 minutes</td>
<td>40 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>(breathing rate 35 L/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate weight</td>
<td>2.2 kg</td>
<td>2.1 kg</td>
<td>2.25 kg</td>
<td>2.5 kg</td>
</tr>
<tr>
<td>(unopened)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate weight</td>
<td>1.2 kg</td>
<td>1.2 kg</td>
<td>&gt;1.5 kg</td>
<td>1.5 kg</td>
</tr>
<tr>
<td>(during usage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>195 mm</td>
<td>189 mm</td>
<td>203 mm</td>
<td>220 mm</td>
</tr>
<tr>
<td>Width</td>
<td>172 mm</td>
<td>205 mm</td>
<td>202 mm</td>
<td>160 mm</td>
</tr>
<tr>
<td>Depth</td>
<td>101 mm</td>
<td>89 mm</td>
<td>116 mm</td>
<td>110 mm</td>
</tr>
</tbody>
</table>

Table 12: Pictures of the protective casing of the four SCSR models

![Model 1](image1.png) ![Model 2](image2.png)  
![Model 3](image3.png) ![Model 4](image4.png)
The shape of SCSRs should be more compatible with the body dimensions of this population. For example, shorter users may be more likely to experience disturbance from the SCSR by making contact with it with the elbow. The anthropometric survey revealed that the participants were generally shorter than members of reference populations. This is expected as this sample was only comprised of women, and women are generally shorter than men. This sample also had higher BMIs and waist and hip circumferences than reference populations. This study found that those with higher BMIs reported slightly higher levels of discomfort when wearing an SCSR than those with lower BMIs.

Findings from the current study support the findings from previous research, which found that wearing SCSRs increases the muscular and physiological strain of the wearers. The literature has explained that females generally have lower physical work capacities and physical strength than males. As a result, it is likely that females would experience higher levels of strain during the use of SCSRs than their male counterparts as a result of their physiological profile. This may be exacerbated by higher average BMIs and, associated with this, possible lower levels of physical fitness and increased likelihood of chronic disease or poor physical health.

**Mass, shape and size recommendations**

Ergonomics principles state that the design of tasks, products, environments and systems should ensure compatibility with the needs, abilities and limitations of people. In this way, the productivity, comfort and well-being of the workers can be optimised. Good ergonomics is also seen to increase the effectiveness and user acceptance of PPE.

As a result of these considerations, it is recommended that SCSRs be made lighter, smaller and shaped to the user’s body as far as practically possible without compromising on the required safe functional duration of the devices. If the units are
contoured to the user's body, this is likely to improve the mass distribution of the unit over a larger surface area of the body and hence cause less discomfort or pain for the wearer. In terms of shape, as the sample was found to be shorter, but with larger waist and hip circumferences than reference populations, shorter but wider SCSRs are likely to be more compatible with this worker group. The depth of the units should be kept minimal to limit potential obstruction. It is anticipated that lighter, more ergonomic units will benefit all potential wearers, regardless of gender. It is expected that smaller and lighter units would improve worker comfort, lead to enhanced work performance, help to alleviate restriction or prevention of movements, and assist in preventing workers from removing these life-saving devices from their bodies while working.

Practical considerations of how this could be done need to be established. It is also notable that a number of OEMs are already in the process of developing smaller, lighter and more ergonomically designed units. New technologies are in the process of being developed, which would enable the contents of the SCSRs to be smaller and lighter, while still allowing the units to maintain the same (or better) functional duration. However, it could still take some time before these changes are implemented.

During discussions with stakeholders, changes to the casing material of SCSRs, particularly those with metal casings, were recommended in order to help to reduce the weight of the units. The casing material of SCSRs adds to the weight of the unit and may increase discomfort, such as when corners of hard metal casings, or even the belt loops, are in contact with the wearer’s body. It was noted that SCSR contact with the body when in the cage to go underground or to the surface was also a challenge, as a result of the confined space. Additionally, it was recommended that the casing design be modified to better fit the wearer’s body. Padded covers over the protective casings of SCSRs, such as in model 2, might also help to improve SCSR wearability. These covers could help to distribute the mass of the SCSR over the body. However, the cover must be sufficiently durable to withstand harsh...
environments and work tasks, and ensure that the inner contents of the unit remain in good working order. Abrasions on SCSRs have been evident. These are affected by the mine type and environment, the tasks performed and the wearing arrangement of the SCSRs.

Another suggestion made by stakeholders and OEM representatives was to make changes to the escape strategies of mines. Due to technical limitations, this was considered to be a more realistic option than making SCSRs smaller while retaining their same functional duration. If there were more refuge bays spaced closer together, the functional duration of SCSRs need not be as long, which would enable the contents of the SCSRs to be reduced so that they can be made smaller and lighter. However, following discussions with stakeholders, this option to alter the escape strategies of mines was not considered to be practically viable in the current context of the South African mining industry.

