Deliverable of Task 2.1.

Prototype description

Prototype of ergonomic protective clothing for medical staff

Summary

Personal protective equipment (PPE), including protective clothing, simultaneously with protective properties must be appropriate to the wearer's morphology (fit), functional and not affecting wearers work capacities during various routine and work movements – ergonomic. Not always the implemented protective clothing sizing system allows the wearer to choose a product that fits. Besides, wearers with similar total morphological features may have a different range of movements, so it is necessary to study their limit values and find appropriate pattern-making solutions for the improvement of clothing fit. Though, to introduce adequate ease-allowances in critical areas, it is necessary to obtain extensive and reliable data on changes in body size and shape. By combining quantitative data with expert judgments and the wearer's subjective assessment of protective clothing, the design processes can be improved by moving towards the creation of an end-user-friendly and ergonomic product.

Description

Reusable protective ergonomic coverall to ensure protection during work activities. Coverall is made to be comfortable, the design, cut and fit (size) must allow sufficient freedom of movement, while preventing it from interfering with the work of the person wearing it. The material used must be light, ensuring high air permeability (allowing air and moisture to escape), whilst providing good protective properties (a barrier to various hazards), coverage, durability, and comfort of wear.

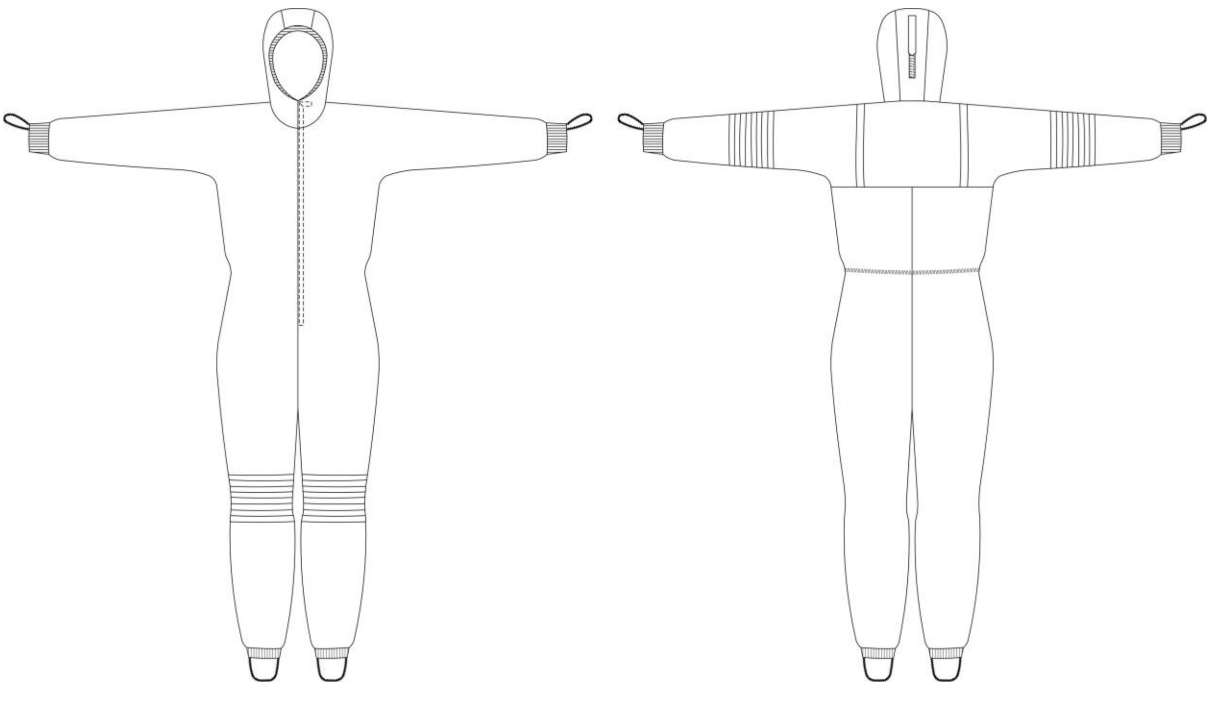

Figure 1. *Technical drawing of protective coverall.*

The protective suit is equipped with adjustable three panel hood, elasticized waist, Velcro closure (with inner storm flap) and tight-fitting knit cuffs around wrists and ankles, that are supplemented with elastic band that surrounds the feet and thumbs to keep the suit in place during extreme work postures. Folds/pleats are placed for additional freedom of movement at the level of elbows and knees, as well as vertically at the level of the shoulder blades. The folds create additional surface area, allowing the clothing to move with the body without causing discomfort and restrictions on movement. In further research, it is planned to experiment with texturing the fabric surface, thus gaining additional flexibility. Such solutions would make it possible to reduce the dimensions of protective clothing and make it more fitted, while not losing comfort.

