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Development of a quantitative system for subjective evaluation of tracked vehicle crew jackets

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Abstract

The purpose of this study is to develop a quantitative evaluation system that reflects the required performance factors that are important for a tracked vehicle crew jacket. We identified and analyzed the necessary performance factors obtained from a focus group interview and a questionnaire survey. Further, we proposed a new method of calculating weights and developed a quantitative evaluation system. This system featured an equation that calculated the evaluation score out of 100, using the factors' percentages in the total factor as factor weights. The system's application was verified by the assessment of subfactors by active-duty soldiers, and by confirmation that the results of the developed factor scores reflected the proposed development direction. The study is significant for its provision of a comprehensive and quantitative evaluation system which has not existed before for protective clothing design, as well as for the verification of the system's application through the process of protective clothing development. The quantitative evaluation system and its development process described in this study may be referenced and widely deployed due to its use of a Likert scale, which is commonly used as a subjective sensory evaluation tool.

Keywords: Protective clothing, Tracked vehicle crew jacket, Quantitative evaluation system, Likert scale, Performance factors

Introduction

The systematic design of protective clothing requires careful consideration of various production, evaluation, and maintenance factors, and designers should consider a wide range of human factors including sizing and fit, ease of donning and doffing, comfort, and function (Ashdown and Watkins, 1996). KS K ISO 13688 (Korean Agency for Technology and Standards 2021) defined protective clothing's general performance requirements for ergonomics, innocuousness and comfort, and ASTM F1154-18 (ASTM International, 2018) contains standard practices for evaluating the comfort, fit, function, and durability of protective ensembles. Rosenblad-Wallin (1985) emphasized that the objective of functional clothing can be divided into functional and symbolic values, which must be considered for user-oriented product development. However, designing protective clothing that optimally satisfies all these conditions can be challenging, as some factors conflict with others (Hong, 2004). To identify potential conflicts, it is necessary to identify those factors that are required by wearers and whether protective clothing developed against particular design criteria is suitable for its target functionality.

Furthermore, it is necessary to evaluate whether protective clothing is developed suitably for the required performance following successful product development. Wearers' subjective evaluations of comfort are essential during the clothing design process to ensure customer satisfaction, and it is common to adopt Likert scales to quantify essentially subjective evaluations. Most previous studies on the development of military clothing have focused on dimensional suitability and motion suitability, measuring such attributes as a wearers' subjective sensations for different clothing parts, using Likert-style rating scales (Han et al., 2016; Jeong, 2014; Lee, 2012; Lee et al., 2012). However, when critical design decisions must be made in the final development stages, it would help to be able to translate those subjective Likert-scale evaluations into quantitative factors that can be presented as objective numbers. Lee and Sim (2016) proposed a method to use the factor loadings based on a Likert scale as weights for the evaluation system to enhance the utilization of the evaluation system. The study of Cho et al. (2008) on the evaluation and optimal design of protective clothing presented quantitative numbers for the ergonomic cost-effectiveness of their proposed flame-proof clothing. However, they could not incorporate improvement percentages for the required performance factors.

The tracked vehicle crew's jacket is part of a protective duty uniform that protects tracked vehicle crew from flames and should be functionally suitable for performing high-intensity missions in extreme winter temperatures and restricted internal environments. However, the current tracked crew jacket's material lacked flame retardance, camouflage, warmth, pockets, and adequate clothing size, and its jumper style required improvement in design and pattern (Choi, 2020). Therefore, the tracked vehicle crew's jacket has been developed through a tracked vehicle jacket development project (Samil Spinning Co., Ltd., 2018) from July 2018 to June 2021 (3 years). At present, its development is currently being evaluated to determine its improvements for required performance as quantitative factors for a final decision of success.

Previous studies using quantitative factors in design and evaluations have mostly focused on environmental design, the process of addressing surrounding environmental parameters (Cho et al., 2010; Yoo, 2013), and industrial design, the process of design applied to products that are to be manufactured by mass production (Im, 2017; Jung, 2007; Park & Lee, 2007). However, these studies have proposed design and evaluation factors without verifying whether the required factors were reflected in the product development stage. Furthermore, although the studies presented quantified data, the researchers and experts collected subjective data, with the experts' evaluation scores used as factor weights. Consequently, their evaluation systems failed to incorporate wearers' evaluations of the functional components they valued most.

Therefore, the purpose of this study was to develop a quantitative evaluation system that reflects the required performance factors that are important for a tracked vehicle crew jacket. To develop a quantitative evaluation system, this study analyzed the required performance factors for protective clothing using data obtained from a focus group interview (FGI) and a questionnaire survey completed by active-duty members.

We proposed a new method of calculation of weights and an evaluation system derived from quantitative factors and tested their application on the development of a tracked vehicle crew jacket.

Methods

Identifying the required performance factors

To identify the required performance factors for the development of a tracked vehicle jacket, we referenced and modified a table on such factors developed by Lee (2016) and Choi (2020), which summarized previous studies on protective clothing (Ashdown & Watkins, 1996; Choi & Kim, 2011; Gupta, 2011; Huck & Kim, 1997; Jeon, 2011; Jeong, 2014; Lee, 2012; Lee et al., 2012; Lim, 2003; Rosenblad-Wallin, 1985; Tan et al., 1998; Wiernicki, 1992). We also conducted an FGI with 16 tracked vehicle crew members on active duty during August 2019 to ask for feedback on their current on-duty clothing. Using information gained during the FGI along with a review of previous research on protective clothing, we identified relevant factors and subfactors.

