Testing a Smartphone Application for the Optimisation of Organisational Outfitting Procedures for Protective Clothing

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Abstract

Allocating protective clothing to personnel of emergency service organisations requires a substantial amount of time and effort. This makes these processes costly and laborious. Data-driven outfitting bears the potential to increase efficiency both economically and ecologically. Therefore, this study explores a smartphone application's feasibility to enable virtual human-product matchmaking within the context of organisational outfitting procedures. This is achieved by testing the application's ability to capture individual body data of users and associate these with product dimensions.

The application's performance is evaluated by contrasting the accuracy of its results with those of a laser-based 3D body scanner as well as through physical inspection of results. For this purpose, an experiment has been conducted in which 63 members of the German Armed Forces were given the task to scan themselves via a smartphone application. Obtained information was transferred to a mock-up online shop where a pretrained algorithm automatically matched various body dimensions to the optimal sizes of ten different clothing products. Thereafter, participants were given the selected products for physical trial fitting. The fit of each solitary product and the products' combinability were subjectively evaluated by the participants and objectively by a clothing technician and a tailor.

Findings show that the smartphone application is feasible to enable the outfitting procedure's digitisation, although body data captured by the smartphone application was of lower accuracy than data gathered by the laser-based 3D body scanner. Furthermore, the experiment's findings helped to uncover issues of incumbent product dimensions and size ranges as well as substantiated the importance of gender-specific clothing since the usage of unisex products led to poor results for the female subpopulation. For the male subpopulation, 86 per cent of products were optimally allocated, the wrong size was chosen in 12 per cent of cases, and in two per cent of cases the system failed to select any product at all. By analysing these aspects, the findings shed more light on technical issues such as measuring errors or flaws of the allocation algorithm.

The study evinces current potentials and troubles of both the smartphone application and the digital outfitting system which offer avenues for future research. Insights into the potential of smartphone applications are valuable for all organisations that face the issue of economic and ecological inefficiencies of human-product matchmaking regardless if they operate in an intraorganisational, a business-to-business, or a business-to-customer context. This was an early approach to employ smartphone-based technology in intraorganisational product-human matchmaking procedures for protective clothing. Although improvements are still possible from a technical point of view, the findings suggest that smartphone-based body scanning will have a key impact on industry.

Keywords: 3D Body Scanning; Smartphone; Outfitting; Protective Clothing; Experiment

1. Introduction

The global and divers set of challenges military personnel are facing requires highly functional and modern equipment. Hereby, outfitting with user-friendly and ergonomic clothing, which satisfy the respective mission's needs, is pivotal. As of now, the Federal Armed Forces of Germany (in the following Bw as abbreviation for 'Bundeswehr') receive clothing products that were designed based on a civil measurement series performed in the 1980s and 1990s. Naturally, demographic developments led to a change in physical appearance of the incumbent population of soldiers, leading to poorly fitting goods [1]. This inhibits soldiers from performing their tasks to the best of their abilities, while also increasing the amount of material abrasion. Moreover, the incumbent outfitting procedure is laborious, time-consuming, and costly. As of now, soldiers have to travel substantial distances to a physical warehouse in order to try on products until the best fitting ones are identified. Particularly when getting their initial set of equipment, this procedure is not uncommon to last for eight hours per person, resulting in significant efficiency-losses. Because not every product is held on stock in every size at every location, soldiers might be unable to identify optimally fitting products. In this case, they are equipped with an imperfect size, resulting in the previously described issues.

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In order to streamline the outfitting procedure's convenience, efficiency (in terms of speed, costs, and returned products), and effectiveness (in terms of accuracy and suitability) decision-makers contemplate the introduction of an online ordering system. This would release logistical economies of scale and scope but only with the premise that soldiers are able to identify and pick the best product size as the reverse logistical expenses could jeopardize the new process's economic viability. To overcome this issue, while simultaneously addressing the earlier described problem, it was decided to gather soldiers' 3D body dimensions prior to them ordering goods online. However, the substantial expenses and operational effort of physical 3D scanners made this option impracticable. Recent developments of smartphone camera based applications are exceptionally promising [2–5]. Thus, using a smartphone application's abilities might be a convenient and decentralised solution. Therefore, the purpose of this study is to craft an experiment that explores a smartphone application's feasibility to enable virtual human-product matchmaking within the context of organisational outfitting procedures [6]. This leads to the following research questions:

RQ1: Is data gathered via a smartphone application adequate for automated product size allocation?
RQ2: Does smartphone-based outfitting lead to a higher level of precision than conventional outfitting?
RQ3: How does data gathered via a smartphone application compare to data gathered via a stationary 3D scanning booth?