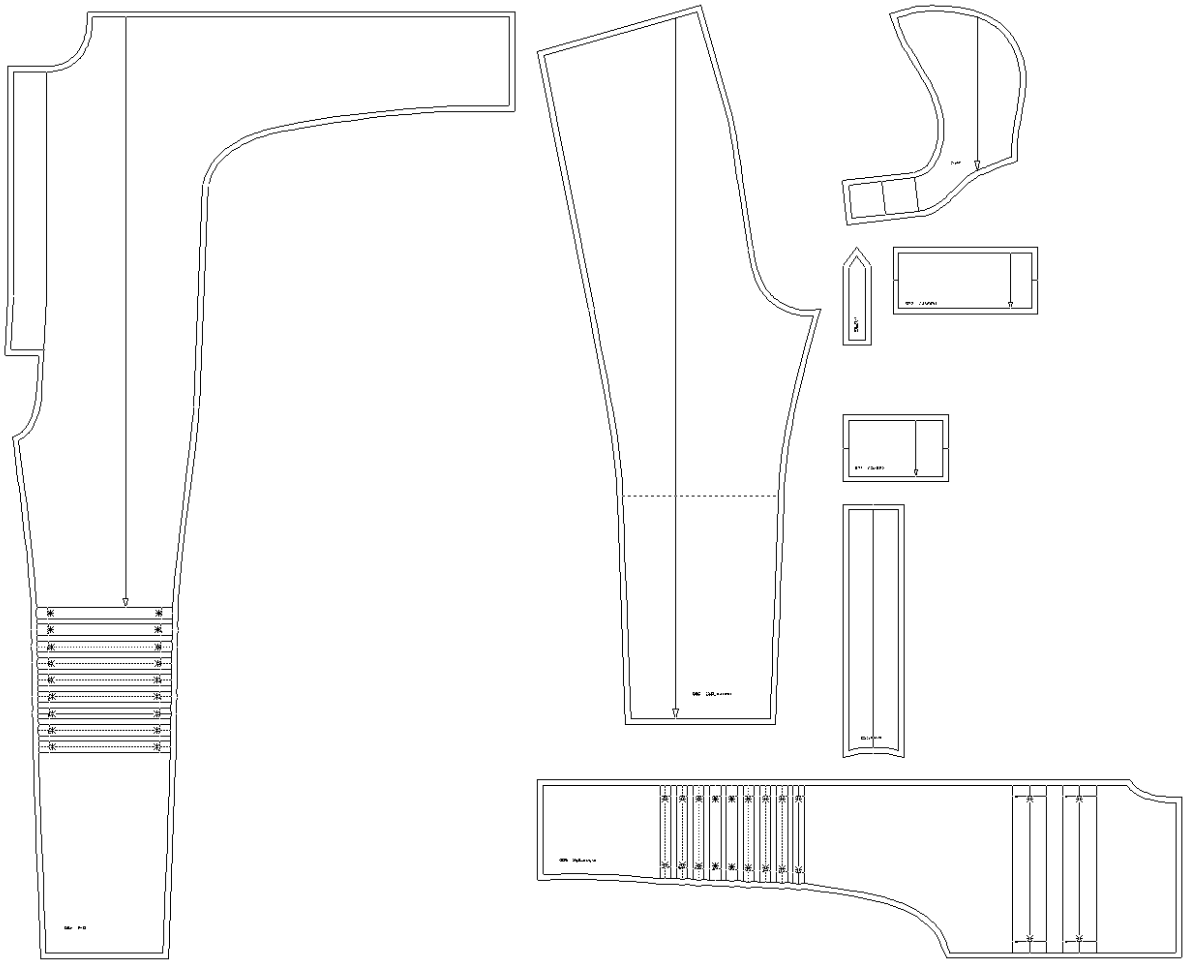

Figure 2. *Pattern set of protective coverall.*

Figure 3. *Protective coverall prototype.*

Characterisation methods

Anthropometric characteristics

Ten wearers of protective clothing (characteristics in Table 1) participated in the studies of protective clothing anthropometric fit and ergonomics to evaluate impact on wearers comfort, mobility and thus work capacity. 3D human body scanning device Vitus Smart XXL® with data proceeding system AnthroScan was used for this purpose.

Table 1. Descriptive anthropometric characteristics of participants.

Gender (f/m)	6 female
	4 male
Characteristic	**Value**
Age (yr)	30 ± 3
Body height (cm)	174 ± 5
Bust/chest girth (horizontal) (cm)	96 ± 5
Waist girth (cm)	78 ± 5
Buttock girth (cm)	100 ± 4
Body weight (kg)	68 ± 6

Sizing

Size labelling of protective suits available on the market is mostly a combination of key measurement intervals - body height and chest circumference. Participants had access to 3 sizes for suits (Table 2) with a theoretical option to choose the suitable one.