Setting required performance factors and subfactors

Between August 19 and September 26, 2019, we asked 253 tracked vehicle active crew members to complete the final version of our questionnaire, which included the subfactors. All respondents had worn a tracked vehicle jacket before. We asked them to rank, using a 5-point Likert scale, the importance of various required performance factors for protective clothing that we had identified from the FGI and a literature review.

We conducted a factor analysis to examine the relevance of the subfactors and factors. Initially, we had 37 subfactors. However, we removed five subfactors that had low factor values (e.g., “It must be comfortable to move my joints,” “The structure of protective clothing should be efficient for carrying out a mission,” and “The functionality of materials must be good”) to increase the total factor loading. This left us with 32 subfactors as design and evaluation criteria.

Developing a weighting method

We set seven essential factor categories for a tracked vehicle crew member’s jacket design. Of these, safety, maintenance, and material functionality (three factors) could be measured using national and international standards already in place. Thus, these factors are usually evaluated using experts’ evaluations and specifications rather than the wearers’ evaluations. For this reason, we focused on dimensional suitability, mission suitability, motion suitability, and aesthetics (four factors) that the wearers were better positioned to evaluate in a timely fashion. Therefore, we selected four required performance factors and conducted a factor analysis again to ensure that each weight applied to developing a quantitative evaluation system.

Developing a quantitative evaluation system

To develop a quantitative evaluation system, we calculated the final four factors’ equation with subfactors’ points, and each factors’ weight. We referenced and supplemented

Required Operational Capability (ROC) criteria from a tracked vehicle jacket development project to determine whether it was successful or not.

Testing a developed evaluation system

The reliability and validity of each subfactor had already been statistically demonstrated through factor analysis. Therefore, we tested the developed subfactors and the evaluation system in terms of its application. To test the developed subfactors' application, we divided the respondents into two groups: a control group of 81 occupational soldiers (soldiers with specific training and duties) who had worn the current tracked vehicle jacket for at least six years, and a comparison group of 172 enlisted soldiers who had worn the jacket for up to two years. We compared the two groups' evaluation scores of the current jacket that proved to be universally applicable to all those not affected by years of service or level of training.

In addition, we asked 15 of the 16 tracked vehicle crew members who had participated in the earlier development of protective clothing to evaluate the current and proposed jackets. They ranked their responses to the subfactors obtained from the factor analysis using the 5-point Likert scale. We then compared the differences in their scores reflecting improvements in design and pattern to test the application of the developed evaluation system. Figure 1 shows a flow chart for the evaluation system development process.

Results and discussion

Identifying required performance factors

Different researchers have used different terminologies to describe the required performance factors for protective clothing. For this study, we organized and divided terms with similar meanings into seven main headings: motion suitability, dimensional suitability, ease of use, aesthetics, safety, material functionality, and maintenance (Table 1).

The FGI showed that tracked vehicle crew members worked in tight, confined spaces, with protruding structures and equipment that could easily snag loose clothing. The

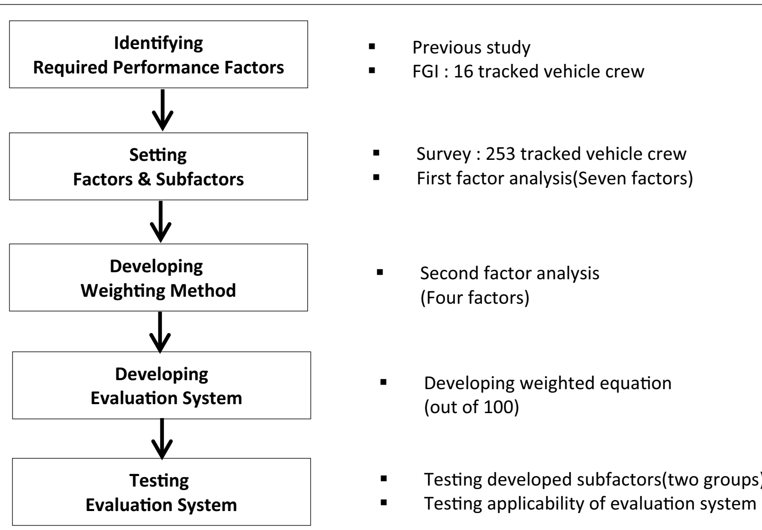

Fig. 1 A flow chart for the evaluation system development process

Table 1 Seven performance factor category definitions for protective clothing

Performance requirement	Definition	Terminologies used in previous studies
Motion suitability	Clothing does not interfere with activities and allows adequate range of motion	Clothing mobility, task mobility, mobility, comfort, motion fitness, ergonomic consideration, changes in relationships between body parts as the body moves
Dimensional suitability	Clothing fits or adjusts to fit different body sizes and shapes to accommodate the mission environment and motion	Sizing and fit, fit, shape fitness, fitness, ease, relationship of body parts to one another and to garments
Ease of use	Clothing components such as fasteners, pockets, vents, and zippers are easy to use	Task visibility, dexterity, task dexterity, usability, functional, functional requirement, functional value, ease of donning and doffing, ergonomic consideration, ease of attaching and detaching inner and outer layers
Aesthetics	Clothing's visual appearance has a psychologically positive effect on the wearer	Psychological satisfaction, symbolic values, psychological requirement, psychological, appearance satisfaction, aesthetic
Safety	Clothing protects the wearer from external risks and has no inherently dangerous features or properties	Protection, innocuousness, sanitation, safety, fire safety, protect the user from task hazard, create no additional safety or health concerns
Material functionality	Clothing materials keep the wearer comfortably warm and dry	Physiological, biomechanical, physiological comfort, heat and moisture transport, comfortable environment, insulation, thermal protection, fabric suitability, function of fabric
Maintenance	Clothing is durable and easy to keep clean and tidy	Durability, ease of handling, cleanability, ease of maintenance, production