In the following, the experiment's setting is described. Subsequently, findings are presented, analysed and discussed. Overall, findings show that the smartphone application is feasible to enable the outfitting procedure's digitisation, although body data captured by the smartphone application was of lower accuracy than data gathered by the laser-based 3D body scanner. Furthermore, the experiment's findings helped to uncover issues of incumbent product dimensions and size ranges as well as substantiated the importance of gender-specific clothing since the usage of unisex products led to poor results for the female subpopulation. By analysing these aspects, the findings shed more light on technical issues such as flaws of the allocation algorithm.

2. Methodology

To approach the research questions, a minimum viable product (MVP) was developed in with two partnering companies from the civilian sector that provided the information technological infrastructure [6]. This MVP was then tested in a laboratory setting. More detail to the study's methodology is given in the following.

2.1. Development of the Minimum Viable Product and Scanning Procedure

The MVP had to capture probands' body measurements, interpret these and transform them into size recommendations. Moreover, probands had to be provided with a digital platform on which they could order clothing and personal protective equipment. Hence, the initial step was subject to the development of a digital ordering system that integrates body measurement, size recommendation, and the logistical management of clothing. This system was labelled BundesWEAR© and registered as protected mark [6]. The system was created in close cooperation between two external software suppliers, technical personal of the BWI GmbH (a German public IT services provider owned by the German Federal Ministry of Defence), and clothing engineers of the Bundeswehr Research Institute for Materials, Fuels and Lubricants. For the sake of simplicity and to be in line with the present experiment's scope, topics such as IT security or data protection have been deliberately neglected.

To scan probands with a smartphone, an AI-supported scanning method was utilised that was entirely adopted from an external supplier (Supplier 1). Scans were performed in the following manner. First, probands had to enter demographic information such as gender, height, weight, and age. Second, probands spun 360 degrees in front of the smartphone camera. Hereby, the front camera of an *iPhone 11 pro* was used. The program records a short video (roughly ten seconds). Throughout the scanning process, the smartphone had to have a network connection, as the data was not stored locally but directly transferred to a cloud server. Probands' faces were pixelated and the video was automatically deleted after the algorithm extracted body measurements. Probands had to wear tight clothing. A neutral background has been used, as recommended by Supplier 1. Third, algorithms computed 30 body measurements (ankle to neck) based on ISO-standards 7250-1 and 8559-1. Calculations rely on Supplier 1's data pipeline which was created through an Artec Leo 3D Scanner. It was, however, noticed that the pipeline is still lacking holism, as the results improved substantially throughout the experiment, indicating an enhancement of the deep learning method through additional sets of data.

A digital platform that was linked to a mock-up SAP ordering system and entailed an allocation program, was provided by a second external supplier (Supplier 2). Algorithms and IT-infrastructure have been adopted, including the software's ability to recognise sizes from body measurements, allocate these to product dimensions, manage selected goods, as well as process and fulfil orders. Slight modifications were only made to the allocation algorithm. Before the experiment, several loops of scanning and allocation have been performed to train the algorithm for dealing with the selected product sample's dimensions. There has been no transfer of personal images between smartphone scan and digital platform. Instead, only the 30 computed body dimensions were transmitted and stored in the BundesWEAR© system. Table 1 gives more details about the IT-systems used in the experiment.

Table 1. Server infrastructure.