Alternate systems have already been patented in South Africa and have been internationally accepted. These include SCSRs that are smaller than those currently in use in the country, and the provision of caches made for sub-units along escape routes in mines. This particular system includes a y-piece and multiple connections, which allows the original primary units to be exchanged for the sub-units without disrupting the oxygen supply and enabling the user to keep the original mouthpiece and nose clip in place at all times. One of the stakeholders noted that logistically this system may be difficult to implement in hard rock mines, such as gold and platinum, since continuous developments are taking place and new routes are being established.

10.2.2. Wearing arrangement

Overview of study findings
Wearing an SCSR on the belt was observed to increase levels of exertion compared to when no SCSR was worn. The participants experienced strain primarily in their lower backs and hips while wearing an SCSR on the belt and navigating the test route. General preferences for normal wearing were shown for models 1 and 2 which, in addition to size, shape and mass, included preferences for the wearing arrangement and the ease of affixing these SCSRs daily to the body.

**Belts worn**

The belts worn were seen to have an important influence on the acceptability of SCSRs during normal use. It is important for belts to be suited to the specific units. Most of the SCSR units were observed to slide to the front of the participants’ bodies while they were crawling. SCSR-specific belts could help to prevent this. Other modifications to belts such as width, padding and adjustability may also be considered in order to improve the comfort of wearing SCSRs. Some belts also have shoulder harnesses, which can help to take some of the weight of the equipment carried on the belt off the hips and can prevent the units from sliding to the front of the body. It should be ensured that training on SCSR donning should incorporate procedures for the different belts in use. The belts should also be suited to the anthropometrics of women in the South African mining industry. As indicated in the Milestone 4 report (Chapter 8), this sample was found to have larger waist and hip circumferences than reference populations. The fit between the SCSR and the belt, including the ease with which the unit can be attached to the belt and the belt to the body also needs to be considered. Further considerations include other equipment carried on the belt, including the cap lamp battery and gas-monitoring devices. These affect the balance of weight on the belt and the wearer’s awareness of the weight of the SCSR. Furthermore, it should be ensured that the belt does not hinder the manoeuvring of the SCSR to the donning position.

One concern of the OEMs was the belts supplied by mines. The belts that mines procured were commonly not those supplied or recommended by the OEMs. This
could be a problem, as there must be a good fit between the SCSR and the belt (and of course the fit between the belt and the wearer). This plays a role in the comfort and wearability of SCSR devices. It was noted that the direct costs of the belts, which are considered to be low compared to the cost of SCSR devices, should not form the basis for the choice of belt procured. Cheaper belts may be of poorer quality and made of materials that are more likely to wear out, which would impair the fit and have to be replaced more frequently. Furthermore, the use of appropriate PPE may reduce the indirect costs of worker injury and/or increase productivity. It was noted that there are commercially available belts that would be more suitable than those commonly in use. Additionally, padding is available that can be fitted to the belts, which would help to ensure better comfort and fit of SCSRs to a range of wearers. These pads are adjustable to fit the different body shapes or physical dimensions of the workforce. Kidney belts may also be considered, as wearers may find these belts the most comfortable belts to wear for any make of SCSR, as the unit does not make direct contact with the wearer’s body when using this type of belt.

**Changes to wearing arrangement**

Changes to the wearing arrangement of SCSRs should also be considered. Although it is important for SCSRs to be body-worn to ensure that they are ready for use in an emergency, alternatives to belt-worn SCSRs may be appropriate. For example, the devices could be worn in a pouch on the front or back of the body. There are some SCSR devices in use that have shoulder straps or chest harnesses so that the wearer does not need to wear the SCSR on the belt. These alternatives may help to reduce asymmetrical strain on the hips, lower back and stomach, and may assist with better interaction with work tasks and the work equipment, such as when sitting to operate equipment, or when crawling through narrow passageways. It is noted that equipment, such as the seats for loco drivers or equipment operators, may not be designed with SCSR use in mind. Reports have been made of wearers removing SCSRs from the belt due to inadequate space in equipment, which can have safety implications and also expose the SCSRs to damage. The anthropometry of women in
the South African mining industry, such as hip dimensions, should also be considered with regard to the fit with equipment. During development and implementation of devices with alternate designs, ease of donning and appropriate donning procedures would have to be ensured. The design of the units would also need to suit a range of anthropometric characteristics. For example, chest-worn models would have to accommodate the larger chest circumferences of women than men, which may affect movement, visibility and comfort.

**Wearing arrangement recommendations**

There has to be compatibility between the SCSRs and their belts with equipment used, tasks performed and other PPE worn. It is also important to consider that changes to any particular part may affect the various systems that the worker interacts with. Implementation of the considerations discussed in this section, along with size, shape and mass, may help to prevent discomfort to the lower back, hips and stomach, prevent hindrance of the activities that have to be carried out, and assist in making the work less burdensome.