spaces inside some tracked vehicles were not temperature-controlled. Most of the crew members' motions during a mission involved upper-body movement. Many respondents had negative comments about the current jacket, among which were the following: the cuffs at the waist and wrists tended to ride up, which felt uncomfortable; there were not enough pockets; the pockets had snaps that were difficult to use; and the jackets stained and snagged easily during operational and maintenance activities. They also commented that the current jackets did not give them a "sense of belonging as a member of the tracked vehicle crew."

Setting required performance factors and subfactors

We organized respondents' feedback into the required performance factor categories to set a direction for the development of the protective clothing. The focus group had many comments and requests that reflected their unique work environments and missions. For example, they wanted clothing components that were more practical and usable (e.g., pockets, vents, and zippers); greater comfort in confined mission environments; and lighter clothing. Therefore, we extended the specific required performance factor "ease of use" used in previous studies to "mission suitability." As a result, seven categories applicable to the development direction were selected: motion suitability, material functionality, dimensional suitability, mission suitability, maintenance, safety, and aesthetics.

To investigate crew members' priorities on the simple category term which could be cross checked with their results when they evaluated them with the subfactors, the crew members were asked to rank the factors from first to third. The numbers of the results were summed up without assigning any weightings. The crew members prioritized these factors in a specific order: motion suitability, material functionality, dimensional suitability, mission suitability, maintenance, safety, and aesthetics (Table 2). The tracked vehicle crew members were more concerned about motion suitability, material functionality, and dimensional suitability, than safety and aesthetics. They may have given safety a relatively low priority because most had not experienced fires directly in military operations or drills, and so did not associate the word "safety" with any real threat. The crew members were more interested in functionality that affected their daily activities—whether the jacket impeded or assisted them in their mission, whether it fit, and whether it had enough or the right kind of pockets—rather than safety, which they could not evaluate based on their day-to-day operations. In addition, the results of items related to the clothing's shape, size, and ease, such as motion suitability and dimensional suitability, were considered to indicate the importance of design and pattern development when developing a tracked vehicle crew jacket.

To set a direction for the development of the protective clothing and to consider usability in terms of factor weightings, we instructed the respondents to evaluate the importance of the required performance subfactors using a 5-point Likert scale. All the subfactors except color (3.59), sense of belonging (3.73), and fancy design (3.38) scored above four points; the respondents considered most subfactors to be important, and there was little difference in importance across the subfactors (Table 3).

While previous studies (Cho et al., 2010; Park & Lee, 2007) used the average importance of the subfactors to weight the factors, doing so makes little sense if there is no significant difference in the importance rankings across the subfactors. Hence, an alternative approach might be required to distinguish the degrees of importance.

Analysis of required performance factors

We conducted a factor analysis of the importance of the various performance subfactors' ranking scale to identify any differences in the perceived importance of functionality based on terminological differences for the subfactors. The results (Table 4) itemized seven required performance factors: Factor 1 (16.13), Factor 2 (11.44), Factor 3 (10.60), Factor 4 (9.79), Factor 5 (9.18), Factor 6 (7.37), and Factor 7 (7.29). The

Table 2 Crew members' priorities for the required performance factors (N = 253)

	Motion suitability	Material functionality	Dimensional suitability	Mission suitability	Maintenance	Safety	Aesthetics
1	110	37	49	20	19	14	4
2	64	69	36	44	22	14	5
3	30	50	38	42	47	24	21
Total	204	156	123	106	88	52	30

Table 3 Crew members' evaluations of the required performance subfactors (N = 253)

No	Required performance subfactor	Importance	No	Required performance subfactor	Importance
1	Bottom circumference fit	4.17	17	Ease of laundering	4.41
2	Sleeve length fit	4.36	18	Sufficient storage	4.21
3	Cuff circumference fit	4.19	19	Ease of storage	4.50
4	Collar circumference fit	4.18	20	Lightness	4.32
5	Posterior shoulder length fit	4.38	21	Mission environment suitability	4.49
6	Total length fit	4.35	22	Ease of dressing and undressing	4.36
7	Chest circumference fit	4.45	23	Torso joint usability	4.46
8	Fire protection	4.37	24	Shoulder joint usability	4.63
9	Fragment protection	4.26	25	Elbow joint usability	4.73
10	Chemical protection	4.37	26	Neck joint usability	4.45
11	Flame retardance	4.47	27	Color	3.59
12	Camouflage	4.40	28	Sense of belonging	3.73
13	Friction resistance	4.32	29	Fancy design	3.38
14	Water resistance	4.39	30	Ventilation	4.57
15	Integrity	4.23	31	Fast-drying	4.52
16	Stain resistance	4.59	32	Warming	4.73

total common factor variance, representing the explanatory power of the factor analysis, was 71.82%. The Cronbach's α ranged from 0.822 to 0.926 across the factors, demonstrating internal consistency.

