2024 International Conference on Multidisciplinary Research (MyRes)
7th-9th November 2024, Pearle Beach Resort & Spa, Mauritius
https://doi.org/10.26803/MyRes.2024.03

Empowering South African Women in Mining: Redesigned Personal Protective Clothing (PPC) Solutions

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Abstract
In recent decades, there has been a significant increase in the number of female workers in the South African mining sector. This change highlights the need for personalized personal protective clothing (PPC) that specifically meets the requirements of female employees, including accommodating diverse body sizes and ensuring the best possible fit. Current studies in South Africa indicate that existing PPCs, initially designed for male miners, should adequately cater to female miners' safety and comfort needs. Specifically, the current one-piece PPC poses practical challenges, particularly regarding ease of restroom use. This research project aims to redesign a one-piece personal protective clothing (PPC) specifically for women miners in South Africa. The study focuses on women's sizes, fit, and functional requirements to create a comfortable PPC. The design process involved female miners to ensure inclusivity. The research used a qualitative method to identify participants for interviews, fit testing and observation checklists for fit assessment. Central to the design process is prioritizing the one-piece PPC's functionality, considering factors like ease of toilet use and movement during work activities. This research ensures that the proposed one-piece PPC is functionally adequate, appropriately sized and well-fitting by actively engaging female miners throughout the development phases. The results indicated that the redesigned one-piece PPC had enhanced size and fit factors, resulting in a comfortable PPC that facilitates easy toilet use. The research demonstrates that engaging PPC users in the process results in a better-designed garment.

Keywords: protective clothing, women in mining, gender equality, current affairs.

1. Introduction

Studies conducted by Zungu in 2012 and 2013 reported that no ready-to-wear PPE apparel designed specifically for women working in mines conformed to their bodies in terms of fit and comfort. The workwear available is based on men's sizing systems, resulting in improper fit for women. Despite Zungu's findings, PPE designed for men continues to be distributed to women miners. Although the number of women entering the mining industry is increasing, only men's protective equipment is available. This situation demoralizes women at work and may lead to ineffective performance. Due to the poor fit of the men's protective clothing provided, women have resorted to coping mechanisms, such as wearing alternative clothing like jeans instead of overalls, undergarment tights, jerseys, and other casual wear, which may not meet the safety standards of the mining industry (Magampa, 2019, p. 6). This issue not only affects the safety and performance of women in the mining industry but also has potential economic implications, such as increased healthcare costs and reduced productivity, which should be a concern for policymakers and industry stakeholders. Current PPE suppliers in South Africa have been in the business for many years but have yet to pay attention to the needs of WIM. The lack of appropriately fitted PPE leaves women with no choice but to wear what is available despite the health and safety dangers of ill-fitting PPE. In South Africa, common PPC are the two-piece and the one -piece PPC. This study focuses on redesigning appropriately fitting one-piece PPC for women working in the mines. Different body types and shapes require various patterns to achieve well-fitting PPE (Zungu, 2013; Ola-Afolayan & Mastamet-Mason, 2013). Research by Wagner, Kim, and Gorden (2013) examined the relationship between PPE, self-efficacy, and job satisfaction among South African women in the building industry. Their study recommended designing, manufacturing, and supplying comfortable two-piece overalls for women, enhancing their appearance, improving their comfort, and fostering a more positive shared workspace.

1.1. Challenges and Practicalities of One-Piece Coveralls for Women in Professional and Leisure Contexts

A one-piece coverall also known as a jumpsuit or boiler suit, is a versatile garment designed to cover the entire body from the neck to the wrists and ankles in a single piece of clothing (Figure 1). It typically includes long sleeves, full-length legs, and may feature a front zipper or button closure for easy wear. These coveralls are commonly used as protective workwear in various industries such as construction, manufacturing, automotive, and maintenance to shield the wearer's clothing and skin from dirt, chemicals, and other hazards (Stephens & Levine, 2011). They are designed to provide full-body coverage and are often made from durable materials like cotton, polyester, or a blend of fabrics to ensure durability and comfort during extended wear (Raj, 2023). One-piece coveralls come in different styles, colours, and sizes to cater to the specific needs and preferences of the wearer, offering a practical and convenient solution for individuals working in environments that require protective clothing (S, 2024).