**10.2.3. SCSR donning**

**Overview of study findings**

The length of time that the participants took to don the units during the practical performance assessment was a cause for some concern, as this could have serious consequences in life-threatening situations. The average donning time was 2 min 32 s. The participants took the longest time to complete donning model 3. The design of SCSR devices and the training provided should be reconsidered with regard to the donning and use of SCSRs.
Opening lever design

Some of the participants experienced some difficulty in lifting the opening levers to open the protective casings of the SCSRs. Left-handed users appeared to experience more difficulty in opening SCSRs fitted with levers that were lifted from the left to the right. This is likely to be experienced by both male and female users. However, the lower average strength of women than men should also be taken into consideration. It should be possible to open SCSRs without difficulty, while still ensuring that the units cannot be opened accidentally. These factors should be considered in the design of the opening levers. Some of the female participants also had longer nails than men would generally have, which could also have made opening the units more difficult as a result of the suboptimal fit of the fingers under the opening levers.

While not the focus of the study, but relevant to the opening of SCSRs, it was noted by one of the stakeholders that mines need to find a suitable balance in dealing with the inappropriate discharge of SCSRs in the workplace. Some workers may open SCSRs out of curiosity or by mistake, and be charged for the violation due to the cost of this occurring. On the other hand, if workers are charged for opening SCSRs inappropriately, it may prevent them from using the SCSR correctly in a life-threatening situation, as they may be uncertain about whether the conditions warrant SCSR use.

Other donning difficulties

Other reasons for the extended donning times of units were, for instance, difficulty removing the protective casing lids (e.g. model 2), untangling and correctly positioning the straps (e.g. model 4), locating the relevant parts (including goggles) and disconnecting the unit from the belt (as in the case of model 3), and making the necessary adjustments. The units which had the body straps attached with a clip for adjustment appeared to be more user friendly than those that had to be tied, as they were easier to adjust. These factors should be considered in the design or redesign of
SCSRs. This would assist to improve readiness in emergency situations, in which there may be further challenges such as reduced visibility, injury and emotional reactions caused by panic. Improved design as well as donning procedure training is also likely to remediate these challenges.

Further general observations and concerns were recorded, which were probably unrelated to the gender of the participants, but which are nevertheless important for those involved with the design, manufacture and supply of SCSRs to be aware of. Some of the units fitted with self-starters did not appear to self-inflate (i.e. model 2); this caused difficulty breathing normally from the SCSR. It is therefore suggested that donning procedures for this model should include blowing at least three times into the mouthpiece, as is standard for the majority of current SCSR models, to ensure that the breathing bags inflate sufficiently. Furthermore, in one of the units, the plastic cord connecting the mouthpiece plug snapped when one of the participants tried to remove the plug. This made it difficult to remove the plug, and could have led to serious consequences in an emergency situation.

Training for donning and use of SCSRs

In-depth and detailed training for the donning and use of SCSRs is critically important. At present, training and demonstrations of donning procedures for SCSRs are provided by OEM-trained mine personnel at mines in South Africa. However, this training usually only involves observation of the procedures rather than the physical donning of SCSRs by the trainee. This training is generally provided only once a year during annual inductions and via posters displayed in lamp rooms or workspaces. It is recommended that wearers of SCSRs be provided with experiential and expectation training in the donning and use of SCSRs. Experiential and expectation training would help the users to better understand and gain practical experience on how to don the SCSR units and to experience the sensation of breathing into them. None of the participants in the practical assessment had previous practical experience of donning and using SCSRs, despite having worn the units on the belt during normal working
activities. Experiential training would help the wearers to be able to don the SCSRs faster and with greater ease during an emergency situation. It would also help to allay adverse emotional reactions such as panic, and help the users to complete the donning procedures even when they are not thinking clearly, or in adverse physical environments. Knowing how the unit would feel during use would also prevent wearers from thinking the devices are not functioning correctly, which could result in their ceasing to use the devices during an emergency.

The OEM representatives noted that training units are available. Ideally, these units should contain live chemicals to give the trainees practical experience of donning the units and experiencing how breathing from an SCSR feels. Exchange cartridges could be used so that the training would not require once-off use of complete SCSR units. However, the cost implications were seen to be a factor that would prevent this from being generally implemented in the South African mining industry. An alternative would be to use units that do not contain chemicals, so that wearers could at least gain experience of donning the units. In this case only the mouthpieces would have to be disposed of and replaced after each use for reasons of hygiene.

The frequency of training provided should also be reconsidered. More frequent training, i.e. at least every six months, will assist the users to remember the donning procedures better. Therefore shorter training intervals and the nature of the training are vital as this will help to ingrain the donning procedures in the users mind and their muscle memory.

10.2.4. Use of SCSRs while donned

Overview of study findings

The participants experienced greater levels of exertion when navigating the test route while the SCSRs were donned and in use than when worn on the belt. Discomfort
was experienced in the areas including the neck, shoulders, jaw, throat and chest. A preference for model 4 was shown when the unit was donned and in use.