The analysis of the common factors among the subfactors revealed dimensional suitability as Factor 1, safety as Factor 2, maintenance as Factor 3, mission suitability as Factor 4, motion suitability as Factor 5, aesthetics as Factor 6, and material functionality as Factor 7. These results demonstrated that the respondents ranked the importance of the required performance factors in the following order: dimensional suitability, safety, maintenance, mission suitability, motion suitability, aesthetics, and material functionality.

Dimensional suitability

Dimensional suitability ranked higher in importance when we included the subfactors. However, when we presented only the simple terms, *motion suitability* ranked higher in importance than it had when we included its subfactors. It is possible that the respondents did not distinguish dimensional suitability from motion suitability since it is inconvenient to move when the dimensions of a garment do not fit. Consequently, since dimensional suitability can also improve motion suitability, dimensional suitability was considered more important. Furthermore, the crew members ranked the importance of dimensional suitability's subfactors in the following order: bottom circumference, sleeve length, cuff circumference, collar circumference, posterior shoulder length, total length, and chest circumference. This is consistent with the FGI discussion of the subfactors, where we learned that the current jacket's bottom circumference and cuff circumference, which are ribbed, rode up and caused discomfort when the crew members moved during their missions. This reinforced our finding that the crew members considered the

Table 4 Results of factor analysis for required performance factors (N = 253)

Factor	Subfactor	Component							Common factor variance (%)	Cronbach's α
		1	2	3	4	5	6	7		
1	Bottom circumference fit	0.837	0.066	0.241	0.144	0.105	0.058	0.018	16.135	0.926
	Sleeve length fit	0.835	0.120	0.036	0.057	0.157	0.070	0.118		
	Cuff circumference fit	0.807	0.132	0.196	0.174	0.127	0.115	0.033		
	Collar circumference fit	0.781	0.090	0.227	0.149	0.112	0.123	0.082		
	Posterior shoulder length fit	0.760	0.170	0.117	0.059	0.146	0.144	0.170		
	Total length fit	0.759	0.053	− 0.003	0.191	0.188	0.110	0.165		
	Chest circumference fit	0.740	0.105	0.071	0.199	0.164	0.068	0.256		
2	Fire protection	0.133	0.878	0.175	0.141	0.016	0.077	0.081	11.440	0.896
	Fragment protection	0.136	0.874	0.169	0.145	0.041	0.094	0.014		
	Chemical protection	0.177	0.850	0.206	0.073	− 0.005	0.139	0.058		
	Flame retardance	0.070	0.735	0.103	0.092	0.085	0.067	0.340		
	Camouflage	0.103	0.536	0.336	0.033	0.147	0.161	0.255		
3	Friction resistance	0.202	0.173	0.769	0.088	0.103	0.124	0.177	10.606	0.883
	Water resistance	0.055	0.204	0.733	0.370	0.044	0.058	0.191		
	Integrity	0.144	0.341	0.694	0.314	0.102	0.112	0.148		
	Stain resistance	0.198	0.104	0.689	0.152	0.186	0.112	0.097		
	Ease of laundering	0.175	0.248	0.661	0.185	0.070	0.130	0.177		
4	Sufficient storage	0.165	0.132	0.046	0.788	0.097	0.194	0.033	9.794	0.839
	Ease of storage	0.066	0.135	0.243	0.765	0.191	0.056	0.026		
	Lightness	0.223	0.014	0.194	0.652	0.171	0.026	0.260		
	Mission environment suitability	0.280	0.096	0.256	0.623	0.190	− 0.001	0.015		
	Ease of dressing and undressing	0.204	0.161	0.276	0.582	0.289	0.035	0.114		

Table 4 (continued)

Factor	Subfactor	Component							Common factor variance (%)	Cronbach's α
		1	2	3	4	5	6	7		
5	Torso joint usability	0.314	0.091	0.148	0.109	0.790	0.029	0.094	9.182	0.857
	Shoulder joint usability	0.175	0.019	0.095	0.339	0.789	− 0.058	0.125		
	Elbow joint usability	0.198	0.023	0.098	0.264	0.783	− 0.051	0.029		
	Neck joint usability	0.135	0.059	0.089	0.079	0.760	0.119	0.166		
6	Color	0.136	0.156	0.104	0.065	− 0.036	0.857	0.084	7.372	0.844
	Sense of belonging	0.137	0.134	0.193	0.056	0.103	0.828	− 0.048		
	Fancy design	0.170	0.086	0.075	0.109	− 0.015	0.812	0.087		
7	Ventilation	0.172	0.132	0.180	0.165	0.123	0.119	0.802	7.295	0.822
	Fast-drying	0.188	0.230	0.270	0.109	0.107	0.032	0.773		
	Warming	0.257	0.160	0.178	0.038	0.162	− 0.014	0.690		
		Total common factor variance (%)							71.824	-

clothing's dimensional suitability when they thought about what made the current jacket uncomfortable. It also highlighted the need for improvements in that area.

Safety

The crew members considered safety more important when we included its subfactors (e.g., fire, fragments) in more specific expressions. The subfactors that correlated to the safety factor were ranked in the following order: fire protection, fragments, chemicals, flame retardance, and camouflage. The respondents seemed more sensitive to the word "safety" when it was associated with the subfactors specific to tracked vehicle risks, such as fires and explosions. The fact that the respondents placed "flame retardance" in the safety category rather than the material functionality category suggests that they considered it a critical feature. "Camouflage" probably had a lower correlation with safety because the tracked vehicle crew members are usually inside their vehicles during missions.