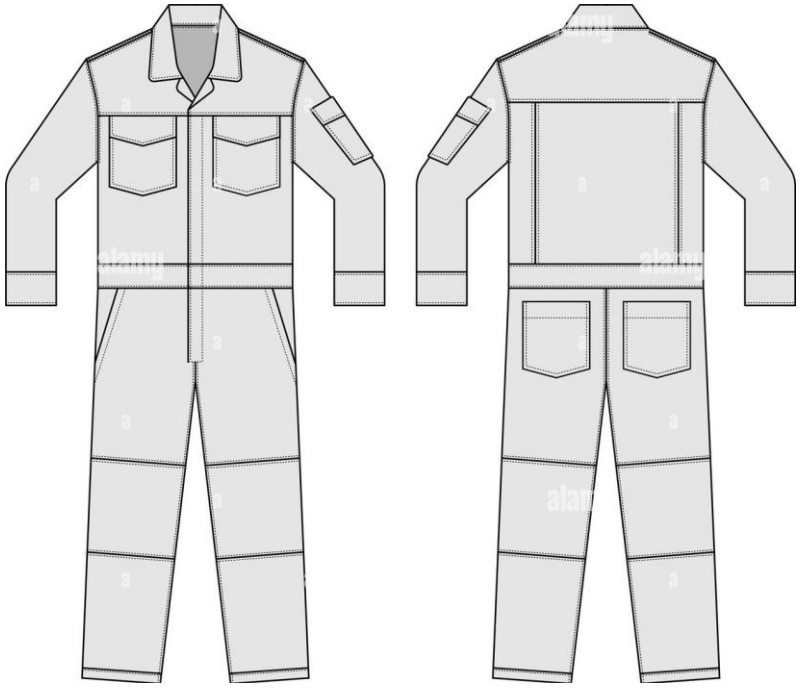

Figure 1. One-piece coverall (https://www.alamy.com/long-sleeves-working-overalls-jumpsuit-boilersuit-template-vector-illustration-white-image448343044.html).

The fashion industry has incorporated jumpsuits as leisurewear, which has garnered widespread acceptance among diverse consumer demographics, including women. However, female wearers of jumpsuits and one-piece coveralls encounter challenges that may compromise their practicality and comfort in professional settings. One significant issue is the inconvenience of using the bathroom, as the entire jumpsuit needs to be partially or entirely removed, leading to a cumbersome and time-consuming process Raj (2023). A proper fit poses another challenge, as jumpsuits must fit well in multiple areas like the torso, waist, hips, and legs, potentially causing discomfort or an unflattering appearance if not tailored correctly (Abulbasal et al., 2023). Additionally, specific designs and fabrics may restrict movement around the shoulders, hips, or knees, limiting mobility and flexibility (Tolani, 2018). Layering with other clothing items becomes challenging, especially in varying weather conditions where addition or removal of layers is necessary (Li, 2023). Moreover, jumpsuits present the risk of a wardrobe malfunction, such as a broken zipper, rendering the entire outfit unusable, unlike separates, where only one part may need repair (Chen et al., 2014). They may also offer fewer styling options, making it difficult to mix and match with other wardrobe items (Chatterjee & Shenoy, 2023). Sizing can be complex as jumpsuits must accommodate various body measurements, potentially leading to length, width, and overall fit issues (Basford et al., 2013). Despite their fashion appeal, these challenges can affect the practicality and comfort of wearing jumpsuits in professional settings. In conclusion, women who opt for jumpsuits or one-piece coveralls face various challenges impacting their daily work experiences. These challenges include functionality, fit, mobility, maintenance, styling options, and sizing, highlighting the importance of considering practicality and comfort when choosing work attire.