Database Server		**B-Op Core Server**	
Operating System	Ubuntu 20.04	Operating System	Ubuntu 20.04
Processor/ RAM	8 Cores/ 32 GB	Processor/ RAM	4 Cores/ 16 GB
Storage	200 GB	Storage	200 GB
Application Server		**Configuration Server**	
Operating System	Ubuntu 20.04	Operating System	Windows Server
Processor/ RAM	8 Cores/ 32 GB	Processor/ RAM	4 Cores/ 16 GB
Storage	200 GB	Storage	200 GB

2.2. Sample

To reduce the complexity that derive from the wide range of heterogenous product variants, a sample of ten different products has been selected. All products are issued during soldiers' basic training. Four of these products are unisex and three are gender-specific and provided in the male and female version. In total, 117 different product-size combinations were populated in the database. Table 2 illustrates the selected products.

Table 2. Overview of products featured in experiment.

Underwear	**Cold Protection Clothes**	**Combat Suit**	**Field Jacket**
♂/♀	♂/♀	♂	♂/♀
			
♂	♂/♀	♂	
			
♀		♀	
			
		♀	
			

All participants were active Bw personnel with an average of 17.8 service years. They were volunteers, who replied positively to a circular which was sent to military facilities in the German state Bavaria. Overall, 63 probands participated in the experiment. Roughly three quarters of the participants were male (76.2 %) and one quarter female (23.8 %). This is good representation of the actual gender distribution in the German Armed Forces. The average age was roughly 40 years, with the majority of participants being in their thirties. Figure 1 illustrates the age distribution of probands.

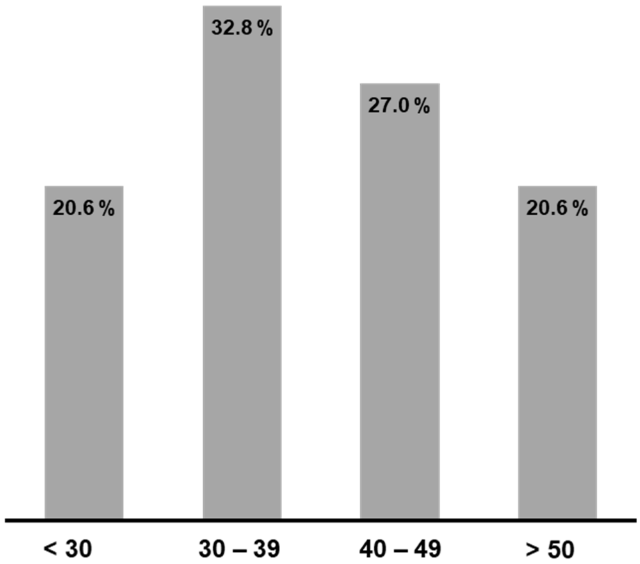

Fig. 1. Participant age distribution.

As depicted in Figure 2, the body height of the male subpopulation had a range from 169 cm – 196 cm and for the female subpopulation the range was 158 cm – 179 cm. The total average was 178 cm.

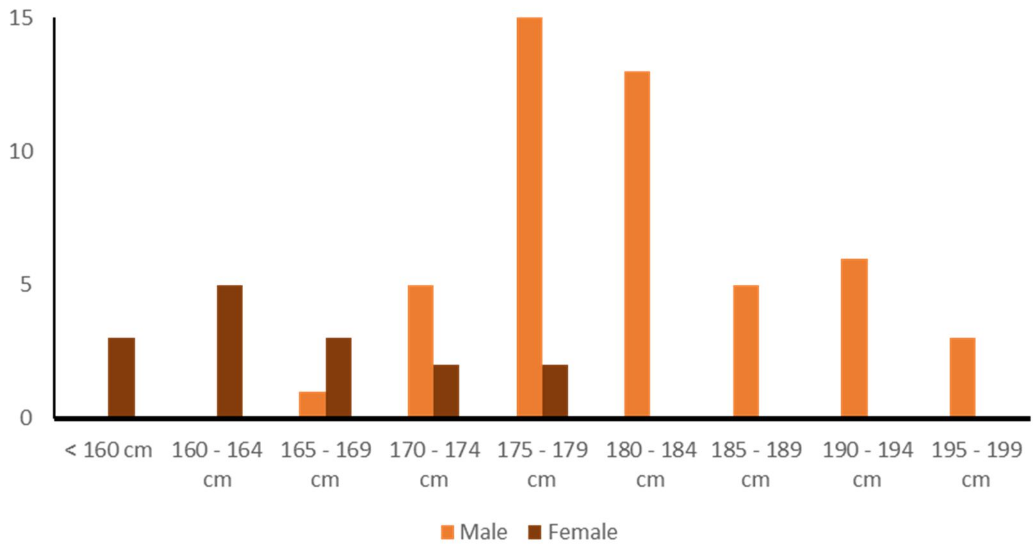

Fig. 2. Participant body height distribution.

