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Usability evaluation for South Korean military backpack based on "context of use"

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Abstract

The military backpack used by the infantry imposes the greatest load on the body and, thus, is also the cause of most user complaints. This study (1) establishes a systematic development procedure for a military backpack that reflects user opinion; (2) suggests a usability questionnaire tool that can identify realistic user needs; and (3) proposes usability verification experiments that can quantitatively measure the usability of the military backpacks. The military backpack development procedure was created in accordance with user-centered design principles. The "context of use" of the military backpack was extracted from a literature review and interviews with experts and actual users. In addition, the usability questionnaire tool and usability verification experiments were devised based on the identified context of use. An analysis of the usability questionnaire answered by 100 infantry soldiers confirms that the region of pain felt by users varies on the size of the human body. Thus, it was possible to recognize the necessity of diversifying the specification of the military backpack. The usability verification experiments did not produce statistical results because only four infantry soldiers performed the pilot test, but the applicability and effectiveness of the proposed experiments could be confirmed through this pilot test. The seven proposed experiments are expected to help confirm the usability differences among different military backpacks or body sizes. The military equipment development procedure, usability evaluation tool, and usability verification experiments are expected to improve user satisfaction and military operations when applied to the development of various military supplies.

KEYWORDS

body size, context of use, load, military backpack, usability evaluation method

1 | INTRODUCTION

South Korea is still in an on-going dispute with North Korea, and due to the fact that the two countries share the same border, South Korea's Army is overwhelmingly larger than it's Navy and Air force (active personnel in Army, Navy, and Air Force are 464,000, 41,000, and 63,000, respectively).

While all South Korean male adults without any disabilities mandatorily serve in the army for about 2 years, South Korean female adults are allowed to enlist in the military by choice. Recently, under South Korean Defense Reform Plan 2.0 (2019), the Ministry of National Defense announced that the number of female enlistments will increase from 10,000 to 17,000. Therefore, figuring out ways to build better working conditions for female soldiers has been highlighted.

More than 60% of South Korean Army are infantry soldiers, and they often carry extremely heavy backpack loads and walk longer distances than most civilians (Attwells, Birrell, Hooper, & Mansfield, 2006; McCaig & Gooderson, 1986). The increasing complexity of the battlefield environment and the rapid development of advanced technologies have caused soldiers to bring more items and army systems during the operation (Dubik & Fullerton, 1987; J. Knapik, Harman, & Reynolds, 1996; Nordeen, 1986). Although it is possible to mechanically transport military equipment using aircraft or ships, military personnel must still use their physical capability when traversing through narrow and rough mountain roads. Moreover, transporting military equipment can be costly as well. Therefore, the ability of individuals to carry the military equipment system is an important consideration for military operations (Williams & Rayson, 2006).

Even though it is recommended that soldiers carry 20–40% of their body weight, given the list and quantity of military supplies that must be brought by them (Birrell, Hooper, & Haslam, 2007), they are sometimes required to use a military backpack (hereafter, MB) that is close to 100% of their body weight (Dean, 2004; J. J. Knapik & Reynolds, 2015).

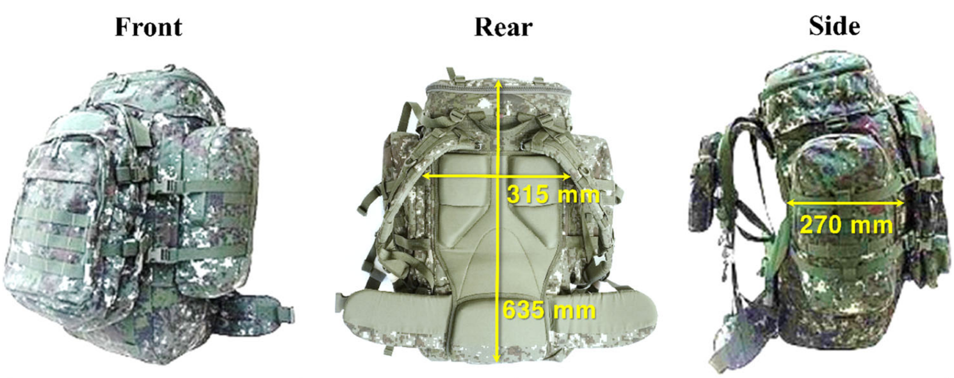
However, carrying an MB exceeding one's physical abilities can lead to musculoskeletal disorders and failure to complete one's task. For example, carrying heavy backpacks could cause a wide spectrum of pain related to musculoskeletal disorders and postural dysfunctions (Ramprasad, Alias, & Raghuveer, 2010). MBs that are too heavy or are incorrectly designed can strain muscles and joints and may cause back pain (Rai & Agarawal, 2013). In addition, heavy MBs can also cause mental strain that adds up to one's cognitive workload. This can cause impairment on one's motor performance (e.g., foot slip, prevents a part of the body from moving as intended) which can lead to a serious injury (Son, Hyun, Beck, Jung, & Park, 2019).

The South Korean Army used foreign MBs until 1972. The first domestic MB was developed in 1972, and since then, the domestic MB has been used. The South Korean MB has undergone a total of two improvement projects (1982, 2011). The current specification of South Korean MB is 315 mm wide, 635 mm long, and 270 mm thick (Figure 1). Its weight is 4.6 kg, including the built-in frame. It is modularly designed to attach an auxiliary knapsack on the back and both sides of the main backpack. However, despite two improvements, complaints from infantrymen who actually use the MB have not been abated.

As a result of the first meeting with the Ministry of National Defense and Army policymakers to carry out this study, it was assumed that there are three reasons why infantrymen are dissatisfied with the current MB.

First, it is likely that during the development process of MBs, the context of use was not considered and analyzed thoroughly. Product development should be preceded by a comprehensive understanding of who will use the product, when the product is used, and under what circumstances it is used (Maguire, 2001). A set of systems must be established to evaluate the product and identify the improvement elements from the user's perspective. Unlike an ordinary bag, MBs have special usage conditions, requiring their carriers to move a given distance within a strict time limit and with a fixed amount of military supplies. Therefore, if an MB is made without understanding the context of use, unexpected inconveniences may arise during military operations. Bevan (1995) emphasized this by arguing that the quality of use of a product is not only determined by the product itself, but also by the context of use, including particular users, specific tasks, and environment. Most existing military supplies have been developed from the point of view of designers and engineers, with a focus on ease of production and meeting minimum operational requirements (Rhie, Kim, Ahn, & Yun, 2017). However, the user's opinions and situation have not been considered.

Second, there was no process of considering different human body size characteristics for each user when manufacturing an MB. Though combat uniforms and military boots have been made in various sizes to suit the size of an individual's body, MBs have been made in one size. If a user wears a backpack that is not suitable for his or her body size, he or she may tire faster or feel unexpected pain. Zakeri, Gheibizadeh, Baraz, Nejad, and Latifi (2016) found that the use of non-standardized backpacks has a statistically significant effect on the incidence of musculoskeletal disorders. Until now, the MB has been produced with a view of "carrying it on one's shoulder." However, it is now necessary to produce MBs from the viewpoint of "wearing it according to each body size," similar to combat uniforms and military boots.