The challenges of a one-piece garment for women who work actively in mines can be complex. One significant challenge relates to the fit and functionality of the garment. In the case of a one-piece garment like a coverall, the design may not adequately account for the range of motion required during physical activities in mining, such as squatting or reaching overhead. One piece coverall poses inconvenience the users of using the bathroom, as the entire jumpsuit needs to be partially or entirely removed, leading to a cumbersome and time-consuming process Raj (2023). The challenges of this limitation can lead to discomfort and restricted movement for female miners, impacting their productivity and overall well-being (Benson & Rajulu, 2009). Furthermore, as mentioned above, women in the mining sector face unique challenges that can make wearing a one-piece garment even more difficult. These challenges include restricted access to mining pits, sexual harassment, inadequate infrastructure facilities, concerns about health and safety, physical difficulties, resistance from male workers, shift work, and issues related to pregnancy and working hours (Botha, 2019). These obstacles can make wearing a one-piece garment especially burdensome for female miners, as it may not adequately meet their specific needs and comfort requirements. Addressing these challenges requires a comprehensive understanding of the unique needs of female miners and a concerted effort to design garments that prioritize safety and comfort in demanding work environments.

This study aims to bridge the gap left by the current major suppliers of PPE in South Africa—by designing appropriately fitting personal protective clothing for women working in the mines. Recognizing that each body size, type and shape necessitates different patterns. This study identified size and fit issues with existing one-piece PPE and used that information to redesign or modify PPE for improved size and fit leading to comfortable coverall PPC.

2. Sampling/Participants

The target population for gaining insight into the challenges associated with the current personal protective clothing (PPC) were five plus-sized women working on the surface of Sibanye Steelwaters Mine, formerly Lonmin Platinum Mine, in the North-West Province. The researchers chose this region for convenience as the mine is near one of the researchers' residences. Additionally, the sister of one of the researchers who works there has been complaining about PPC for almost five years. After analysing the challenges, the researchers redesigned the new PPC, which was then fit-tested by a model selected from the interviewed women. The chosen woman model wore clothing size 20, which is the average size for the plus-sized women. The model's measurements were adjusted to align with South African women's sizing standards. Four professional designers and garment makers conducted the fit assessment.

Design

The research design combined three aspects – quantitative, qualitative, and using practice-based research where necessary, in a meticulous and thorough manner. An example of the research design's three-pronged focus was that one-dimensional body

measurements (quantitative) were extracted from the size charts and transposed into two-dimensional patterns (quantitative). Once the two-dimensional patterns were developed, garments were cut and sewn together applying techniques of practice-based research that had to align the body shape in form of measurements and patterns to come up with a three-dimensional garment. The three-dimensional garment underwent various stages of experimentation during its development after which, it was tested for fit and comfort using quantitative assessment scales. The nature of the research problem in the study required a blended research approach applying quantitative, experimental, and practice-based research approaches interchangeably.

Materials

Five women were interviewed to gather information about the challenges of the current PPC. The fit model filled out an open-ended questionnaire about how the redesigned PPC fit her while standing, moving, squatting, and reaching as she does while working in the mines. The four fit assessors used a closed-ended questionnaire to evaluate the fitness while standing still, moving or reaching out, and squatting.