Maintenance

Maintenance also ranked higher when its subfactors were included. They were ranked in the following order of importance: friction resistance, water resistance, integrity, stain resistance, and ease of laundering. Crew members enter tracked vehicles through a narrow hatch, and protruding structures inside the vehicle create a tight, awkward workspace for operations. Moreover, the vehicles easily transfer dirt and oil to the crew members' clothing during maintenance activities. For this reason, some of the subfactors related to material functionality were also related to maintenance.

Mission suitability

Mission suitability ranked the same whether the respondents were presented with the primary category name alone or the category with the subfactors. It is noteworthy that they were interested in having adequate and easy-to-access personal storage—pockets and the like—since they operate in a confined, dark space in which finding items quickly can be problematic. Furthermore, since the crew members preferred to layer their clothing for temperature variations and wore combat vests during drills, they considered lightweight clothing important. The modifications suggested to fix the current jacket's disadvantages (e.g., bulging sleeve pockets and a bulky form that snag on the vehicle's structures) were positively correlated to mission suitability. Ease of dressing and undressing was also correlated to mission suitability since response time is critical for the crew members' missions.

Motion suitability

While the crew members considered motion suitability very important when they were presented with the simple category term, they ranked it lower when its subfactors were included. Even so, the factor loadings of the subfactors were all above 0.760, showing that they were highly correlated to motion suitability. Loading shells, one of the most physically demanding operations in the crew members' missions, requires flexibility for nearly all of the body's joints; thus, the usability of the torso joint, shoulder joint, elbow joint, and neck joint were all highly correlated to motion suitability.

Aesthetics

While aesthetics ranked low when the crew members were presented with the simple category term and its subfactors, the subfactors all had a high correlation with aesthetics (above 0.812). Although color and design are generally considered important elements in aesthetics, the tracked vehicle crew members primarily wanted the visual design to enhance their sense of belonging—a subfactor obtained from the FGI. The crew members pointed out that they were soldiers, and they wanted a clothing design that enhanced their sense of belonging, identity, and pride in being tracked vehicle crew members.

Material functionality

As with motion suitability, the crew members considered material functionality very important when they were presented with the simple category term, but they ranked it lower when its subfactors were included. Most of the respondents' seemed to equate material functionality with the clothing's overall functionality. When the subfactors were included, however, material functionality was highly correlated to ventilation, fast-drying, and warming. This was an anticipated result since the FGI showed that tracked vehicle crew sweat a lot during shell loading, one of their primary mission activities, and that the current jacket's lack of vents made them feel uncomfortable. In addition, it was cold inside the tracked vehicles during winter drills.

The above results show that the crew members ranked the factors' importance differently when they were given just the factor's category name as opposed to when the subfactors were included. However, the subfactors were grouped into seven factors obtained from the literature review, and the subfactors' importance showed higher factor loadings, meaning that the subfactors effectively explained the factors affecting protective clothing. Furthermore, a high Cronbach's α demonstrated internal consistency. Therefore, we could conclude that including the subfactors better reflected the respondents' needs than the factors alone. The crew members' priorities for the performance factors for protective clothing, as expressed with these factors and subfactors, should be considered in the development and evaluation of protective clothing.

Developing a weighting method

This study used common factor-variance percentages obtained from factor analysis as a weighting method. Factor loadings represent the size of the covariance that a subfactor has with a common factor. Common factor variances can show the percentage of covariance explained by the factor. These were all relevant concepts in this study, and it is to be noted that factor loadings were also used in a previous study (Lee & Sim, 2016). However, technically speaking, factor loadings represent the level of correlation between subfactors and a common factor, whereas common factor variances represent the explanatory power of a common factor among all common factors. Accordingly, since the importance of a common factor among all common factors for required performance in protective clothing matters in this study, we decided that calculating common factor-variance percentages, rather than the factor loadings, as used in the previous study, would better represent the factor's explanatory power. In calculating the factor weights, we converted the factors' total variance percentages into common variance percentages and standardized them so that the percentages would add up to 100%.

We conducted a factor analysis again to obtain the factor loadings for the four factors: dimensional suitability (Factor 1), mission suitability (Factor 2), motion suitability (Factor 3), and aesthetics (Factor 4) (Table 5). To develop the factors that could be used to determine the suitability of the required performance factors in developing protective clothing, we standardized and calculated the factors' percentages in the total factor loading (70.551): 37.19% for dimensional suitability, 23.89% for mission suitability, 21.38% for motion suitability, and 17.52% for aesthetics.

Developing a quantitative evaluation system

The following flow chart shows a quantitative evaluation system for subjective evaluation (Fig. 2). The evaluation score was based on the ROC reference criteria from a tracked vehicle jacket development project (Samil Spinning Co., Ltd. 2018) of at least 3 points out of 5 points, based on a 5-point Likert scale. There are only criteria for success (above; 60 out of 100) according to the reference criteria, but the criteria developed in this study further presented inadequate criteria which are capable of improvement. However, these criteria may vary depending on the objectives of the evaluation institution.

While the explanatory power of the subfactors varied in this study since the different factors had a different number of subfactors, we identified the optimal number of subfactors for explaining each factor, using factor analysis. Since the factor loading percentages were weighted, we divided the sum of the points from each factor's subfactors by the sum of the maximum points. We did this to remove any influence from the number of subfactors and to prevent the percentages from being weighted redundantly. Since this study was based on a 5-point Likert scale, we calculated the score as shown in Fig. 3, with seven subfactors for dimensional suitability (35 points), five subfactors for mission suitability (25 points), four subfactors for motion suitability (20 points), and three subfactors for *aesthetics* (15 points). Finally, we multiplied the scores calculated from E1, E2, E3, and E4 by the weights standardized from the factor loadings. We summed these weighted scores for the four factors into the total score for protective clothing evaluation (E5).