Size	Weight	Capacity	Material
315 x 635 x 270 mm	4.6 kg	99 L	Nylon

FIGURE 1 Dimension of current military backpack

Third, there was a lack of practical usability experiments to measure the usability of MBs. The efforts to improve the MB only considered the differences in terms of visual design including aspects such as size and shape, thus neglecting factors relating to its usability. Although the existing usability tests that are generally used are fairly straightforward and proven to be valuable across studies, it can still be difficult to prove that it is enough to know if the product being evaluated works normally (Gould & Lewis, 1985; Rubin & Shirk, 1996). Therefore, it is necessary to complement the existing usability test by devising verification experiments that can identify the differences in usability. Previous studies have evaluated the usability of MBs by checking changes in the gait and angle of the user's body when walking with an MB (Attwells et al., 2006), or by measuring the user's oxygen consumption and heart rate when using MBs of different weight (Beekley, Alt, Buckley, Duffey, & Crowder, 2007). However, it is difficult to identify the actual physical and cognitive workloads experienced by infantry when using MBs through such experiments.

To solve these shortcomings, we developed a user-centered MB development procedure based on the context of use and, thus, devised usability questionnaire tools and various usability verification experiments.

2 | METHOD

The MB development procedure (Figure 2) was based on the user-centered design principles presented by ISO 9241-210:2010 (2015) to fully reflect the user feedback. This study covered Phase 1 of the MB development procedure; Phase 2 and Phase 3 will be addressed in the next study based on the results of this study.

2.1 | Identifying the requirements and context of use

Figure 3 shows the process for devising the usability evaluation system for MB in this study.

To identify the organizational requirements of MB, interviews were conducted with 10 military policymakers of logistics (a major general, two colonels, three lieutenant colonels, two captains, and two commanders). They consisted of logistics officers from the Army, Navy, Marine Corps, and executives from the Ministry of National Defense. An hour-long interview resulted in extracting four representative organizational requirements for MB. In addition, with the cooperation of the Ministry of National Defense and the Army, we visited the army units and conducted a preliminary survey on 100 infantrymen, which enabled us to secure the individual user's requirements.

To investigate the context of the use of MB, we visited the Army Military Education Training Corps and conducted interviews with military experts (two majors, one captain) who have been using MBs for at least 10 years. The interviews lasted an hour, and the main interview questions were the environment for using an MB, the type of tasks performed while wearing an MB, and the inconvenience caused by the MB. Their responses became the basis for establishing the usability verification experiments.

2.2 | Development of usability evaluation questionnaire tool for MB

Usability variables were extracted from the results of the previous interviews which identified the organizational and individual user requirements and the context of use. These variables served as the basis for the development of the usability evaluation tool.

We visited the Army units to conduct a usability evaluation questionnaire, and 100 infantrymen who participated in the preliminary survey participated in usability evaluation questionnaire. The developed usability questionnaire consists of Likert scale, multiple-choice, and descriptive questions.

Beforethe statistical analysis of Likert-type questions, factor analysis was conducted to check whether there were common factors among the sub-variables affecting the satisfaction of the MB and to verify the validity of the devised usability questionnaire. The method for factor extraction is Principle Axis factoring, and the Varimax rotation was performed. The suitability of this test was subjected to the use of Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of Sphericity. If the KMO value is greater than 0.6 and Bartlett's test is large and significant ($p < .05$), factorability is considered possible (Hair, Anderson, Babin, & Black, 2010; Shehu & Mahmood, 2014). All 13 variables did not impede validity. The factor analysis yielded a KMO value of 0.746. Bartlett's test was evaluated through χ^2, indicating significance at the 0.000 level. Therefore, the data were suitable for factor analysis. Items with factor loadings (>0.3) will be accepted to represent the factor because such values are considered the threshold to meet the minimum level for interpretation of the structure (Hair et al., 2010; Sekaran & Bougie, 2003).

The multiple-choice questions were designed to identify the direction in which the body is primarily leaning during training with MBs and to distinguish specific body parts that are not well in contact with the MB. To identify the pain and fatigue caused by the MB on body parts, the local muscular workloads chart presented in The International Organization for Standardization (2004) was improved (Figure A1) and provided to users. The users were asked to select three pain and fatigue parts in order of severity, and then evaluated the scores on a 10-point scale for each part.

The descriptive questions were answered after the brainstorming to share and develop the opinions of individual users on improvements to current MBs. Brainstorming was carried out in two groups (50 each), with each session lasting approximately one hour. Participants freely shared their opinions on the causes of the current MB's inconvenience and the need for improvement and responded to descriptive questions after organizing their thoughts.

Upper body dimensions should be used as a basis for classification to identify the difference in the usability of the MB. However, due to the lack of information with regard to the respondents' sitting height

Phase	Human Centered Design Cycle (ISO 9241-210)	Military backpack development procedure	Methods	Outputs
Phase I	Understand and specify the context of use	Investigation on context of use	· Literature Review · Military Experts Interview	· Deployment to specific area - Marching on flat land - Marching in mountainous terrain - Combat zone passage - Carrying military supplies
Phase I	Specify the user and organizational requirements	Extraction of key usability elements	· Military policymakers Interview · Preliminary Survey	· Maneuverability Factor · Interaction Factor · Design characteristics Factor
Phase I		Development of usability questionnaire tool	· Contextual Analysis · Deliberation of experts	· Likert type questions · Multiple-choice questions · Descriptive questions
Phase I		Usability evaluation questionnaire for the current military backpack	· Usability questionnaire · Statistical analysis	· Influence of Variables on Usability of military backpack · Requirements for Improvement of military backpack · Difference between usability results by body size
Phase I		Development of the usability verification experiments	· Contextual Analysis · Deliberation of experts · Usability evaluation questionnaire results	· 7 usability verification experiments
Phase II	Produce design solutions	Analysis of the design parameters and body size characteristics Optimal design range proposal considering body size	· Literature Review · Statistical analysis	· Clustering physical dimensions based on body size of infantry · Mismatch equation for design variables · Improved military backpack dimension system
Phase III	Evaluate designs against user requirements	Prototyping of military backpack to comply with optimal design range considering body Size	· 3D modeling	· Different sized military backpacks made according to the improved military backpack dimension system
Phase III		Usability verification experiments on a soldier wearing the newly military backpack	· 7 experiments · Additional field test	· Improvement effects using a new military backpack suitable for body size
Phase III		Usability questionnaire evaluation for the newly developed military backpack	· Usability Evaluation · Statistical analysis	· Changes in user's satisfaction with military backpack to fit body size

FIGURE 2 Military backpack development procedure

and torso length, this study classified the participants according to their stature. Through *K*-means clustering analysis, respondents were classified into three clusters, consisting of 13 members in the first cluster with a small stature, 54 in the second cluster with medium stature, and 33 in the third cluster with a large stature (Table 1). In addition, the one-way analysis of variance (ANOVA) was used to identify differences between clusters with different body size. All analyses were performed using SPSS version 25.