**Head versus body worn units**

The participants experienced strain in the neck, jaws and teeth when using the model that was worn on the head when donned, and therefore showed a preference for units that rested on the body. Some of the participants also reported that this model obstructed their vision to some degree. It is understood that a chest-worn unit has already been designed by the manufacturer of the head-worn unit.

**Accommodation for different body dimensions**

In terms of accommodating different body lengths and sizes during the practical assessment, the participants rated models 2 and 3 the lowest. From the anthropometric survey it was established that the participants had on average larger head circumferences than reference populations. This was most likely the result of the hairstyles of the participants. During the practical assessment it was evident that this affected the fit of the unit with the head straps (model 2). However, as the straps were adjustable, the participants were still able to don these units. The casing of model 3 is designed to remain attached to the inner unit while donned and in use. This may have resulted in increased strain on the participants as a result of the increased weight. Comfort may have been reduced because of the bulky equipment resting on or below the participants’ chests. The location of the inner unit when the unit is donned should be reviewed, especially when considering the larger chest circumference of the sample population (or for women in general) than the reference population. The positioning of the unit in terms of downward visibility for women in mining should also be considered; however, the participants in the current study did not report this to be a concern.
The breathing tubes of some of the units appeared to be too short (e.g. model 1, 3 and 4). If these tubes were longer, it would help to increase the bend, or “gooseneck effect”, in the breathing tube. This would allow better movement of the head when looking up or from side to side, such as when crawling. However, the apparent shortness of the tubes may also have been due to incorrect adjustment of the neck and body straps. The neck straps of some of the units appeared too long as they reached their adjustment limit. If they could have been made shorter, the inner units may have been allowed to rest higher on the body, thus also increasing the “gooseneck effect” in the breathing tube.

Most of the participants were observed to steady the SCSRs with their hands while navigating the test route, especially while stooping. In some cases, this was done to decrease the strain on their necks as a result of the weight of the inner units (e.g. for models 2 and 3). This was also observed to be done to prevent the inner units from falling forwards. It therefore appeared that the units did not feel stable enough. The units could have been too heavy and the adjustment of the SCSR straps may not have been adequate.

**Comfort**

In terms of comfort of use, the participants reported some discomfort with the nose clip, particularly for models 1 and 3. As all four units use the same nose clip, the ratings may have been the result of how the units were donned, and therefore experiential and expectation training, as noted above, could assist with this situation. The lowest comfort ratings for the mouthpieces and also for contact of the unit with the body were reported for models 2 and 3. This could be a result of the perceived weight of these units and jaw strain experienced when wearing the head-worn unit. Additionally, in the head-worn unit the heat from the inner unit made direct contact with the skin. The poorest ratings for breathing resistance and temperature were reported for model 3. Comfort ratings were highest for model 4.
Visibility

Visibility while the units were used should also be considered. This applies especially to units that include goggles, or units for which it is planned to provide goggles in the future, as is the case with some OEMs. Some of the participants’ goggles misted up, which made it difficult to see through them clearly. Goggles should therefore have adequate anti-fogging properties. As females have smaller faces than males, this should also be considered so as not to reduce the range of vision. Considerations of workers that wear spectacles may also be considered in goggle design. It should also be noted that in emergency situations one of the main purposes of goggles is to prevent exposure of the eyes to toxic gases, rather than to improve visibility, as there may be environmental factors such as smoke that would in any case prevent escapees from being able to see. It was noted that goggles are important to prevent sore eyes or damage to the eyes.

Recommendations for use of SCSRs while donned

As a result of these considerations, units that are worn on the body rather than the head are recommended. The fit of units and appropriateness of the strap adjustments to accommodate different body shapes and sizes need to be considered. Neck straps should allow more adjustability. Furthermore, it is important that goggles developed and provided do not obscure the vision of the wearers. It is hoped that the anthropometric data obtained in this study will assist in ensuring that the range of body dimensions of wearers is taken into account in the design of SCSRs.

10.2.5. SCSR developments

It is evident that SCSR devices, which are vital owing to their life-saving function, are generally not considered to be comfortable for wearing daily on the belt or while donned and in use. There is scope for improvement of the design of the unit to improve comfort and functionality. It is understood that it is probably not feasible, nor
necessary, to design separate units for males and females. Interventions can rather focus on adjustments that would benefit and be suited to both genders and all potential user groups. SCSRs should be designed to accommodate a range of wearers. As far as anthropometric characteristics are concerned, it is unlikely that any single person would be average in every dimension measured; every population group will contain individuals with a range of dimensions.

As noted, a number of OEMs are already in the process of developing new SCSRs or modifying and redesigning existing SCSRs. It is likely that these modifications will incorporate factors to improve the ergonomics of these devices. Ways of making the units smaller, lighter and more user friendly are being considered. These modifications should be assessed in terms of all possible user populations, including women in the South African mining industry. The importance of usability testing on the relevant population groups is also highlighted. Any changes in the units may result in changes to other aspects. This should not be overlooked, as the benefits gained in one area may influence other aspects negatively.