Testing a developed evaluation system

Testing the evaluation subfactors

To test the developed subfactors, we divided the respondents into a reference group (occupational soldiers) and a comparison group (enlisted soldiers) and compared

Table 5 Factor analysis on required performance factors (N = 253)

Factor	Subfactor	Component				Total common factor variance (%)	Cronbach's α	Weight out of 100
		1	2	3	4			
1	Sleeve length fit	0.846	0.059	0.185	0.085	26.244	0.926	37.19
	Bottom circumference fit	0.842	0.219	0.107	0.083			
	Cuff circumference fit	0.816	0.247	0.123	0.138			
	Collar circumference fit	0.794	0.227	0.118	0.150			
	Posterior shoulder length fit	0.790	0.091	0.178	0.178			
	Total length fit	0.765	0.231	0.189	0.082			
	Chest circumference fit	0.761	0.176	0.211	0.105			
2	Ease of storage	0.066	0.804	0.188	0.089	16.856	0.839	23.89
	Sufficient storage	0.153	0.750	0.097	0.204			
	Mission environment suitability	0.275	0.716	0.156	0.025			
	Lightness	0.245	0.685	0.200	0.038			
	Ease of dressing and undressing	0.223	0.684	0.279	0.073			
3	Torso joint usability	0.325	0.155	0.806	0.048	15.088	0.857	21.38
	Shoulder joint usability	0.171	0.362	0.792	− 0.054			
	Neck joint usability	0.150	0.114	0.781	0.132			
	Elbow joint usability	0.183	0.298	0.772	− 0.050			
4	Color usability	0.151	0.100	− 0.026	0.873	12.363	0.844	17.52
	Sense of belonging usability	0.135	0.101	0.099	0.854			
	Fancy design usability	0.180	0.101	0.004	0.819			
		Total factor loading (%)				70.551		100.00

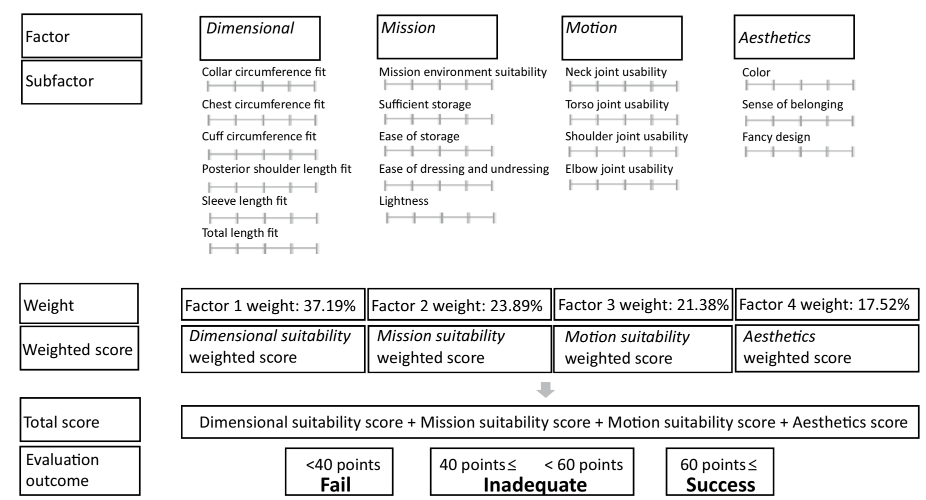

Fig. 2 Quantitative evaluation system for subjective evaluation (5-point Likert scale)

$$\textbf{\textit{Dimensional suitability}} \textbf{ score} = \frac{\sum \text{Points from subfactors}}{\text{maximum points (35)}} \times 100 \quad \text{E-1}$$

$$\textbf{\textit{Mission suitability}} \textbf{ score} = \frac{\sum \text{Points from subfactors}}{\text{maximum points (25)}} \times 100 \quad \text{E-2}$$

$$\textbf{\textit{Motion suitability}} \textbf{ score} = \frac{\sum \text{Points from subfactors}}{\text{maximum points (20)}} \times 100 \quad \text{E-3}$$

$$\textbf{\textit{Aesthetics}} \textbf{ score} = \frac{\sum \text{Points from subfactors}}{\text{maximum points (15)}} \times 100 \quad \text{E-4}$$

Total score (out of 100) = *Dimensional suitability* evaluation score × 0.3719 + *Mission suitability* evaluation score × 0.2389 + *Motion suitability* evaluation score × 0.2138 + *Aesthetics* evaluation score × 0.1752 .... E-5

Fig. 3 Calculating the total score in quantitative evaluation system

their evaluation scores for the current jacket (Table 6). We found no significant difference in the scores at the level of $p < 0.05$ between the two groups. Hence, the subfactors were proven to be universally applicable to all tracked vehicle crew members, because the scores were not affected by years of service, level of training, or other group characteristics.