2.3 | Designing the usability verification experiments

The usability verification experiments for MBs were designed based on the context of use and the results of the usability questionnaire, and these experiments were supplemented through the deliberation of experts from three different fields (four ergonomists, three athletic scholars, and three mechanical engineers). Deliberation of

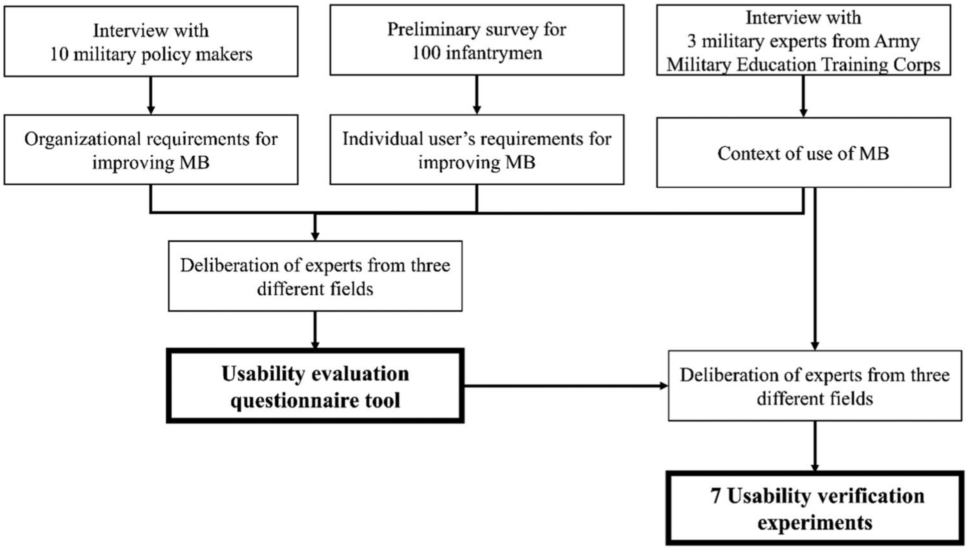


FIGURE 3 Process for devising usability evaluation system for military backpack

TABLE 1 *K*-means clustering by user's stature

Cluster	Number of samples	Minimum (cm)	Maximum (cm)	Final cluster center (cm)
1	13	159	168	164.5
2	54	169	176	172.4
3	33	177	189	180.2

experts was conducted a total of four times, twice before the usability questionnaire tool development, and the two used before the usability verification experiments design.

Many useful ideas for designing usability verification experiments were obtained by linking the various experimental methods of the existing study with the various contexts of use of the MB collected in the previous procedure. In this study, after connecting various experiments that could be performed in relation to the identified detailed tasks (Figure 4), the types of final experiments were determined through the deliberation of experts.

The electromyogram (EMG) measurement experiment was designed based on the “Marching on flat land” and “Marching in mountainous terrain” contexts of use. Because the EMG measurement is a very good way to measure the degree of physical fatigue that occur in various parts of the body when using the MB, similar experiments have been performed in previous studies (De Looze, Bosch, Krause, Stadler & O'Sullivan, 2016; J. Knapik et al., 1996; Quesada, Mengelkoch, Hale, & Simon, 2000). Based on the results of contextual analysis and usability questionnaire, five pairs of muscle parts (erector spinae, rectus femoris, biceps femoris, tibialis anterior, gastrocnemius) which were found to be painful were selected for EMG measurement.

The movement interference measurement experiment was designed based on the “Marching in mountainous terrain,” “Combat Zone passage,” and “Carrying military supplies” contexts of use. When wearing an MB, the movement of the upper body area is inevitably restricted, and the degree of restriction of movement may vary depending on the difference in the body size of the user and the MB's design characteristics. In this experiment, participants performed six upper body movements (flexion, extension, horizontal flexion, horizontal extension, abduction, and adduction; Figure 5), and the maximum possible angles of each movement were measured. The larger maximum possible angles of each movement, the more comfortable the user's activity.

The proximity measurement experiment was designed based on the “Marching on flat land,” “Marching in mountainous terrain,” and “Combat Zone passage” contexts of use. One of the main requirements of users extracted through a preliminary survey is to increase the closeness between the MB and the body. As the distance between the military backpack and the body becomes farther away, the load of the MB may cause the user more physical fatigue in dynamic tasks such as power rush. However, this experiment does not directly measure the distance between the MB and the user's body. Instead, it identifies the extent of unity between the user's body and the MB. Therefore, this experiment was designed based on the running context, where this unity is often lacking. We measured the position variation and time differences between the body and the MB in three axes directions (yawing, pitching, and rolling). If these are large, then the MB highly deviates away from the body and shakes too much. However, if they are small, the MB becomes closer to the user's body, indicating better unity.

The shooting capability measurement experiment was designed based on the “Combat Zone passage” context of use. Most tasks using MBs are maneuvering tasks, such as walking or running. However, battles can occur at any time, even when users are physically tired. Therefore, even when wearing an MB, shooting capability is a very important requirement for infantrymen. The rifle, which is used by most infantry soldiers, was used as an experimental

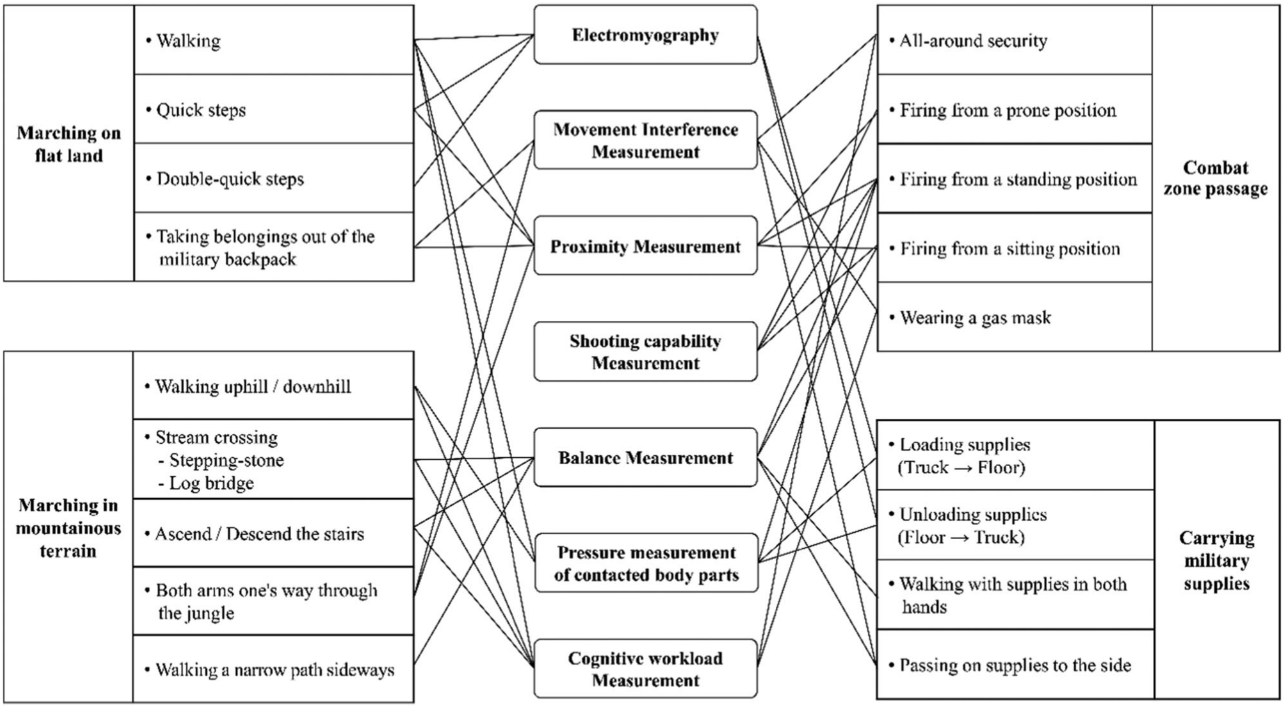


FIGURE 4 "Context of use of military backpack" against possible experiments

tool. Users did not actually shoot a rifle, because we only need to gauge the accuracy of the target aim. Hence, a laser pointer was installed on the front sight of the rifle to check the user's target sighting condition in real time. To stimulate fatigue or breathlessness while using an MB, the participants were required to walk on a treadmill for 30 min while wearing the MB before measuring their shooting ability. Then, the participants were asked to take a knee, which is a common shooting position, on a force plate 5 m away from the target (Figure 6). Given with a signal, the users took aim at the center of the target for 5 s. During the aim, the changes in the users' center of pressure(COP) and the state of the laser reflected on the target were observed. The range of movement of the laser pointer on the target can be used to evaluate accuracy and precision, which form the evaluation scale of the shooting capability. If the range of the laser pointer moving on the target is narrow, but far from the center of the target, the precision is high, but the accuracy is low. In contrast, if the range of movement of the laser pointer moving on the target is large, but close to the center of the target, the precision is low, but the accuracy is high.