Procedure

Five women were interviewed at their workplace during lunchtime. One-piece PPCs in size 20 were created using Aldrich (2007) and the WIM body measurements. Four evaluators with expertise in clothing design and garment construction were purposefully selected to ensure the validity and reliability of the assessment exercise. Each assessor received a standardised guideline for assessment, which included three sections of the current PPC and the redesigned PPC as per Brown and Rice (2014, p. 160) and according to Liechty, Rasband & Pottberg (2016, p. 119) evaluation criterion for assessments. The evaluation scale for assessing the PPC size included 2.75-3 = signifying good quality; 2-2.5 = indicating a moderate quality size; and 1.5-1.9 = showing poor quality. The evaluation scale for the fit of the PPC was 2.75-3 = indicating a good quality fit, 2-2.5 = highlighting a moderate quality fit and 1.5-1.9 = signifying a poor-quality fit. The size and fit assessment form indicated the standard fit dimensions expected of the selected PPC. The fit assessment took place at the researchers' institution.

3. Results and discussions according to the objectives of the research (Actual name of this section may differ)

The research had two objectives as follows:

3.1 To determine and describe the nature of size and fit complaints experienced by WIM with existing one-piece coverall PPC.

To address this objective, five women working in the mines were interviewed on how the one-piece PPC fits them in various critical fit points in relation to jumpsuit type of garment such as the hips, the thighs, the shoulders, the crotchline and lengths in relation to the body height and sleeve length. To report on major problem areas, all the five women indicated that the one-piece PPC restricts their movement particularly when squatting or when making long strides, while working. The same women reported that the current PPC is tight around the hips and thighs as well as the bust

line. They also report that the crotchline is too tight and restrict their movements leading to accidents and discomfort while working. Table 1 shows some of the verbatim responses from the women interviewed.

Despite having the option to wear a two-piece outfit, the individual voiced their frustration at being required to wear a one-piece garment. They described donning the one-piece outfit as a violation of their fundamental human rights, particularly their freedom to use the restroom comfortably. These findings confirm Raj (2023) sentiments that one piece coverall poses inconvenience the users of using the bathroom. The same women report having to wear their personal denims sometime because the PPC are uncomfortable. Benson and Rajulu (2009) affirm that limitations posed by one-piece coverall can lead to discomfort due to restricted movement, impacting their productivity and overall well-being. These findings further corroborate with Ola-Afolayan (2019) study that shows that most women in South Africa were pear shaped and had difficulties finding clothes that fit well around their hips and thighs. The participant's response is confirmed when the model wore the PPC as shown in Figure 2.

Table 1: Reported fit problems experienced by the women in the mines

Area	Problem	Challenges
Bust	Loose sometimes tight	"This area on the breast is tight sometimes when I take the size I like and when the size is larger it becomes too loose"
Sleeves	Too long	"But the sleeve is very long, and I have to always fold it because I'm afraid it will hook me"
Hips	Too tight	"The sides of the pants are small, and I don't have enough space for my hips".
		"I need it to give me space, to be a little looser. Because it makes me feel otherwise, like my confidence changes, it's too tight when I walk and sit or bend".
Waist	Too small sometimes too big	"When I wear one size larger around my waist, thinking I am being a comfortable loose fit, it gets too big around the thighs…when I take my size it is too small and very tight around my thighs". "But this one is big; I don't like it"
		it's too tight when I walk and sit or bend, I want it to be a bit high waist so that when I sit or bend it won't pull down.
Leg length	Too long Too wide	"Me I'm short so the pants are too long at the legs, I have to fold them up and I don't look nice".
		"I am only big here (hips) and my legs are thin so the pants are too wide, at least, they must be tailored or shaped on the sides to reduce the wideness".
Crotch	Too deep	"For my one-piece the front is long, and I don't like the back, it is big I don't know why it is like this at the back (pointing to the back crotch sagging) have big hips, so it pulls, so it takes the crotch down, that is why it is like that".
Thighs	Loose	"How it fits on my thighs for this one (one-piece) is okay because I don't like it tight".