Participants were asked to state their preferred style of clothing fit for their civilian as well as for their combat clothing. The results can be found in Figure 3. It demonstrates that soldiers wish their combat clothing to fit more loosely than their civilian clothing, regardless of their gender. This demonstrates important differences between renown market dynamics and specific circumstances of outfitting for emergency service organisations that need to be accommodated by the digital platform. This difference gets especially apparent when the preference for tight lower body clothing is compared with the preference for loose lower body clothing. For the male subpopulation, the preference for tight fitting pants for the combat clothes compared to civilian clothes decreased by 20.8 percentage points from 25 per cent to 4.2 per cent, while it increased for loose fitting pants by 18.7 percentage points from 6.3 per cent to 25 per cent. In the case of the female subpopulation, the preference for tight fitting pants for combat clothes compared to civilian clothes decreased entirely, as 26.7 per cent state tight fitting pants as their preferred style for civilian clothes compared to nobody who would prefer tight fitting combat pants. For loose fitting pants, the preference increases by 26.6 percentage points from 6.7 per cent who like loose civilian pants best to 33.3 per cent who like loose combat pants best.

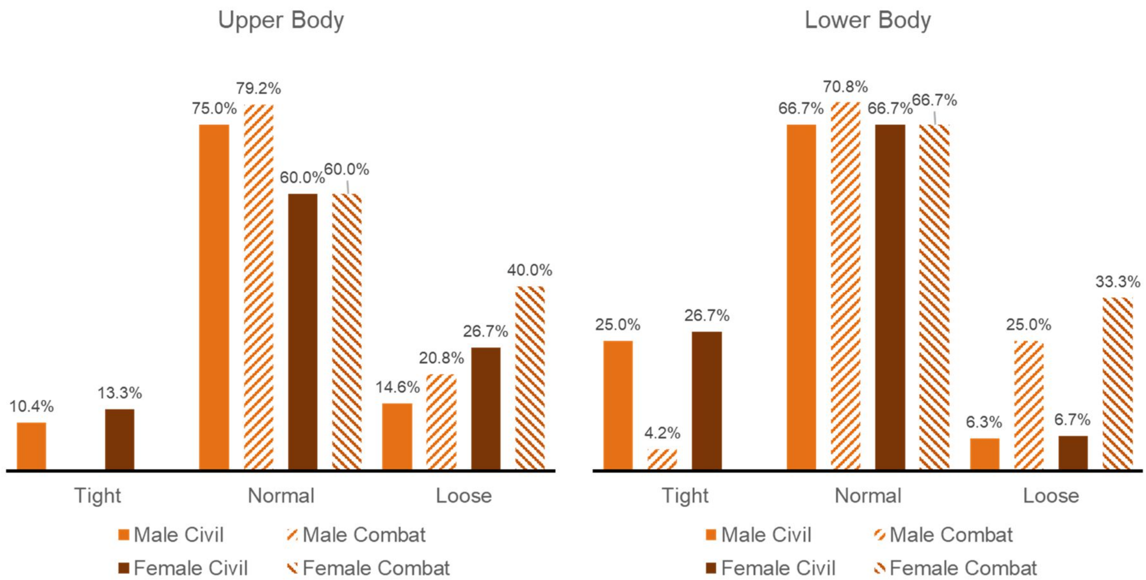

Fig. 3. Participant preferred style of fit.

2.3. Laboratory Setting

The experiment was conducted during ten days within a two-week period in February 2022. Every day, between five and eight probands completed the experiment. A comprehensive overview regarding the experiment's parkour is provided in Figure 4.