The balance measurement experiment was designed based on the "Marching in mountainous terrain," "Combat Zone passage," and "Carrying military supplies" contexts of use. In the previous studies, it

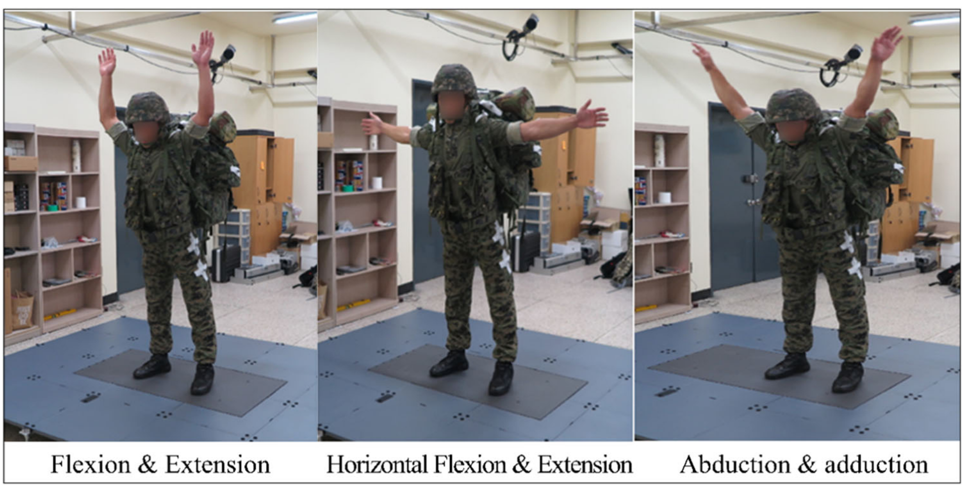


FIGURE 5 Movement interference measurement

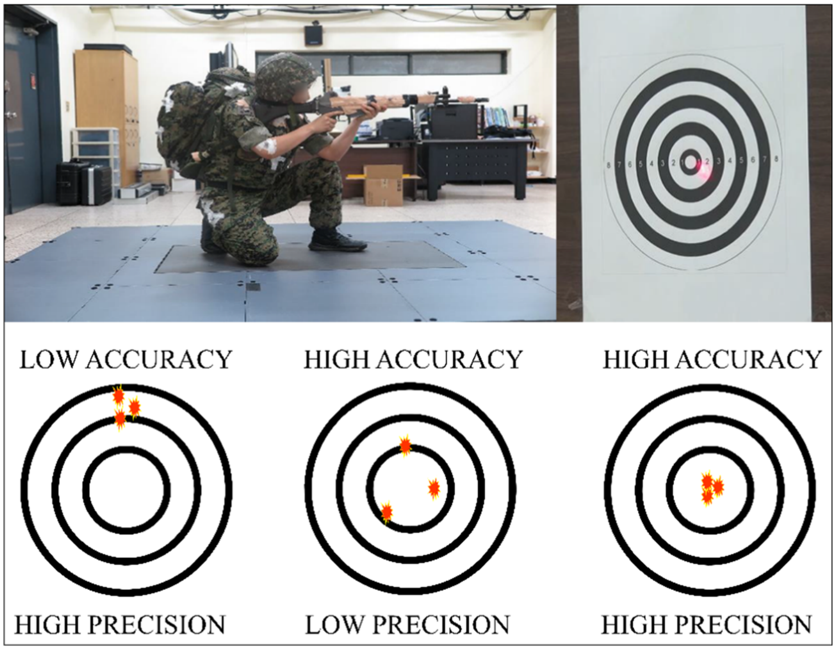


FIGURE 6 Shooting capability measurement

was difficult to find an experiment to measure the user's balance while wearing an MB. However, this experiment is very necessary considering that there may be tasks such as crossing a log bridge or passing a narrow path with an MB due to the topographical characteristics of South Korea with many mountainous terrains. In this experiment, the user wears an MB and measures the degree by which the COP changes when standing on the force plate for a certain period. It can be interpreted that balancing is difficult when the COP change is large and that balancing is relatively easy when the COP change is small.

The pressure measurement experiment is related to all contexts of wearing an MB. As a result of the usability questionnaire, the most painful body part was identified as the musculoskeletal system of the shoulder and lumbar. Although EMG measurement is generally the most obvious way to measure the muscle fatigue, EMG measurement is unfit because the shoulder and lumbar parts are directly in contact with the military backpack and body. Therefore, the pressure measurement method was used to measure the fatigue in these body parts, and we checked the degree and distribution of loads on them. It can be interpreted that the higher the pressure imposed on a specific body part and the narrower the distribution range of pressure, the more severe the pain may occur.

The cognitive workload measurement experiment was designed based on the "Marching on flat land," "Marching in mountainous terrain," and "Combat Zone passage" contexts of use. As described in the introduction section, when the physical burden is increased, the cognitive workload can be raised as well. In addition, from the interview with the three military experts, it was mentioned that physical fatigue caused by heavy MBs can also cause mental fatigue and deteriorated concentration levels. Therefore, this experiment was designed to measure different types of cognitive workloads, such as visuo-spatial memory, phonological memory, and computational, by applying experiments performed in previous studies. First, the visuo-spatial memory measurement test was designed based on the Corsi–Block task (Corsi, 1973). In this test, 7 of 12 blocks displayed on the screen in front of the user flashed in sequence at random positions. After the blocks had finished flashing, the user was asked to respond to the sequence and the position of the flashed blocks. Second, the phonological memory measurement test is based on the Digit Span Task (Wechsler, 1939). This test is designed to allow users to listen to seven of the numbers from 0 to 9, or seven of the alphabets from A to Z, in random order through voice, and to recite in the order by memory. Finally, the computational ability measurement test was designed with ideas from Jurden (1995), and the user calculated the simple arithmetic consisting of three double digits mentally before responding. The experiment was conducted after a user wearing an MB walked on a treadmill for 30 minutes.

The pilot tests conducted to confirm the applicability and effectiveness of each of the proposed experiments were supported by the Army and involved four infantrymen (two men and two women). The current Korean MB and the U.S. Marine Corps MB (hear after, FILBE) were used as samples for testing. The specification of FILBE is 320 mm wide, 610 mm long, and 380 mm thick. FILBE is an external frame-structured backpack weighing 4.2 kg. One month after the subjects participated in the pilot test with the current Korean MB, they performed the same test but with the FILBE, whereby the weights of both MBs were equivalent (35 kg for men and 20 kg for women). To compare the difference in usability of both MBs, the measured data of FILBE was presented in percentage with respect to those of current Korean MB.