Testing application of a developed evaluation system

This study incorporated the respondents' suggestions for required performance factors obtained from the FGI and the questionnaire survey, using them to develop a tracked vehicle jacket. Figure 4 shows the design of the proposed jacket in comparison to the current one. The proposed jacket is safari style, and is longer than the combat uniforms required to be worn. The number of outer pockets has been increased from three to five for sufficient storage, and the existing snap button has been changed to a zipper. In addition, the protruding pouch has been changed to an inner pocket to suit the confined duty space, and the cuffs and hem have been changed to attach with fastener tapes and stoppers. We also designed a functional sleeve pattern in which the direction of shoulder

Table 6 Results of an application on the subfactors by two groups (N = 253)

Factor	Subfactor	A	B	*t*-value	Factor	Subfactor	A	B	*t*-value
Dimensional suitability	Bottom circum. fit	3.09 (1.03)	2.94 (0.99)	− 1.12	Mission suitability	Sufficient storage	2.88 (1.07)	3.23 (0.99)	0.88
	Sleeve length fit	3.02 (1.07)	2.92 (1.03)	− 0.72		Ease of storage	2.72 (1.04)	2.97 (1.03)	1.83
	Cuff circum. fit	3.16 (0.97)	2.98 (1.02)	− 1.32		Lightness	2.93 (1.10)	2.93 (1.04)	0.03
	Collar circum. fit	3.23 (0.86)	2.95 (0.96)	− 2.30		Mission environment suitability	3.16 (0.99)	3.11 (0.93)	− 0.36
	Posterior shoulder length fit	3.20 (1.02)	2.91 (1.02)	− 2.08		Ease of dressing and undressing	3.56 (1.00)	3.33 (1.03)	− 1.61
	Total length fit	2.98 (1.06)	2.89 (1.09)	− 0.56	Motion suitability	Torso joint usability	3.19 (1.04)	2.99 (0.99)	− 1.45
	Chest circum. fit	3.07 (1.02)	2.97 (1.04)	− 0.74		Shoulder joint usability	3.01 (1.09)	2.81 (1.07)	− 1.37
Aesthetic	Color	3.20 (0.94)	3.42 (0.92)	1.76		Elbow joint usability	3.02 (1.12)	2.77 (1.07)	− 1.76
	Sense of belonging	2.99 (1.09)	3.35 (1.07)	2.48		Neck joint usability	3.20 (1.13)	2.92 (1.09)	− 1.83
	Fancy design	3.00 (1.01)	3.09 (0.95)	0.67	–				

A: Reference group; B: Comparison group; circum.: circumference

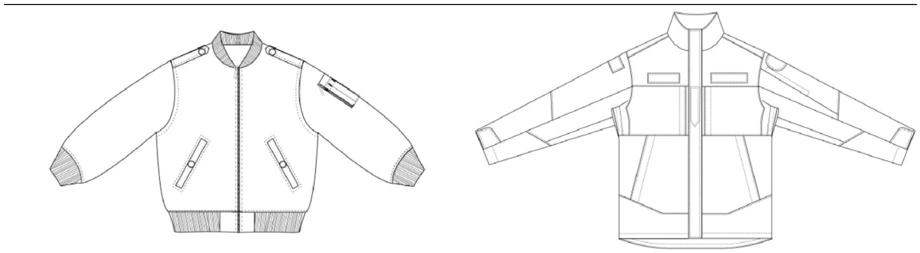

Fig. 4 Jackets for tracked vehicle crew

joint during the mission was considered. Four patches, including those depicting the Korean Army and the *Taegeukgi*, the national flag of Republic of Korea were attached to each jacket to instill a sense of belonging in those who would wear them.

To examine whether the factors developed in this study properly reflected a desirable development direction, we compared the scores of the factors for the current and the proposed jacket (Table 7). The proposed jacket scored higher on every factor than the current one at $p < 0.001$, demonstrating that the tracked vehicle crew members were more satisfied with the new design that incorporated their feedback, than with the current one. The current jacket scored 58.1, and the proposed one scored 87.3; the current one was evaluated as inadequate while the developed one was evaluated as successful. These results showed that the differences in design and pattern between the two jackets had a significant effect on the required performance factors. Hence, the developed evaluation system's applicability was verified by confirmation that the results of the developed factor scores reflected wearers' satisfaction with the proposed development direction.

Conclusions

To propose a quantitative evaluation system that could determine the success of developed protective clothing, this study analyzed the required performance factors for a tracked vehicle crew's jacket obtained from an FGI and a questionnaire survey completed by members on active duty. We developed performance factors and an evaluation system derived from quantitative factors, applied them to the development process of a tracked vehicle jacket, and tested its application. The results are summarized below.

The FGI revealed that tracked vehicle crew members had needs related to the jacket's general usability, such as pockets, vents, and zippers. They also had needs related to their unique work environment, which involves heavy missions conducted in tight quarters and dark spaces. Hence, this study extended the "ease of use" performance factor of previous studies to mission suitability. We established seven performance factors required to develop a tracked vehicle crew jacket, an item of protective clothing worn by tracked vehicle crew members: motion suitability, material functionality, dimensional suitability, mission suitability, maintenance, safety, and aesthetics.