To address this objective further, critical body measurements for a size 20 model were selected and compared to the measurements on the current clothing worn by women working in the mines. The current clothing uses a lettered sizing system, such as 2XL, which does not accurately represent the critical fit points for women. As seen in Figure 2, there are significant differences in the measurements and the fit of women. The height measurements do not align with the female body; for instance, the crotchline is shorter at the back and longer at the front. The shoulders are excessively larger than those of the actual body. Specifically, the current manufacturer's shoulder measurement is 22 cm compared to the model's measurement of 11.5 cm, a difference of 10.5 cm. The model's bust measurement is 120 cm compared to the manufacturer's 109 cm, a difference of -11 cm. The model's waist measurement is 116cm, while the manufacturer's is 94cm, resulting in a difference of -22cm. Similarly, the model's hips measure 136cm, which is -17cm compared to the manufacturer's 119cm. Based on the differences, the current one-piece PPC is not suitable for a female body in terms of fit and of size. Size standards adapted from the UK do not address size and fit issues of the South African people. Makhanya (2015, p. 6) asserts that the country lacks easily accessible anthropometric data from South African people and therefore adapted measurements cannot work for South African women.

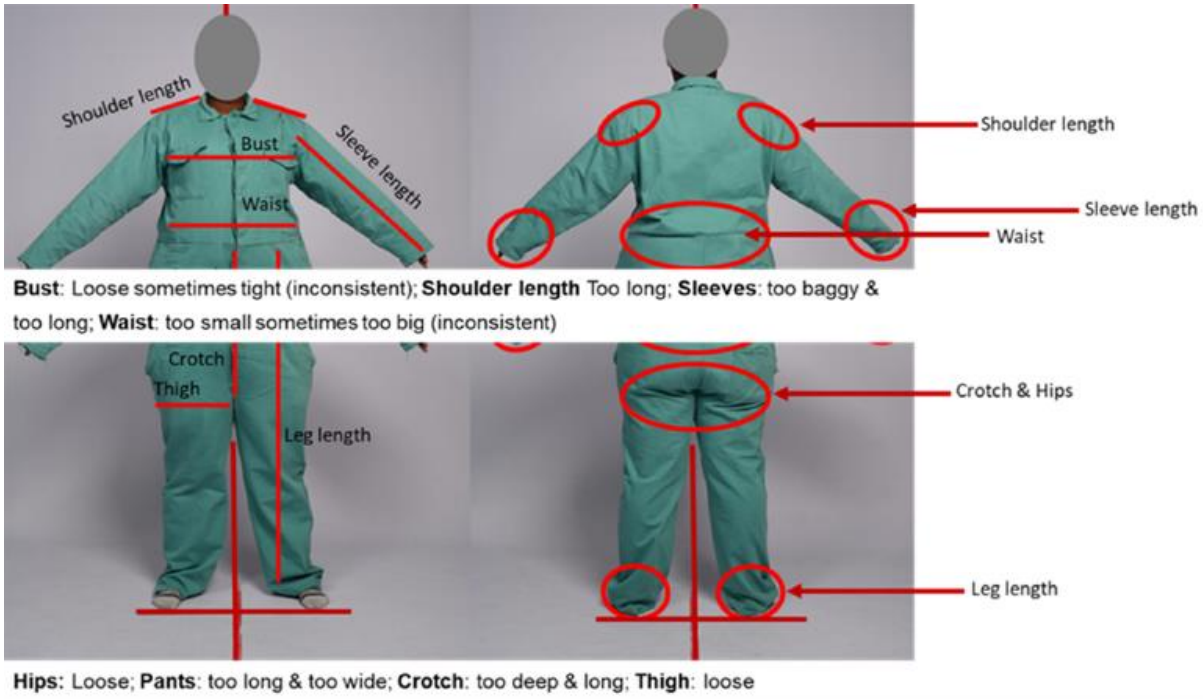

Figure 2. Assessing size and fit of the current one- piece overall on a model (Photo taken by the lead researcher, 2021).

The sizing system currently used to manufacture and supply PPC for WIM in South Africa is based on male sizes that are outdated and inappropriately-fitting and they do not reflect the body shapes of the WIM. The above-described sizing body measurement difference, especially from the current PPC manufacturer, contributes to the size problems experienced with the fit of the current PPC worn by WIM in South Africa (Makhanya, 2015, p. 7; Muthambi, 2015).