3 | RESULTS

3.1 | Requirements and context of use

3.1.1 | Organizational and individual user's requirements

Based on the two interviews with 10 military policymakers to collect the Army's organizational requirements, we found four requirements for the MBs: maneuverability, survivability, sustainability, and movability. Maneuverability refers to the ease of moving around, such as walking or running with the MB, and survivability means that the user's life should not come under threat when carrying out a mission while wearing an MB. Sustainability means the MBs should be continuously available until the mission is completed, whereas movability means that there should be no obstruction of motion for combat during a mission that requires wearing the MB.

A preliminary survey of 100 infantrymen (average age 24.4 years; *SD*: ±4.2, average stature 173.9 cm; *SD*: ±5.8) was conducted to collect user's requirements, and the average weight of the MBs carried by the respondents was 35 kg, with some carrying 54 kg MBs depending on the characteristics and positions of the unit. According to preliminary survey, 58 out of 100 users answered that the MB is not closely attached to the body, and they wanted to improve the MB to increase the closeness between the MB and the body. Also, they wanted to prevent the load from concentrating on specific body parts.

3.1.2 | Context of use of MBs

Based on interviews with military experts, the context of use of MBs could be divided into four categories: (1) Marching on flat land, (2) Marching on mountainous terrain, (3) Combat zone passage, and (4) Carrying military supplies. In addition, the main tasks and human movements performed by the context of use are as follows.

First, the context of marching on flat land included tasks of walking at 4 km/h, running lightly at 7 km/h, and taking out necessary items such as raincoats, goggles, and hot packs from the MB while marching. The analysis confirmed the importance of a biological electric experiment to measure changes in muscle fatigue, an experiment to measure changes of proximity between MB and user's body, and an experiment to measure the range of motion of the upper body.

Second, the context of marching on mountainous terrain included tasks of climbing up and down the slope or stairs, crossing the stream using a stepping-stone or a log bridge, passing through the jungle, and walking sideways on a cliff or narrow path. The analysis confirmed the need to design experiments that measure the balance required to cross streams or narrow roads, including a biological electric experiment. Because large upper body movements are required when passing through the jungle, an experiment to measure the range of motion of the upper body should be performed. It should include an experiment to measure changes in proximity between the MB and user's body in the sloped terrain.

Third, the context of combat zone passage included tasks of sprinting while wearing an MB, all-around security with a rifle, shooting in various stances, and wearing a gas mask. The analysis found that experiments should be conducted to measure the range of motion of the upper body because considerable upper body movement is required when tasked with all-around security or wearing the gas mask. The experiments should be conducted to check whether the shooting ability is different when wearing an MB. It is necessary to check whether there is a change in proximity between the MB and user's body when the body moves suddenly, such as running at full speed.

Fourth, the context of carrying military supplies included tasks of unloading supplies from truck to floor, loading supplies from floor to truck, walking with supplies in both arms, and relaying supplies to fellow soldiers next to them. The analysis confirmed the need for experiments to measure the biomechanical changes that occur when lifting and lowering supplies, and experiments to measure the change of closeness between the MB and body and the change of body balance during transportation work.

3.2 | Usability evaluation questionnaire tool

The usability evaluation questionnaire involved 100 infantrymen who participated in the preliminary survey, and the 13 variables of the usability questionnaire extracted by reflecting user's requirements and organizational requirements are as follows; load, fatigue, pain, balance, closeness, size suitability, color and pattern congruity, emergency release device completeness, durability, wearing difficulty, downhill march limit, flat march limit, uphill march limit.

3.2.1 | Functional evaluation questions

Table 2 shows the result of factor analysis for usability variables: All the items were loaded onto a single factor with eigenvalue greater than 1.0. The single factor extracted 54.781% of the total variance explained, and the variables were classified into three factors.

The first factor included six items, all of which have commonality of “interaction” that occurs when the user wears an MB. The second factor included four items, all of which were caused by the “design characteristic” of the material or accessories of an MB. The third factor includes three items, all of which have the common point of wearing and maneuvering an MB.

The reliability analysis found that all the study variables possess an acceptable level of internal consistency; Cronbach's α (interaction = 0.822, maneuverability = .684, design characteristics = 0.621). All the variables met the minimum threshold (over 0.6) as recommended by Hair et al. (2010), and there are no usability questions that impede reliability, so we conducted the analysis without removing any questions.

TABLE 2 Factor analysis results for usability variables

Item	Factors 1	2	3
Load Lv.	0.812		
Fatigue Lv.	0.748		
Pain Lv.	0.736		
Imbalance Lv.	0.682		
Weak closeness Lv.	0.658		
Size unsuitability Lv.	0.636		
Color and pattern incongruity Lv.		0.728	
ERD incompleteness Lv.		0.666	
Weak durability Lv.		0.644	
Wearing difficulty Lv.		0.629	
Downhill march limit Lv.			0.814
Flat march limit Lv.			0.807
Uphill march limit Lv.			0.632
Eigenvalue	3.274	1.972	1.875
% of common variance	25.185	15.172	14.424
Cumulative %	25.185	40.357	54.781
KMO = .746, Bartlett's χ^2 = 374.459(ρ < .001)			

Note: Kaiser–Meyer–Olkin = 0.746; Bartlett's χ^2 = 374.459 (ρ < 0.001).
Abbreviation: ERD, emergency release device.

The results of one-way ANOVA by clusters for usability variables are shown in Table 3.

All the subvariables of the interaction factor were found to have significant differences. The results of Scheffe's posthoc analysis showed that the load, pain, fatigue, imbalance, and weak closeness levels were higher in the first cluster than in the second or third cluster. Also, all the sub-variables of the maneuverability factor were also found to have significant differences. Scheffe's posthoc analysis showed that, in the cases of flat march limit level and uphill march limit level, the first cluster was higher than second cluster or third cluster, whereas the third cluster were higher than the first cluster or second cluster in the case of downhill march limit level. In contrast, all the subvariables of the design characteristics were found to have no significant difference by body size.

3.2.2 | Physical evaluation questions

The analysis of the responses to the multiple-choice questions showed that 85 of 100 users answered that their bodies were tilted "backward" by the MB. Moreover, 52 out of 100 users answered that the "back" did not come in full contact with the MB, whereas 34 users answered "lumbar." The results of the users' responses to these two questions did not vary depending on body size. Thus, excessive back deflection and lack of proper closeness to the back and lumbar are serious problems causing discomfort irrespective of body size.

In addition, it was found that the fatigue and pain parts of the musculoskeletal system were almost identical. That is, fatigue may have developed into pain while using the MB. Eight infantry soldiers gave only pain priority without evaluating pain scores. Therefore, only 92 pain scores, excluding missing values, were used in the analysis. Equation (1) expresses the degree of pain imposed on particular muscles and joints based on the pain score given by the users of each cluster.

$$\lambda_{ik} = \frac{1}{n_i}\sum_{j=1}^{n} x_{jk}. \tag{1}$$

In Equation (1), λ_{ik} is the pain score of part k felt by the i cluster's users; n_i is the number of users in the i cluster; and χ_{jk} is the pain score evaluated for the k part by the jth user of i cluster.