Table 2. Protective suit sizes and correspondance.

	Body height interval (cm)	**Chest/bust girth interval (cm)**	**Corresponding test-persons (number)**
Size			
S	162-170	84-92	1
M	170-176	92-100	4
L	174-181	100-108	1

As a result, 6 out of 10 participants by their body characteristics fall within the specified size ranges (four “M”, one “S” and one “L” size), but despite the theoretical correspondence, it was indicated that the fabric tension and body limitations are still felt during the movements. The remaining 4 participants do not fall within the following sizing system - when choosing clothes according to body height, a person's chest circumference is larger or smaller than indicated on the label, and vice versa. Thus, the chosen protective garments may be inappropriate in circumferences or length.

Dynamic anthropometry

3D scan images of different postures allow to analyze changes in body shape during dynamic movements. The axes were chosen characterizing the body position for the quantitative characterization (by angles) of the movement range, and comparison of the participant physical abilities was performed by superimposing scan contours. For example, posture “Bending forward” with axes: Cervical vertebrae 7CV through Gluteus maximus; Lumbar Vertebrae L5 through the medial axis of Medial malleolus (Figure 4). And posture “Raised arms” with axes: Lumbar Vertebrae L5 to Olecranon (elbow) in relation to the medial axis of the body; Lumbar Vertebrae L5 to Acromion in relation to the medial axis of the body (Figure 5).

Figure 4. *Movement range in bending forward posture.*

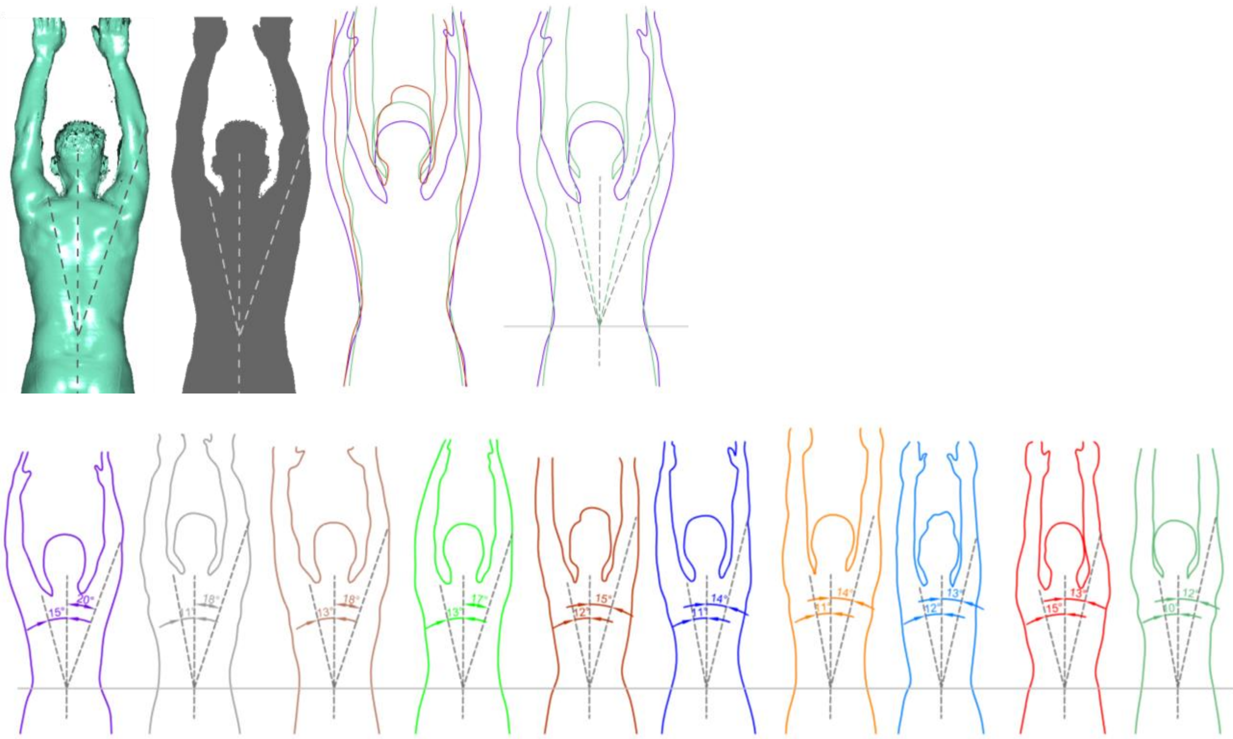

Figure 5. *Movement range in raised arms posture.*

Within the experimental set, differences in movement ranges were determined, indicating disparities in the ability to perform specified postures even without wearing the suit (Table 3). Values in the bending position indicate different abilities to reach hands towards the floor by bending forward torso, and in the raised arm position to raise arms at the shoulder and elbow joints.