Table 7 Comparison of scores in evaluation system for the current and proposed jackets (N = 15)

Factor		Subfactor	Current tracked vehicle jacket			Proposed tracked vehicle jacket			*t*-value
			Points	Score	Standardized score	Points	Score	Standardized score	
Dimensional suitability	1	Bottom circum. fit	2.8	55.1	20.5	4.5	85.4	31.8	− 9.5***
	2	Sleeve length fit	2.7			4.6			
	3	Cuff circum. fit	2.8			4.5			
	4	Collar circum. fit	2.6			4.2			
	5	Posterior shoulder length fit	3.0			4.5			
	6	Total length fit	3.1			4.5			
	7	Chest circum. fit	2.3			3.1			
	Subtotal		19.3			29.9			
Mission suitability	1	Sufficient storage	3.1	62.0	14.8	4.8	89.6	21.4	− 8.4***
	2	Ease of storage	2.7			4.7			
	3	Lightness	3.3			4.3			
	4	Mission environment suitability	3.3			4.4			
	5	Ease of dressing and undressing	3.1			4.2			
	Subtotal		15.5			22.4			
Motion suitability	1	Torso joint usability	3.0	57.5	12.3	4.4	86.0	18.4	− 7.0***
	2	Shoulder joint usability	2.9			4.3			
	3	Elbow joint usability	2.9			4.3			
	4	Neck joint usability	2.7			4.2			
	Subtotal		11.5			17.2			
Aesthetics	1	Color	2.9	60.0	10.5	4.7	89.8	15.7	− 8.9***
	2	Sense of belonging	3.2			4.2			
	3	Fancy design	2.9			4.6			
	Subtotal		9.0			13.5			
	Total		–	234.6	58.1	–	350.8	87.3	− 10.7***

Total evaluation score for the current tracked vehicle jacket = 55.1 × 0.3719 + 62.0 × 0.2389 + 57.5 × 0.2138 + 60.0 × 0.1752 = **58.1**

Total evaluation score for the newly developed tracked vehicle jacket = 85.4 × 0.3719 + 89.6 × 0.2389 + 86.0 × 0.2138 + 89.8 × 0.1752 = **87.3**

circum.: circumference

*** $p < 0.001$

Previous studies used the average importance of the subfactors to distinguish the factors' importance. However, there was no difference in the tracked vehicle crew members' evaluations of the importance of the subfactors in this study. Therefore, we added subfactors in our factor analysis and compared common factor variance for the importance of each common factor among all common factors. Our results revealed differences in the importance rankings: Factor 1 was dimensional suitability, Factor 2 was safety, Factor 3 was maintenance, Factor 4 was mission suitability, Factor 5 was motion suitability, Factor 6 was aesthetics, and Factor 7 was material functionality. Those results, including the subfactors, showed high factor loadings and Cronbach's α, demonstrating validity and internal consistency. Thus, we concluded that including the subfactors better reflected the respondents' needs than the factors alone, and they were used for development and evaluation, accordingly.

To develop a quantitative evaluation system, we re-conducted the factor analysis on the four factors where subjective evaluation was the main criterion for evaluation (dimensional suitability, mission suitability, motion suitability, and aesthetics). Common factor-variance percentages were proposed in the total factor loading (70.551) as a weighting method: 37.19% for dimensional suitability, 23.89% for mission suitability, 21.38% for motion suitability, and 17.52% for aesthetics. This study used these percentages as weightings and proposed an equation that calculated the evaluation score out of 100:

$$\begin{aligned}\text{Total score(out of 100)} &= \textit{Dimensional suitability evaluation score} \times 0.3719\\ &+ \textit{Mission suitability evaluation score} \times 0.2389\\ &+ \textit{Motion suitability evaluation score} \times 0.2138\\ &+ \textit{Aesthetics evaluation score} \times 0.1752\end{aligned}$$

In the results of testing the application of the developed subfactors and evaluation system, there were no significant differences in the evaluations of the current jacket by the reference group (occupational soldiers serving for at least six years) and the comparison group (enlisted soldiers), which proved the subfactors' universal application. In addition, the proposed jacket scores for each of the factors were different from those of the current jacket at $p < 0.001$, demonstrating that their differences in design and pattern affected the required performance factors significantly. Hence, the developed evaluation system's applicability was verified by confirmation that the results of the developed factor scores reflected wearers' satisfaction for the appropriate development direction.

This study's major contribution is that it incorporated wearers' subjective evaluations using a new method of weighting, It developed a comprehensive and quantitative evaluation system that has not existed before for protective clothing design. In addition, the system's application was verified by the assessment of subfactors by active-duty soldiers, and confirmed that the results of the developed factor scores reflected the appropriate development direction. However, this study focused on one wearer group (tracked vehicle crew members in Korea) and their unique work environment. Therefore, the results are not generalizable to all other soldiers with different mission environments and types. Studies should therefore be conducted with other soldiers (e.g., those with different work environments and mission types) and possibly with other clothing items (e.g., extreme cold weather uniforms and protective vests) for further verification. Furthermore, since there are many different types of protective clothing, such as chemical, fire, and medical protective clothing, it may be necessary to develop different evaluation systems in accordance with varied protective clothing's purposes. Nevertheless, the quantitative evaluation system and development process proposed in this study may be referenced and widely used since they were developed on the basis of a Likert scale, which is commonly used as a subjective sensory evaluation tool.

Declarations

Availability of data and materials
The data sets used and analyzed in this study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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Authors' Contributions
HEC and YR collected and analyzed the data and HEC have drafted the work. KC proposed and designed of the work. All authors read and approved the final manuscript.

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Ethics approval and consent to participate
This research was conducted under the approval and supervision of the Public Institutional Bioethics Committee designated by the Ministry of Health and Welfare (IRB Approval No.: P01-201908-23-007, P01-202002-13-001) regarding ethical issues including consent to participate.

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