Figure 7 is the "Body parts pain chart" for 33 muscle parts and 14 joints produced using Equation (1), and it also includes the pain scores of five areas that users in each cluster reported were most painful. The results of the analysis for the major body parts are presented in Table 4.

Users of all clusters responded that pain in the left and right trapezius (16,17) was the greatest compared with other body parts. Although significant differences between clusters cannot be identified, it can be interpreted that the load of the MB was excessively concentrated on the left and right trapezius through the shoulder strap.

In addition, the first cluster's users were found to have severe pain in the gluteus maximus (28,29), where the waist pad contacted, whereas the third cluster's users were found to have severe pain in the erector spinae (26,27). These parts had significant differences in pain scores among the clusters. Duncan's posthoc analysis showed that the pain score of the gluteus maximus (28,29) was higher in the first cluster than in the second or third clusters, whereas the pain score of the erector spinae (26,27) was higher in the third cluster than in the first or second clusters.

The pain in the rectus femoris (12, 13) and the tibialis anterior (14, 15) of the first cluster's users is more severe. These parts also showed significant differences in pain scores among the clusters. Duncan's posthoc analysis showed that the pain scores of the rectus femoris (12,13) and the tibialis anterior (14, 15) were higher in the first cluster than in the second or third clusters.

Although there was no significant difference among clusters, users of all clusters felt severe pain in the cervical vertebra (K), lumbar vertebra (M), sacrum (N), and knee joint (G, H) compared with other parts when using the current MB.

3.2.3 | Empirical evaluation questions

Results from the descriptive questions yielded 230 opinions regarding the components of various military equipment, such as

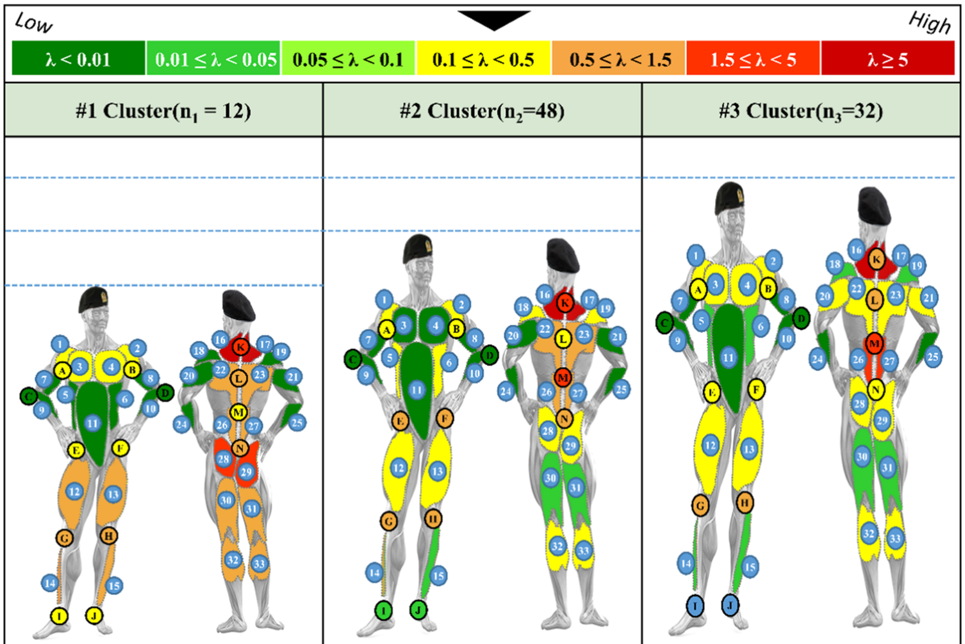
TABLE 3 One-way analysis of variance results by user clusters for usability variables

Dependent variables		Cluster	Mean	SD	F	p	Scheffe
Interaction factors	Load Lv.	1(a)	6.08	0.760	14.279***	.000	b, c < a
		2(b)	4.72	0.878			
		3(c)	4.73	0.839			
	Pain Lv.	1(a)	6.15	0.801	6.581**	.002	b, c < a
		2(b)	5.24	0.751			
		3(c)	5.30	0.951			
	Fatigue Lv.	1(a)	5.69	0.630	8.604***	.000	b, c < a
		2(b)	4.72	0.712			
		3(c)	5.12	0.960			
	Imbalance Lv.	1(a)	5.62	1.044	5.163**	.007	b, c < a
		2(b)	4.69	0.843			
		3(c)	4.82	1.044			
	Weak closeness Lv.	1(a)	5.85	0.689	8.563***	.000	b, c < a
		2(b)	4.69	0.928			
		3(c)	5.09	1.011			
	Size unsuitability Lv.	1(a)	5.46	0.877	22.698***	.000	b < a, c
		2(b)	3.81	0.913			
		3(c)	4.88	1.023			
Maneuverability factors	Flat march limit Lv.	1(a)	4.85	0.689	3.303*	.041	b, c < a
		2(b)	4.28	0.763			
		3(c)	4.24	0.792			
	Downhill march limit Lv	1(a)	5.00	0.816	8.227**	.001	a, b < c
		2(b)	4.94	0.811			
		3(c)	5.67	0.854			
	Uphill march limit Lv	1(a)	6.23	0.725	10.358***	.000	b, c < a
		2(b)	5.33	0.824			
		3(c)	5.06	0.747			
Design characteristics factors	Weak durability Lv.	1(a)	4.08	1.256	1.395	.253	–
		2(b)	4.06	1.753			
		3(c)	4.27	1.701			
	Color and pattern incongruity Lv.	1(a)	3.00	1.414	0.178	.837	–
		2(b)	3.24	1.359			
		3(c)	3.64	1.245			
	Wearing difficulty Lv.	1(a)	4.38	1.121	0.088	.915	–
		2(b)	4.56	1.449			
		3(c)	4.58	1.146			
	ERD incompleteness Lv.	1(a)	4.85	1.345	0.106	.899	–
		2(b)	4.63	1.773			
		3(c)	4.70	1.667			

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

MBs, combat vests, military boots, and combat uniforms. More than 30% of them were opinions related to the improvement of MBs. The main inconveniences and improvement requirements of the current MB, which are caused by differences in body size, are as follows.

First, on the length of the back plate of the MB, the first cluster's users responded that the waist pads were positioned lower than their sacrum because the length of the back plate is relatively longer than their back length. Further, the buckles of the waistband are constantly in contact with the upper thigh when walking, causing limited maneuvering. The third cluster's users responded that, because the length of the back plate is shorter than their back length, the waist pad is positioned above their lumbar. When they wear the current MB over a combat vest, interference occurs between the waistband buckle and the items stored inside the combat vest.



PARTS(k)	Point(λ_{1k})	PARTS(k)	Point(λ_{2k})	PARTS(k)	Point(λ_{3k})
16,17	6.25	16,17	5.21	16,17	5.00
28,29	1.75	M	1.65	26,27	2.48
K	1.67	K	1.58	M	1.97
12,13	1.41	26,27	1.31	G,H	1.03
N	1.33	N	0.93	K	0.78

FIGURE 7 Body parts pain chart by user clusters

Second, users with narrow shoulders responded that the gap between both shoulder straps of current MB is too large, so shoulder straps can easily flow out of the shoulder. On the contrary, users with wide shoulders responded that the shoulder straps were close to the neck, causing difficulty in breathing, as well as excessive pain in the trapezius.