3.2 To design a one-piece coverall PPC for the women in the mines

The findings of objective 1 (3.1) required the redesign of a one-piece PPC that not only fits well and is comfortable for women but also allows them to use the toilet while working in the mines efficiently (see Figure 3). Its size and fit were further tested by being worn by a fit model and evaluated by four-panel assessors for comfort and fit while the model simulated working in the mines. Garment patterns were drafted, manipulated and developed using paper. According to the South African Bureau of Standards recommendations, the researcher made the PPC using D59 cotton fabric. Other workwear applies similar standards due to its ability to withstand wear and tear during use, its resistance to abrasion, and its wide range of colours. Principles of clothing construction guide its manufacture, ensuring the sewing specifications and standards required by the SABS of 2012, 2013 and 2015.

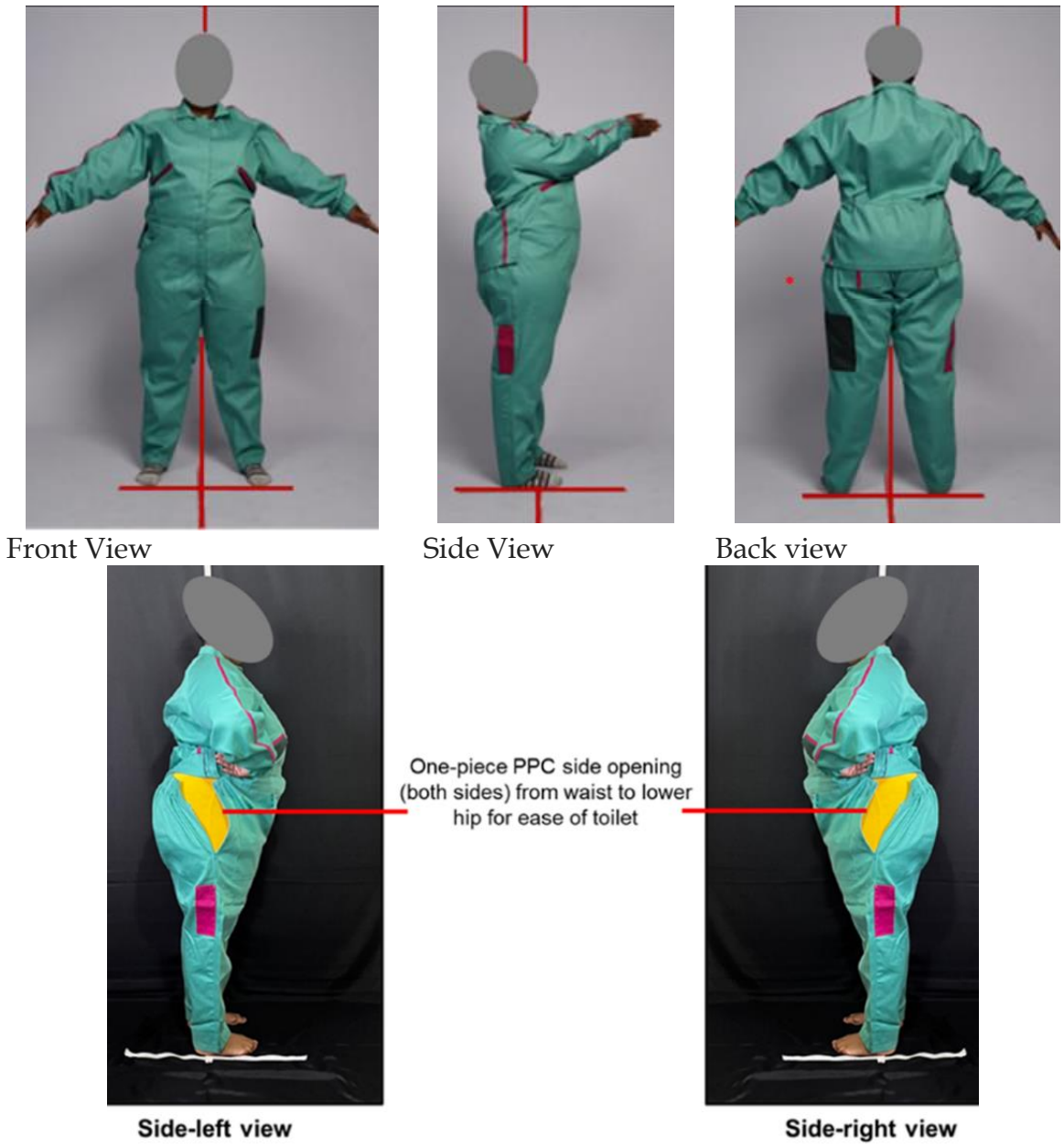

Figure 3. Redesigned one-piece coverall PPC with a functional component allowing easy use of toilet.

The outcome of the redesigned PPC (Figure 3) shows an improved comfort of size and fit, as reported by women working in the South African mining sector. As shown in Figure 3, the new design provides enough flexibility for the miners to move around, stretch, reach out, and squat as required by their work. The frontal section of the new design remains a single piece. The back of the PPC has two parts, with the upper part overlapping the lower elasticated waistband and having two side openings. The new PPC's sleeves have been changed from inset sleeves to raglan sleeves with a shortened length (Figure 4) to allow for easy arm stretching and reaching out. The new PPC's sleeves have been changed from inset sleeves to raglan sleeves with shortened lengths (see Figure 4), allowing for more accessible arm stretching and reaching out.

Figure 4. Raglan sleeve and sleeve length introduced

The original one-piece had a tight fit that caused friction in the inner thighs when moving, which was uncomfortable. The PPC pants incorporate inner thigh support with two layers of fabric and comfortable batting in between. In addition, they were crafted from durable, high-quality cotton. Please consult Figure 5 for a visual depiction.