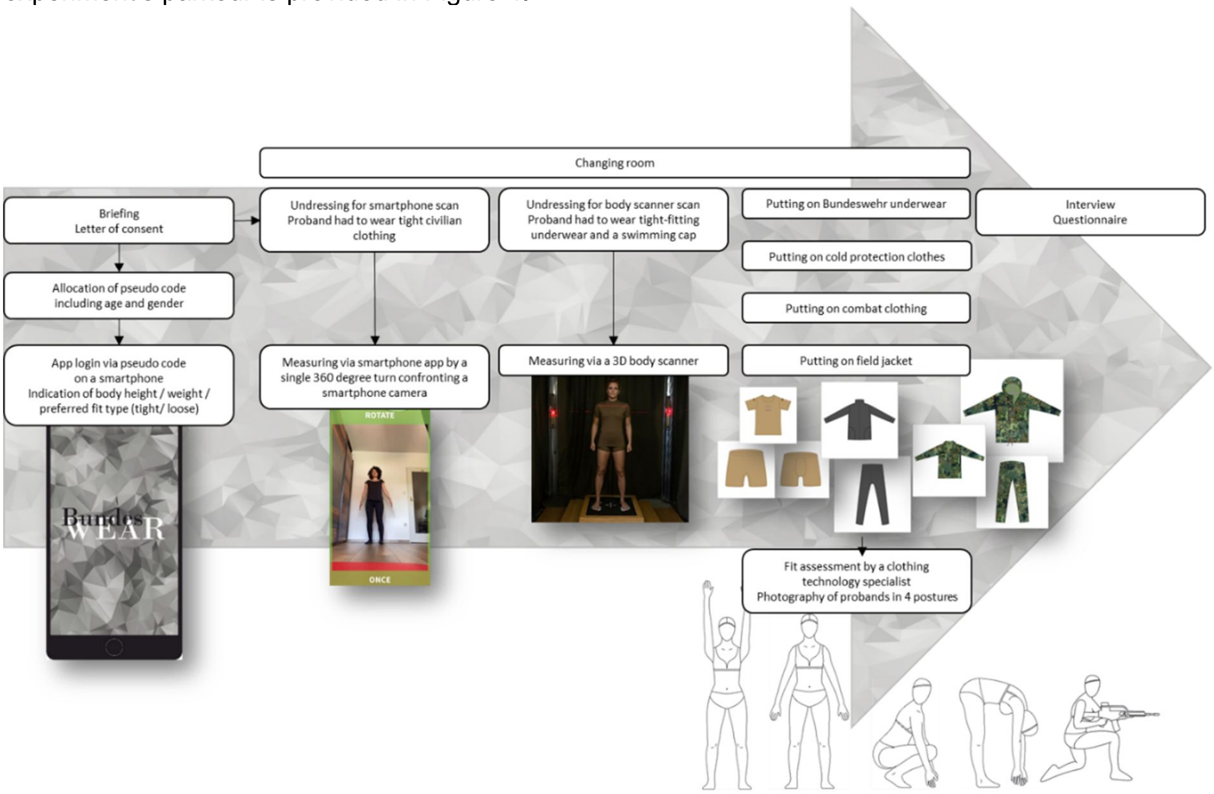

Fig. 4. Illustration of the experiment's procedure.

Upon arrival, probands were briefed and signed a letter of consent regarding the usage of their personal data. Thereafter, they were given a pseudo code which they used to register in the BundesWEAR© system on a provided smartphone. They also gave details regarding body height, weight, age, and preferred fit type (tight/ normal/ loose). After successful registration, probands moved to another room where they could privately undress. Here, they followed the instructions given by the BundesWEAR© application by performing a full spin facing the smartphone's front camera. The described steps are illustrated by Figure 5.