Finally, the respondents commonly demanded improvements in the MB regarding better contact when wearing the MB. That is, because users cannot feel a sense of unity between their own movement and the movement of their MB, they consume more energy while using their MB. This also results in greater fatigue and pain.

3.3 | Usability verification experiments

This section describes the concepts and some outcomes for each experiment, and the experimental procedures and detailed data will be included in the follow-up study.

3.3.1 | EMG measurement

Pilot tests showed that muscle fatigue levels during the use of the FILBE are only about 33.3% of the fatigue levels in the current Korean MB. This means that there is less muscle fatigue when wearing the FILBE.

3.3.2 | Movement interference measurement

Pilot tests showed that the movement interference levels while using FILBE are about 92.5% of the current Korean MB. This means that the range of motion can be wider when wearing the FILBE.

3.3.3 | Proximity measurement

Pilot tests showed that the proximity levels in the use of the FILBE are about 126.7% of the current Korean MB. This means that the users felt that the FILBE were closer to their bodies compared with the Korean MB.

3.3.4 | Shooting capability measurement

Pilot tests showed that the shooting capability in the use of the FILBE are about 107.5% compared with the current Korean MB. This means that the FILBE has better accuracy and precision support.

3.3.5 | Balance measurement

Pilot tests revealed that balance levels while using FILBE are about 132.7% of the balance levels of the current Korean MB. This means

TABLE 4 One-way analysis of variance results by user clusters for pain scores of main body parts

Body parts	Cluster	Mean	*SD*	*F*	*p*	Duncan
Left and right rectus femoris (12,13)	1(a)	1.42	3.315	3.658*	.030	b, c < a
	2(b)	0.15	0.772			
	3(c)	0.41	1.132			
Left and right tibialis anterior (14,15)	1(a)	1.33	3.114	6.305**	.003	b, c < a
	2(b)	0.04	0.289			
	3(c)	0.09	0.530			
Left and right trapezius (16,17)	1(a)	6.25	3.251	0.599	.551	–
	2(b)	5.21	3.389			
	3(c)	5.00	3.529			
Left and right erector spinae (26,27)	1(a)	0.92	2.151	3.124*	.049	a, b < c
	2(b)	1.31	2.064			
	3(c)	2.47	2.688			
Left and right gluteus maximus (28,29)	1(a)	1.75	3.251	5.494**	.006	b, c < a
	2(b)	0.31	1.095			
	3(c)	0.19	0.738			
Left and right knee joint(G, H)	1(a)	0.58	2.021	0.272	.762	–
	2(b)	0.79	1.738			
	3(c)	1.03	2.207			
Cervical vertebra (K)	1(a)	1.67	3.085	0.945	.392	–
	2(b)	1.58	3.024			
	3(c)	0.78	2.028			
Lumbar vertebra (M)	1(a)	0.33	1.155	1.558	.216	–
	2(b)	1.65	2.740			
	3(c)	1.97	3.157			
Sacrum (N)	1(a)	1.25	2.989	0.923	.401	–
	2(b)	0.94	1.951			
	3(c)	0.47	1.295			

*$p < 0.05$.
**$p < 0.01$.

that it is quite easier to maintain one's balance when wearing the FILBE.

3.3.6 | Pressure measurement

Pilot tests showed that the current Korean MB dispersed 39% of the total load from both shoulder to lumbar, while FILBE dispersed 44%. This means that there may be lesser shoulder pain when wearing FILBE.

3.3.7 | Cognitive workload measurement

Pilot tests showed that cognitive workload levels in the use of the FILBE are about 90.9% of the current Korean MB. This means that FILBE requires a little less cognitive workload compared with the current Korean MB.

4 | DISCUSSION

4.1 | Requirements and context of use

Interviews with military policymakers and preliminary survey for infantrymen to confirm organizational and individual requirements revealed that the Army's organizational requirements were rather abstract, while those of individual users were specific and realistic. These responses confirm that the Army's organizational requirements are to make an MB that can achieve operational goals, whereas the actual user's needs are to make an MB that can complete the mission in consideration of their physical condition. Actually, the weight of current MB was heavier than the weight recommended in previous studies, given that the respondents' average body weight was 70.9 kg. Therefore, the majority of respondents (72 of 100) demanded that the ergonomic improvement of current MB design to reduce its excessive weight.

In addition, this study has great significance in that it reflects various context of use of MB in usability measurements. While previous studies could measure the usability of the MB only at a physical level, this study could more practically measure usability by devising a variety of experiments that could identify users' physical workloads as well as cognitive workloads based on context of use and detailed tasks.

4.2 | Analysis of usability questionnaire results

Results from the factor analysis (Section 3.2.1) showed significant differences in subvariables within the interaction and maneuverability factors across clusters. However, subvariables within the design characteristics factor yielded nonsignificant results. Possible explanations are as follows.

First, it is assumed that the reason why the load, pain, fatigue, imbalance, and weak closeness levels were higher in the first cluster than in the second or third cluster is that the participants from the first cluster generally have a smaller frame, thus, lesser muscle mass. Moreover, based on the result that the size unsuitability level was lowest in the second cluster, it can be interpreted that the specification of the current MB is more suitable for the body size of the second cluster. Therefore, additional MBs with different specifications that are suitable for the body size of users from the first and third cluster are needed.

Second, it is assumed that the reason why users in the third cluster, who are most advantageous in terms of muscle mass and physique, were more restricted compared with users from different clusters in downhill maneuvering is that their body's center of gravity is relatively higher. By the principle of leverage, in case of downhill maneuvers, the higher the body's center of gravity, the easier the body will lean forward. The more the body will lean forward, the greater the force it takes to maintain balance. Hence, users in the third cluster found greater difficulty in maneuvering downhill than users from other clusters. On the same principle, users of the first cluster are more likely to feel the weight of an MB pulling the body backward than other clusters during uphill or flat maneuvers because the body's center of gravity is relatively low. This makes the task more difficult compared with users from different cluster.

Third, it is assumed that all the subvariables of design characteristics did not have any significant differences across clusters because the evaluation of appropriateness for durability, wearability, completeness of emergency release device, and color and pattern are more likely to be determined by individual preference rather than body size.

Results from the physical evaluation questions (Section 3.2.2) revealed that regardless of body size, users reported that they have experienced the highest pain in the trapezius muscle. To disperse the excessive load imposed vertically on the left and right trapezius, the shoulder strap should be widened, so that the contact area can be expanded and the load can be dispersed to the back and lumbar parts (Harman, Frykman, Pandorf, Tharion, & Mello, 1999).

Furthermore, it was also found that there are several pain parts that yielded significant differences in the degree of pain by cluster. It was identified that users from the first and third clusters experience severe pain in the areas of the body that are in contact with the waist pad. These results are consistent with the experts' opinion—that is, the abnormal contact position of the waist pad may cause unexpected pain. Therefore, the bottom of the MB should be designed in such a way that it would rest in the curve of one's lower back, so that the load of the backpack can be distributed to the proper position of the body (Lucas, 2011).

Moreover, it is assumed that the reason why the users from the first cluster feel pain in lower body parts more severely than the others is that the body's center of gravity of the users from the first cluster is lower, resulting in relatively greater use of lower body muscles during maneuvering. Liu (2007) proved through experiments that the position of the center of gravity can significantly affect the user's ability for physical activities, such as changes in the mean respiratory frequency, mean oxygen consumption, and muscle activity.