Table 3. Movement ranges.

		Range (°)	Mean ± standard deviation
Posture	**Angle axis**		
Bending forward	Cervical vertebrae 7CV through Gluteus maximus and Lumbar Vertebrae L5 through medial axis of Medial malleolus	87 - 66	$75^o \pm 8^o$
Raised arms	Lumbar Vertebrae L5 to Olecranon (elbow) in relation to the medial axis of the body	20 - 12	$15^o \pm 3^o$
Raised arms	Lumbar Vertebrae L5 to Acromion in relation to the medial axis of the body	15 - 10	$12^o \pm 2^o$

In both cases, even at similar length values, the differences occur in the shape of the back, shoulders, and arms, potentially causing dissimilar interaction of the garment layer with different bodies and thereby diverse tension zones.

Clothing layer interaction with the human body

For the analysis of the garment layer interaction with a human body, transverse cross-sections were obtained superimposing the body clothed in underwear and body clothed in a protective suit. Transverse cross-section at the chest/bust level of "M" size coverall (body height 170-176, chest/bust circumference 92-100) on 4 different wearers (Figure 6) indicated an increased volume of the fabric at the back and tight-fit at the chest/bust part in front.

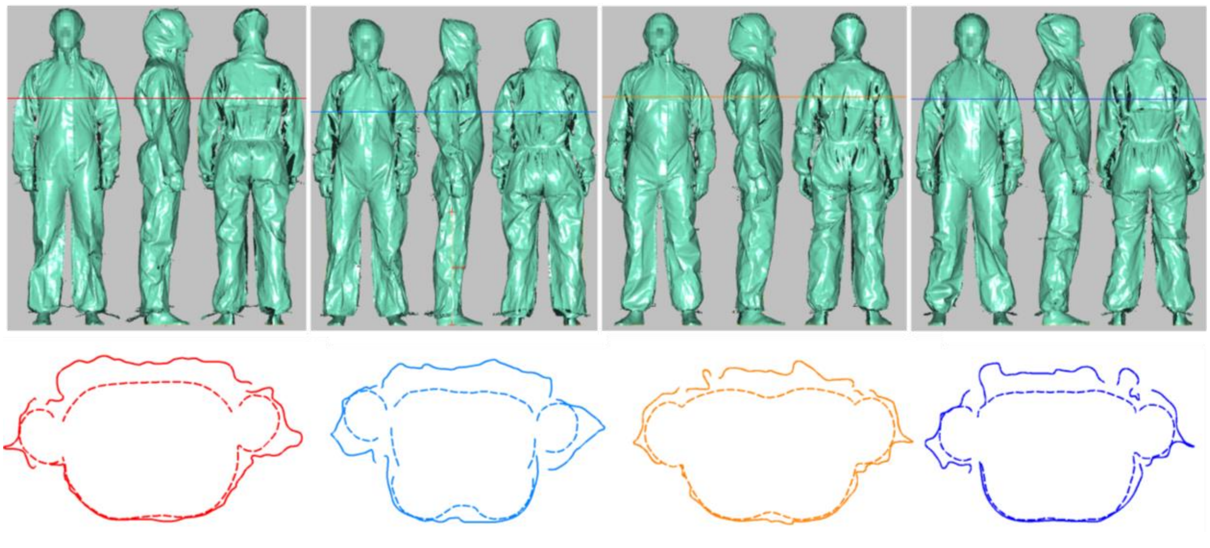

Figure 6. *Superimposed scans and cross-sections in chest/bust level.*

The extra volume (ease-allowance for freedom of movement) ensures that the wearer is not restricted during movements, however, the excess volume can also be a distraction. Therefore, solutions such as elastic material (if meets protective requirements) or folds of different extent may be more appropriate in protective garment design to adapt the garment to changes in body shape.

Subjective evaluation of fit and ergonomics

During the experiments, the feedback was obtained on the freedom of movements and effects of different garment parts when moving. For example: to be able to perform squat or kneel movements, most wearers first pull up the thigh section of the trouser leg. Also, after making these movements, the trouser leg parts remain puckered and do not return to the starting position (anklet (cuff or band) required). It was concluded that in a squat and kneel positions the top of the fastener makes pressure on the neck in the under-chin zone if garments that do not have a sufficient ease-allowance for the length at the back, as well it causes a tight feeling in the knee area. When bending forward, the wearers feel the tension in the seat seam and the buttock area in general, as well as tightness in the thigh area. For most of the participants, tension is felt in the crotch part when lifting arms