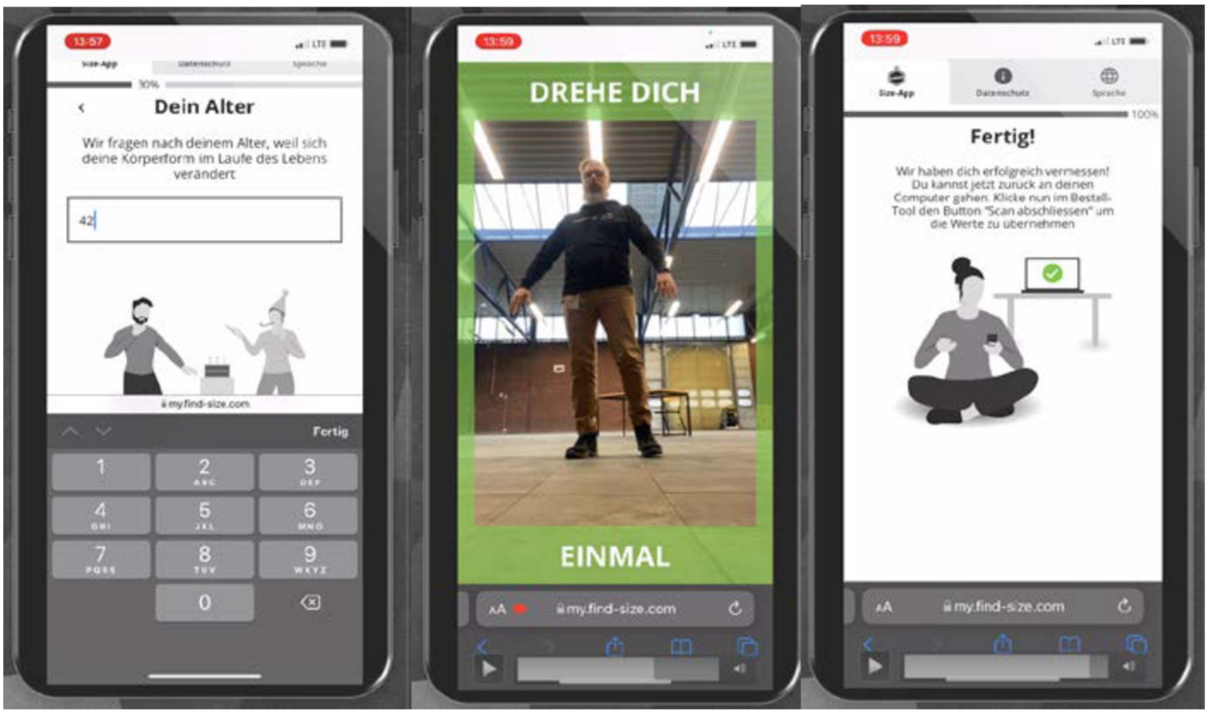

Fig. 5. Depiction of BundesWEAR©'s user interface.

Obtained data is transferred to the system and, as previously described, the algorithm computed size recommendations which are then displayed in the user interface of the BundesWEAR© app. Probands had the chance to review the chosen sizes but, for the sake of the experiment's research goals, were not allowed to change them manually. A depiction of the user interface is provided in Figure 6.

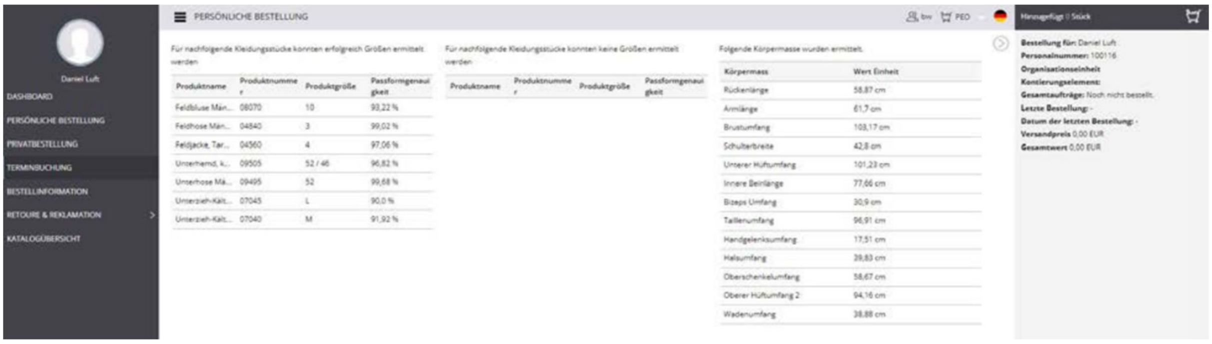

Fig. 6. Depiction of the system's reporting of measurements.