Figure 5. Redesigned one-piece coverall PPC inner thigh support patch

To ensure that the new design had improved quality, the PPC was worn by the fit model and subjected to two tests.

3.2.1 Fit assessment by the experts while the model is wearing the redesigned PPC.

Four pattern and fashion design/garment experts were appointed to evaluate and assess the size and fit of the current PPC garments constructed according to the standardised male size 44 and redesigned PPC using the size 20 participant's measurements. The one-piece PPC evaluation scale was as follows: 3 = good quality of size, 2 = moderate quality of size, and 1 = poor quality of size, which was also used for the fit evaluation scores. The size and fit comparison results are shown in Table 2.

Table 2. Quality of PPC's size and fit as assessed by the 4 experts

	Assessment scale	Existing PPC (Men's size 44)	Re-designed PPC (Women's size 20
SIZE	Good quality = 3	Front neck, front shoulders, armhole, front and back midriff section, upper hip, armhole	the shoulders, alignment of the shoulders, armholes, sleeve length, upper front, upper hips, pants over the abdomen, front hip area, buttocks, lap, pant width, pant length, and hems at both legs
	Moderate quality = 2	Chest area, lower part of the pants and back width	Hips, thighs, bust, crotchline
	Poor quality = 1	Hips, thighs, bust, back crotchline	No reports
FIT	Good quality = 3	Front neck, front shoulders, armhole, front and back midriff section, upper hip	Front neck, front shoulders, armhole, front and back midriff section, upper hip, Chest area, lower part of the pants and back width
	Moderate quality = 2	Chest area, lower part of the pants and back width	the front and back waist and the front crotch/inseam
	Poor quality = 1	Hips, thighs, bust, crotchline	No reports

As seen in Table 2, the four assessors found that the redesigned one-piece PPC had a good quality fit in several areas. These areas included the shoulders, alignment of the shoulders, armholes, sleeve length, upper front, upper hips, pants over the abdomen, front hip area, buttocks, lap, pant width, pant length, and hems at both legs. The fit of the current one-piece PPC was rated as moderate around the front and back waist and the front crotch/inseam. The redesigned one-piece PPC showed improved fit quality compared to the previous version.