It is noted that OEMs will design SCSRs based on the required specifications. These rely on legislation and the market for the units as directives or standards guide the specifications of SCSRs. For example, if there were more refuge bays, SCSR caches, mobile refuge chambers, or chambers for SCSR exchange in mines, the distances to these points would be shorter, and the duration of the SCSRs could then be reduced. If units of 15 minute duration are required, then the SCSRs could easily be made smaller and lighter. It is also noted that different types of SCSRs with a range of durations are already in existence globally, some of which may be suitable for implementation in South Africa if the escape strategies of mines were redesigned. The cost implications of this should be assessed compared to the costs of not implementing new strategies, including indirect costs of poorer health, lower productivity and less safety. The necessary certification and approval of units must also be considered as regards new technologies.
In addition to making the SCSR units smaller and lighter, further improvements to the design, as discussed in this chapter, would also help to improve the ergonomic compatibility of the devices with the workforce. These improvements include modifications to the shape, casing material, adjustment limits and accommodation for a range of body dimensions. Changes to belts worn and wearing arrangements may also lead to improved comfort, health and safety, while improved training would assist to remediate some of the potential challenges with SCSR donning and use.

10.2.6. Study limitations and recommendations for further research

This study aimed to assess the ergonomic design of SCSRs in relation to the anthropometry of female mineworkers in South Africa. Many factors regarding the wearing of units on the belt and the donning and use of SCSRs are evident. Some factors were identified and assessed in the current study. However, some factors were beyond the scope of the study, but should nevertheless not be disregarded. Opportunities for further research in this field exist. Some of the limitations of the study and opportunities for further research are considered in this section.

Comparative study for males

No comparative study has been conducted for males in the South African mining industry. The available anthropometric database for males in the South African mining industry is outdated, and does not include the full range of measurements taken in this study. Additionally, no comparison could be made between practical assessment outcomes between the females in this study and their male counterparts. Studies conducted in other workforces or countries may not be applicable. Only inferences could be made regarding the application of the findings to other groups beyond the group studied. It is therefore recommended that further research should include a comparative ergonomic study of male mineworkers in South Africa.
Assessment of interventions

Further research would also include the practical assessment of developments by OEMs to improve the design of new-generation SCSRs. An assessment of responses by mineworkers to wearing SCSRs on different belt types would also be informative.

Sample size

A further limitation of the study was the sample size. The study sampling limitations, however, are not considered to detract from the validity of the findings and the conclusions applicable to this study. The sample size was based on the scope of the study, and for the anthropometric assessment the sample was large enough for statistically significant results to be evident. However, a larger sample size will always increase the accuracy and reliability of the findings and allow further inferences to be made and statistical analyses to be conducted. For example, comparisons of discomfort and strain between those with different anthropometric measurements were limited, because if the group had been divided into smaller subgroups it would have weakened the analyses. As the study indicated that current anthropometric norms and previous study data available differed from the anthropometrics of the study sample, further study may be conducted to develop norms for that are inclusive of a representative sample.

Length and order of testing

In the practical performance assessment conducted during this study, the length of the test route was limited to prevent over-exertion of the participants. As numerous tests were conducted, physical fatigue could have impacted negatively on the consecutive tests performed, and therefore on participant wellbeing and drop-out rate. This was also because the focus of the study was on anthropometry rather than physiology. All the participants were able to safely complete the test routes. However, if the test routes had been longer, exacerbated or additional strain may have been
identified. For example, the heat and breathing resistance levels during the use of the SCSRs may have increased. This factor therefore needs to be kept in mind when designing or redesigning SCSRs and for possible further testing or study. It would be worthwhile to assess physiological responses of males and females in the South African mining industry in terms of SCSR use and duration.

The order of testing should also be considered. Although the SCSRs were tested in different orders in the two participant groups for this reason, the ordering could still affect the strain reported by the participants caused by the different models. One of the reasons for this could be due to cumulative fatigue. The difference between the results of the different models used in this study should therefore be interpreted with caution. The aim of this study was to assess concerns regarding the use of belt-worn SCSRs in general rather than for specific units. However, the findings from the study of each of the models led to better understanding of the preferences regarding each model, which could be used to inform further SCSR design and modification.