Size recommendations were then accessed by the experiment's staff, who held every product in each available size on stock and could thus prepare bundles of 'ordered' goods. Simultaneously, probands moved to the next station, where they redressed themselves with tight fitting underwear and a swimming cap to be scanned in the standard A-pose with a 3D body scanner. Hereby, the 3D laser scanner *VITUS XXL*, manufactured by *Vitronic Dr.-Ing. Stein Bildverarbeitungssysteme GmbH*, has been used [7]. Body measures derived from the 3D scan using Anthroscan software without any further processing of the raw scan data.

Subsequently, probands went to the fit assessment stage, where they tried on all products that were prepared for them based on the algorithm's choices. As the combinability of different products, such as cold protection clothing with regular combat clothing, is relevant for the environmental circumstances of soldiers' operations, probands tried on the clothing bundle twice, the first time with and the second time without cold protection. To objectively evaluate product fit, an inspection concept has been developed that builds on the standardised NATO method 'Fitscore STANREC 4833' [8]. Thus, dressed probands had to take four poses ('uplifted arms', 'bent', 'squad', and 'aiming position') that should mimic military movements [9]. For each pose they had to face two clothing technicians who evaluated product fit for each body zone (such as chest circumference, inner leg length, etc.) by examining width and length of body zones in relation to the particular clothing item. Moreover, pictures were taken for documentation purposes and later triangulation of the respective fit evaluation.

Finally, probands were interviewed to gain insights regarding factors such as comfort, ease of use, and customer experience.

Fig. 7. Three exemplary poses used during fit evaluation.

3. Results and Discussion

In the following, the fit evaluation's results are presented, analysed, and discussed. Noticeably, and as described in Figure 3 and Figure 4, measurements obtained through the smartphone application were equally precise for both genders, as for both genders 91% of body zones, for example chest circumferences, were sufficiently measured to allow for size matchmaking. However, the algorithm-based size recommendation's results for men were substantially better than the results for women. Table 3 and Figure 8 both depict the findings for the female subpopulation, while Table 4 and Figure 9 display the findings for male probands. As Table 3 summarises, the algorithm was able to select the most appropriate product for women in 58.6 % of cases, in 18.7 % of cases it made a mistake and for 14.1 % of cases it failed to select any product at all, due to a too high discrepancy between computed body measurements and available product dimensions. Compared to that, and as shown in Table 4, for men, the system chose the best possible product in 85.8 % of cases, a wrong product in 12.3 % of cases, and made no choice in 2.0 % of cases for previously described reasons.

Table 3. Performance of algorithm based size recommendation for female probands.

Algorithm based size recommendation		
♀	Absolute (total: 128 clothing items)	Relative
Recommended by app	75	58.6 %
Recommended by app; changed manually	24	18.7 %
No size recommendation by app; assigned manually	18	14.1 %
No size recommendation by app; manual allocation not possible	11	8.6 %
Automatically allocated body zones (total: 1,349 body zones)		
Ill-fitting body zones	123	9 %
Well-fitting body zones	1,226	91 %

Table 4. Performance of algorithm based size recommendation for male probands.

Algorithm based size recommendation		
♂	Absolute (total: 351 clothing items)	Relative
Recommended by app	301	85.8 %
Recommended by app; changed manually	43	12.2 %
No size recommendation by app; assigned manually	7	2.0 %
No size recommendation by app; manual assignment not possible	0	0.0 %
Automatically allocated body zones (total: 5,621 body zones)		
Ill-fitting body zones	523	9 %
Well-fitting body zones	5,098	91 %