3.2.2 Fit model's response on the new PPC's comfort when carrying out daily ergonomic activities at work

To clarify the quality of the redesigned PPC, the model gave her views on the comfort experienced while donning the redesigned Personal Protective Clothing (PPC) and engaging in tasks that replicate her work conditions. The focus was on addressing the problem areas previously reported with the old PPC. The four assessment experts

were present to observe and guide the steps made by the model. Experts observed the model's movements as she explained her comfort preferences and corresponding PPC positions involved during the actions. The focus areas were the participant's ergonomics, such as bending, walking, squatting, and extending her arms overhead and cross-body as shown in Table 3.

Table 3. Reported comfort experienced by the model wearing the redesigned one-piece coverall PPC

Redesigned one-piece PPC	
Ergonomics	**Women in mining perceived comfort and experienced**
Bending	"The overall doesn't pull here on the waist at the back when I bend, look, I bend by pulling the overall pants up,
Climbing	"The up part doesn't pull at the hands and back, I like it and the thighs are not too tight, nice and loose I can climb up and down easily"
Walking	"Me I like the overall when it is like this, loose-fitting because I work with men, so this one doesn't expose my body, I like it like this".
Squatting	"Even if it has elastic I still don't pull, and I like this part, the flap that covers the pant, it covers well and I like that it is loose fitting like I want it, I feel comfortable and free to squat without thinking about it"
Extending arms overhead	"The sleeves don't feel tight when I am doing this like they don't go up too, it's like nothing is happening, I like this size it is comfortable for me. I also like that it has elastic here at the hands."

The findings show that the participant expressed joy and comfort when demonstrating her daily ergonomic activities. She experienced great comfort while the loose-fitting PPC allowed her confidence to squat without worrying because the redesigned PPC easily and comfortably allowed easy pulling when performing daily ergonomics. In a study, Motubatse (2015) noted that size and fit directly impact the comfort characteristics of a garment. The discovery above can be extrapolated to the current inquiry, wherein the comfort level of a participant with her existing one-piece personal protective clothing (PPC) directly impacted the researcher's decision-making process while redesigning the one-piece coverall PPCs. The model's preference for a loose-fitting one-piece PPC informed the new designs' functional aspects added. The PPC's current inappropriate fit psychologically impacts the participant's preference. Considering the male-dominated environment she navigates; the individual prefers a more considerable and looser-fitting personal protective coverall (PPC) to mitigate potential harassment from male colleagues. Pandarum et al. (2011) observed that women encounter discomfort when wearing improperly fitting attire. Their research findings indicate that standard bust girth and under-bust measurements cannot accurately determine bust volume.

4. Conclusions

The study found that women working in the mining industry, especially those wearing sizes 16, 18, 20, 22, and 24 (with an average size of 20), faced significant challenges with the fit and comfort of their current Personal Protective Clothing (PPC). The main issues were related to essential body measurements such as bust, hips, waist, pant and sleeve lengths, and the crotch area. The research successfully redesigned a one-piece personal protective clothing (PPC) for female miners in South Africa,

prioritising size, fit, and functional requirements. By actively involving female miners in the design process, the study addressed practical challenges, such as ease of restroom use, and ensured the redesigned PPC was comfortable and functional. The results showed that the redesigned PPC improved size and fit, resulting in a better-designed garment that meets female miners' safety and comfort needs. The improved size and fit in the redesigned PPC indicate that the industry has neglected women's rights, and there is a need for their employers to respond to their needs.

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