Commodity mined

Participants for the practical assessment were recruited from a coal mine and a metalliferous mine to ensure representation of these different mine types and the associated occupations. A factor to be considered in this regard is that some of the participants came from mines in which the activities performed during the practical assessment may not have mirrored those conducted at work, such as crawling for those from the coal mine. This may have somewhat affected the responses that were obtained from some of the participants. However, it is understood that the findings are still relevant and comparative to those obtained from the participants from the metalliferous mine. Further studies could be conducted that are specific to conditions and tasks with low versus high ceiling heights. Environmental factors should also not be overlooked as, for example, high temperatures within gold mines would affect the physiological strain experienced by the participants.
Fitness for duty

Fitness for duty is another factor that should be considered. It is important for all mineworkers to be able to conduct their work safely and be able to escape from the mine should an emergency arise that necessitates the use of an SCSR. While SCSR design has an important role to play in this, it is also important for the workplace to be correctly designed to ensure that mineworkers of all fitness levels should be able to safely reach refuge bays. Fitness for duty tests conducted at mines should be designed with escape strategies, along with work requirements, in mind. Fitness for duty might also be associated with BMI. For example, candidates with BMIs of over 35 are considered unsuitable for physical work in hot environments (Schutte, 2010). It is important for the mining industry to ensure that fitness for duty norms are applied consistently. Fitness levels, body weight and exercise intensity of mineworkers have also been seen to affect the duration of SCSRs when donned and in use.

Escape strategies

In turn, the escape strategies of mines should be reassessed to ensure that they are appropriate in emergency situations. The changes that have occurred in the mining industry and in mineworker populations since the regulations were put in place should not be overlooked, as these could affect the applicability of the findings from previous research in this field. These changes include the incorporation of women into the mining industry. Differences in strength, work and aerobic capacities between males and females will play a role. It would also be worthwhile to assess revised escape strategies as these plans may realistically allow the use of smaller and lighter SCSRs.

Cost-benefit analysis

As a number of the recommendations recorded in this study have cost implications, it would be worthwhile for a thorough cost-benefit analysis of all possible remedial actions to be undertaken. Both direct and indirect costs, the financial risks of not
implementing the potential actions and the financial benefits of implementation should be predicted. Examples of interventions include modifications to escape strategies, providing optimal belts, changes in training strategies, changes in the wearing arrangements of SCSRs, and SCSR redesign. The benefits of interventions include reduced injuries such as work-related musculoskeletal disorders leading to reduced healthcare costs, increased productivity and decreased likelihood of loss of life. The risks and benefits should be assessed when considering the different stakeholders concerned.

10.2.7. Guidelines for the implementation of the recommendations

Following discussions with the MHSC and stakeholders, practical suggestions for the implementation of findings from this project were discussed. “Quick win” solutions were suggested in order to address some of the challenges faced in the shortest space of time and at relatively low costs. These suggestions were in the areas of belts worn and experiential training. These are detailed further in this section, along with a brief discussion of other potential intervention strategies.

While the most obvious solution to address ergonomic challenges with SCSRs faced by women in the South African mining industry would be to reduce the weight of the devices, practical considerations prevent the possibility of regulating an optimal weight for SCSR devices used by women in mining. The weight (and associated with this, the size) of SCSRs is driven by the functional duration required in order to escape from the mine safely in an emergency situation. If this duration was reduced in order to make the SCSRs lighter, this may prevent the wearer from making a successful escape, which would result in a serious safety problem. Technological developments to make SCSRs lighter and smaller, while still maintaining required functional durations, are still in progress.

Changes to the escape strategies in mines currently, such as by reducing the distance between refuge bays, in order to reduce the required functional duration of
SCSRs were indicated by stakeholders to be unfeasible at this stage. This was because of cost implications in the already financially strained sector, as well as because of potential safety risks involved with the implementation of the changes. However, reassessment of the escape strategies of mines is recommended, in order to ensure that these are still appropriate for the current mining workforce, including women in mining. This is also related to mineworkers’ fitness for duty. Further research on previous successful and unsuccessful escapes would also be beneficial.

**Belts worn and wearing arrangement**

As per the discussion in Section 10.2.2 of this report, the belts worn have an impact on the comfort and acceptability of SCSRs. Belts worn also offer a relatively low-cost and easy to implement solution to reduce some of the ergonomic challenges faced with SCSRs. The belts worn need to have optimal compatibility with the SCSRs as well as with the wearers. Mines should procure belts that are specifically designed and recommended by the OEM of the SCSR in use at the respective mine.

Scope for adjustments to the belts and a harness system that would enable alternate wearing positions (e.g. on the hip, back or chest) should be available. This would enable a level of user preference and accommodate for individual differences such as anthropometry and occupation, amongst other factors. For example, chest harnesses may be used specifically by machine operators so that the SCSR fits on the chest, when space on the seat of the machine is limited.

Additionally, shoulder harnesses or braces can help to keep the waist belts in place and reduce the weight of the SCSR on the waist, and should be provided. Additional padding that may be fitted to belts can also be provided to improve wearer comfort. Furthermore, kidney belts, which are broader on the back and side, should be considered. Pouches for SCSRs were also recommended by stakeholders to improve comfort when wearing the SCSRs and to prevent the SCSRs from moving around the body. Developments to SCSR belts and wearing arrangements should be considered.
It must be noted that the current study did not set out to assess the use of SCSR belts, as it focussed on the ergonomic design of the SCSR devices themselves. Further study is warranted to assess the compatibility of the recommended belts with women and men in the South African mining industry, to assess the ergonomic design of harnesses, pouches and belt padding, and to assess the appropriateness of the belts and harnesses for different occupations and job tasks performed.