Besides that, representative complaints identified through the empirical evaluation (Section 3.2.3.) were related to the back plate, shoulder straps, and the proximity. Previous studies revealed how the non-standard size of backpack can cause unexpected musculoskeletal disorders (Zakeri et al., 2016), and nonergonomic backpacks that are not suitable for a user's body size may have covert and overt consequences, including hyperlordosis, lateral deviation of the spine, gait pattern changes, the occurrence of cardiovascular changes (such as heart rate, systolic and diastolic blood pressure), respiratory problems (such as the number of breaths per minute and ventilation of pulmonary volumes), and metabolic problems (Daneshmandi, Rahmani-Nia, & Hosseini, 2008; Hong, Li, Wong, & Robinson, 2000; Motmans, Tomlow, & Vissers, 2006). With that, since the South Korean MB is produced in a single specification, users who do not fit the size of MBs can experience various disorders mentioned in previous studies, and the usability satisfaction of users with different human body sizes may be different.

4.3 | Consideration of usability verification experiments

Results from the pilot tests of the usability verification experiments showed that all users performed better with FILBE than with the current Korean MB. In addition, after further inquiries, the users stated that they felt that FILBE were closer to their backs than the current Korean MB.

Although the same participants participated in the same experiment under the same experimental conditions, the reason for this difference is assumed to be due to the difference between the specifications and the frame structure of the two MBs.

From the pilot test results, it can be seen that FILBE, which has an external frame-structure, is better in terms of usability than the current Korean MB, which has built-in frame-structure. Thus, we are planning to make a new MB with an external frame-structure. Moreover, the specification of the new MB will be derived based on the South Korean body size characteristics. For future studies, we will conduct the usability verification experiments proposed in this study using the newly manufactured MB and compare the differences in usability with existing MBs.

4.4 | Design implications

The implications for the MB design identified through user feedback are as follows.

First, to solve the problem related to the length of the back plate, it is necessary to design a variety of back plate lengths or allow the waist pad to be positioned according to the user's lumbar position. Of course, in the future, a study should be conducted on the number of steps required to make the length of the back plate and the sizes to set for each stage.

Second, a device should be designed to adjust the gap between the shoulder straps according to the user's shoulder width. Adjusting the length of the chest strap can help adjust the gap between the shoulder straps, but too tight can cause difficulty breathing. Therefore, it is necessary to devise a device to adjust the distance between both shoulder straps, or to improve the width of the shoulder strap itself considering the shoulder length of the users.

Third, to improve the proximity between the MB and the user's body, it is change to an external frame-structured backpack. As confirmed in the usability verification experiments, the built-in frame attached to the current MB makes it difficult for the MB to lie closer to the body. Therefore, it is necessary to take the frame out like FILBE so that it can get closer to user's back.

5 | CONCLUSION

In this study, a systematic MB development procedure was proposed based on the context of use. According to the proposed procedure, a usability evaluation questionnaire tool was developed to collect the substantive needs of infantry soldiers for the current MB. Seven usability verification experiments were devised to quantitatively measure the usability.

The usability questionnaire revealed a statistically significant difference in the regions of pain felt by the user as well as the main usability factors of the MB according to the size of the human body. Thus, we find that it is necessary to design areas of the backpack that come into direct contact with the body, such as the back plate of an MB, with respect to the size of the user's body. The usability verification experiments proposed in this study consist of not only existing experiments, but also modified experiments. If a new MB is developed considering the user's body size characteristics, these experiments can be used to compare the difference in improvement between the new and existing MBs.

However, this study has certain limitations. The user's stature data were used to classify the users into three clusters. Future studies should consider the actual measurement data on the upper body to confirm more accurate usability differences. Furthermore, the number of pilot test participants in the present study was too small to obtain statistically significant evidence for the proposed usability verification experiments. Further studies will require these usability verification experiments to be conducted on more participants with varying body sizes, thereby ensuring statistical evidence to demonstrate differences in usability by body size characteristics.

Finally, we are planning to conduct additional research that will cover the process of developing an optimal MB dimension system that reflects South Korean body size based on the results of this study. The results from comparing the usability difference between the current and improved MBs manufactured according to the optimal MB dimension system will be included. If the methodology and results presented in this study are applied to other military supplies, we expect greater improvements in user satisfaction and military operations.

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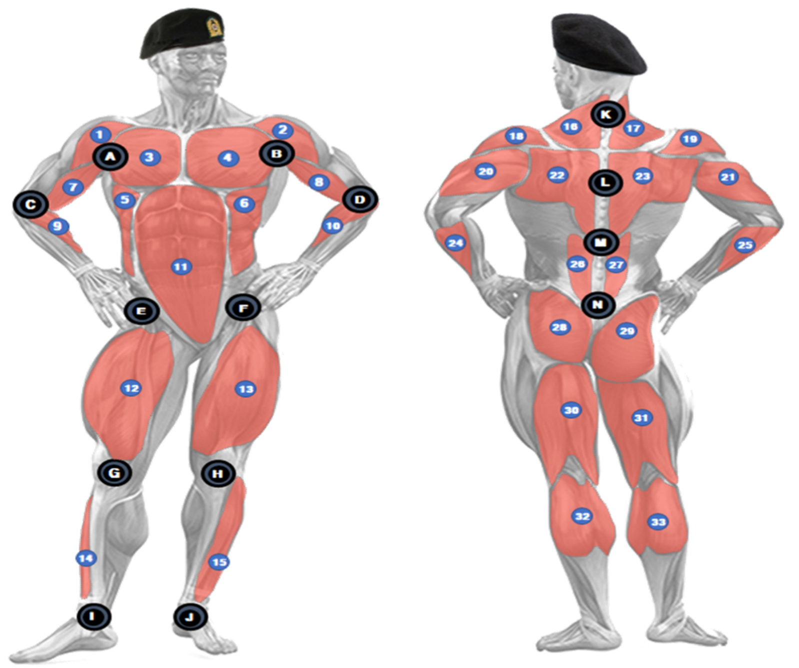
APPENDIX A



1	Right Deltoid	17	Right trapezius	33	Right gastrocnemius
2	Left Deltoid	18	Left supraspinatus	A	Right shoulder joint
3	Right pectoralis major	19	Right supraspinatus	B	Left shoulder joint
4	Left pectoralis major	20	Left triceps brachii	C	Right elbow joint
5	Right external oblique	21	Right triceps brachii	D	Left elbow joint
6	Left external oblique	22	Left rhomboideus	E	Right hip joint
7	Right biceps brachii	23	Right rhomboideus	F	Left hip joint
8	Left biceps brachii	24	Left flexor carpi ulnaris	G	Right knee joint
9	Right flexor carpi radialis	25	Right flexor carpi ulnaris	H	Left knee joint
10	Left flexor carpi radialis	26	Left erector spinae	I	Right ankle joint
11	Rectus abdominis	27	Right erector spinae	J	Left ankle joint
12	Right rectus femoris	28	Left gluteus maximus	K	Cervical vertebra
13	Left rectus femoris	29	Right gluteus maximus	L	Thoracic vertebra
14	Right tibialis anterior	30	Left biceps femoris	M	Lumbar vertebra
15	Left tibialis anterior	31	Right biceps femoris	N	Sacrum
16	Left trapezius	32	Left gastrocnemius		

FIGURE A1 Musculoskeletal chart