**Experiential-expectation training for donning and use of SCSRs**

It was evident that experiential and expectation training for the use of SCSRs is of significant importance in order to ensure fast and successful SCSR donning and use. The use of the South African “SCSR X-spectation trainer” training device, which was invented and developed by the CSIR, could be incorporated into SCSR user training. This training unit is ready and could be implemented within weeks, if supported by the Regulator. This would greatly enhance and improve the training for those required to wear SCSRs at work. These individuals would receive hands-on experience on the correct donning of an SCSR. This training should be conducted during annual inductions and refresher training and each individual needs to have the opportunity to don a training unit in this time.

**SCSR design**

Further suggestions regarding the design of SCSRs, should be taken into consideration for future developments. These include the suggestions of making the units lighter and smaller, and ensuring adequate breathing tube lengths and adjustability of neck and body straps. Furthermore, SCSRs should be shaped to the contours of the human body (rather than being flat). These adjustments should be informed by the anthropometry of the wearer groups. Considerations can be made with regard to changes to the casing material. The use of head-mounted units should be avoided, and SCSR goggles should be optimally designed. Ensuring ease of
locating parts of the SCSR during donning is important for a quick donning time, while appropriate SCSR donning training would also assist with this.

10.2.8. Technology transfer options

Workshops and meetings held by the MHSC and discussions with stakeholders are beneficial to disseminate the findings of the study and to plot the way forward based on the results of the study. Feedback on ideas of new developments needs to be provided to the relevant stakeholders, including the TTC, OEMs and labour. This information would include policies and procedures anticipated in the future, which would have an effect on the various members associated with the mining industry. This would allow the stakeholders to implement action or provide solutions to address the identified needs.

10.3. Conclusion of recommendations

In summary, a number of recommendations have been made which, if implemented appropriately, will help to improve the ergonomics of SCSRs for women in the South African mining industry. The view is that a number of the proposed interventions to improve the fit of SCSRs for women will also benefit the male workforce, if implemented.

Solutions that were identified to be most readily implementable and that would address some of the challenges faced were to:

- Ensure the provision of specific belts recommended by the respective OEMs.
- Implement, as a matter of urgency, experiential and expectation training for the donning and use of SCSRs.

Further recommendations that could inform future SCSR design included:
• Make SCSRs lighter and smaller, as far as practically possible.
• Shape SCSRs to the contours of the body.
• Consider changes to the casing material of SCSRs.
• Ensure ease of locating parts of the SCSR when donning.
• Avoid the use of head-mounted units in future developments.
• Ensure adequate length of breathing tubes.
• Ensure adequate adjustability of neck and body straps.
• Ensure optimal design of SCSR goggles.
• Consider changes to the wearing arrangement of SCSRs.

Opportunities for further research were also highlighted. These included:

• A comparative ergonomics study of males in the South African mining industry.
• The assessment of proposed interventions and developments.
• Reassessment of the escape strategies of mines while taking female mineworkers into consideration.
11. CONCLUSIONS

The aim of this study was to assess the ergonomic design of body-worn SCSR devices for use by women in the South African mining industry. A review of the literature was conducted, which confirmed the value of this study and provided direction to the methodology followed. Following the review, an anthropometric survey and a practical ergonomics assessment were conducted and recommendations for improvement were drafted.

The anthropometric assessment was conducted on a sample of 100 women in the South African mining industry. Data for 29 body dimensions relating to the design and use of SCSRs were provided in this report. A number of significant differences between the data collected and the reference data were evident. Participants experienced discomfort while wearing SCSRs on the belt at work and most considered the devices to disturb their work and be too heavy.

Findings from the practical ergonomics assessment showed that participants experienced the least strain while navigating the test route without wearing an SCSR; the strain increased while the SCSRs were worn on the belt, and increased further when the unit was donned and in use. While they were wearing the SCSRs on the belt, the participants mostly reported body discomfort in their lower backs and hips, and experienced strain in the neck, shoulders, jaw, throat and chest while the units were donned and in use. Preferences for aspects of each of the four SCSR models tested, in terms of comfort, donning and use, were recorded.

Recommendations to improve the ergonomic design of SCSRs were drafted on the basis of the study findings and were discussed with subject matter experts and stakeholders. The recommendations are provided in Chapter 10. The suggestions for improvements are expected to improve the fit of SCSRs for both female and male wearers; however, a comparative study would be required to validate this assumption.
12. REFERENCES


*NOTE: Asterisked citations (*) are secondary sources. These were not directly consulted and are referenced as fully as primary sources.
13. **APPENDICES**

13.1. **APPENDIX A: Respiratory protective devices torso**

![Respiratory protective devices torso diagram](image)

**Figure 39: Respiratory protective devices torso (taken from ISO/CD 16900:5.2)**

A. Height of prominent neck vertebra, sitting  
B. Shoulder breadth (deltoid)  
C. Shoulder (acromion) height, sitting  
D. Mid-shoulder height, sitting  
E. Chest breadth, at level of nipples  
F. Chest circumference, at level of nipples  
G. Chest depth, at level of nipples  
H. Trunk height to the top of breast bone, sitting  
I. Lower abdominal depth  
J. Waist breadth  
K. Waist circumference – natural indentation  
L. Height of maximum lumbar curvature, sitting  
M. Sacral height, sitting  
N. Hip breadth  
O. Mid-hip circumference
13.2. APPENDIX B: Respiratory protective devices headform

Figure 40: Respiratory protective devices headform (taken from ISO/CD 16900:5.2)

A. Maximum head width
B. Interpupillary distance
C. Eye-to-nose diagonal
D. Nose breadth
13.3. **APPENDIX C: RPE scale**

<table>
<thead>
<tr>
<th>RPE Scale</th>
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</thead>
<tbody>
<tr>
<td>6.</td>
</tr>
<tr>
<td>7. VERY, VERY LIGHT</td>
</tr>
<tr>
<td>8.</td>
</tr>
<tr>
<td>9. VERY LIGHT</td>
</tr>
<tr>
<td>10.</td>
</tr>
<tr>
<td>11. FAIRLY LIGHT</td>
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<tr>
<td>12.</td>
</tr>
<tr>
<td>13. SOMEWHAT HARD</td>
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<tr>
<td>14.</td>
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<tr>
<td>15. HARD</td>
</tr>
<tr>
<td>16.</td>
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<tr>
<td>17. VERY HARD</td>
</tr>
<tr>
<td>18.</td>
</tr>
<tr>
<td>19. VERY, VERY HARD</td>
</tr>
<tr>
<td>20.</td>
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</tbody>
</table>
13.4. **APPENDIX D: Body discomfort map**

![Body discomfort map and rating scale](image)
13.5. **APPENDIX E: Ergonomic assessment questionnaire**

Ergonomic assessment questionnaire

From an ergonomic point of view, rate the escape apparatus in terms of the criteria listed below on a scale from 0 – 10 where:

- 0 is totally unacceptable
- 5 is acceptable
- 10 is highly acceptable.

If deemed necessary, a motivation for the rating indicated shall be written in the remarks column. If a rating of less than 5 is given in any category or subcategory, it shall be motivated or explained in the remarks column.

<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ergonomic design for normal wearing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Shape of escape apparatus (shaped to body contours, comfort)</td>
<td></td>
<td></td>
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<tr>
<td>b) Size of escape apparatus (too bulky for routine work, or only if in confined spaces, bruising, bumping, catching)</td>
<td></td>
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<tr>
<td>c) Mass of escape apparatus (are you aware of the mass of the escape apparatus, and if so how would you rate it?)</td>
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<tr>
<td>d) Wearing arrangement – belt and suspension to belt (comfort in napping the effect of mass?)</td>
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<tr>
<td>e) Daily affixing of escape apparatus on body (cumbersome?)</td>
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<tr>
<td>f) Prevention of accidental opening of escape apparatus</td>
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<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>2. Ergonomic design for donning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Ease of manoeuvring escape apparatus into donning position</td>
<td></td>
<td></td>
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<tr>
<td>b) Ease of opening the container</td>
<td></td>
<td></td>
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<tr>
<td>c) Ease of handling essential parts:</td>
<td></td>
<td></td>
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<tr>
<td>1) breathing tube</td>
<td></td>
<td></td>
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<tr>
<td>2) insertion of mouthpiece</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) fixing of noseclip</td>
<td></td>
<td></td>
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<tr>
<td>d) Ease of affixment and adjustment of ancillary webbing/equipment:</td>
<td></td>
<td></td>
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<tr>
<td>1) head strap</td>
<td></td>
<td></td>
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<tr>
<td>2) bag strap</td>
<td></td>
<td></td>
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<tr>
<td>3) body strap</td>
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<thead>
<tr>
<th>Category</th>
<th>Rating</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>3. Ergonomic design for negotiating escape routes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Accommodation for different torso lengths and sizes in respect of breathing tube and ancillary webbing, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Comfort</td>
<td></td>
<td></td>
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<tr>
<td>1) nose-clip</td>
<td></td>
<td></td>
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<tr>
<td>2) mouthpiece</td>
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<tr>
<td>3) physical contact of set with body – too hot?</td>
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<td></td>
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<tr>
<td>4) breathing resistance</td>
<td></td>
<td></td>
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<tr>
<td>5) breathing temperature</td>
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<td></td>
</tr>
<tr>
<td>6) headache?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comments**

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