During fit evaluation, each product has been awarded a binary code, where '0' represents a well-fitting and '1' an ill-fitting product. The codes where then used to calculate mean values for the sake of comparability among different product groups. By and large, Figure 8 and Figure 9 demonstrate that the automated size assignment outperforms the manual one. This reinforces the assumption that there is a disparity between subjective and objective fit evaluation. Again, results display a substantially poorer fit for the female subpopulation in contrast to the male one. This is mainly due to an outdated and inadequate size code because each increase in size number represents an increase of two regular size numbers for female soldiers (for example up to eight centimetre in chest circumference). Moreover, pattern constructions have not been designed for differently pronounced morphotypes. For instance, female soldiers with a relatively straight waist-to-hip ratio are more likely to be given combat pants designed for men. Since unisex items were originally designed for a predominantly male target audience, they naturally fit men much better than women. Similar issues are observable for clothes designed to protect against cold climates as the size range neglects to accommodate the requirements of, for instance, slim and tall people. Thus, the results point to the necessity of revising the incumbent size code fundamentally. As expected, goods manufactured from elastic material, such as underwear and cold protection items, were easier to appropriately allocate than goods made from non-elastic material such as the combat clothing. Hence, prioritisation of different measuring sections has to be improved during training of the machine learning algorithm to guarantee mobility. The results further evince that product development should incorporate considerations regarding morphotypes, body shapes, and body dimensions in concert with the combinability of products that are worn in layers.

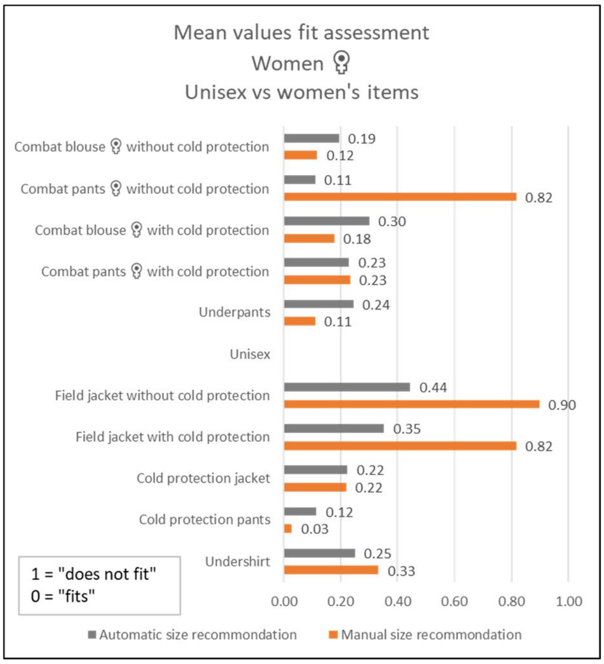

Fig. 8. Mean values of product based fit assessment for female probands.

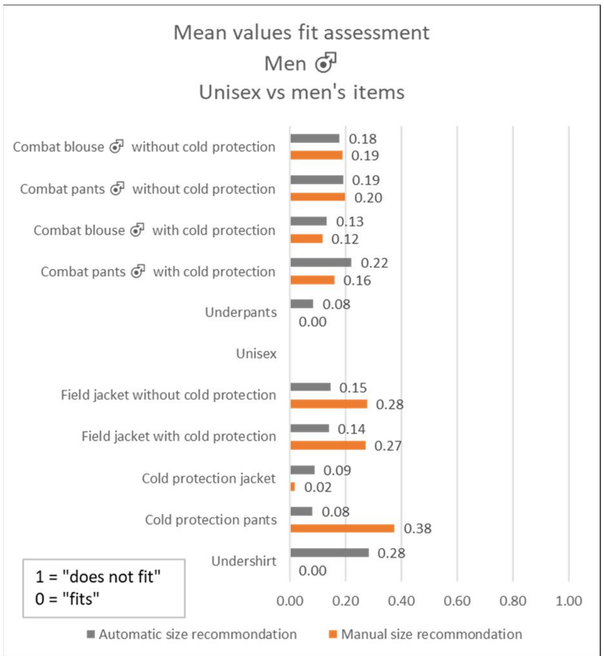

Fig. 9. Mean values of product based fit assessment for male probands.

With the aid of suitable software packages (e.g. Anthroscan), 3D body scanners were able to directly generate 3D point clouds of probands' bodies and derive body dimensions from scan data without the necessity of prior digital twin modification or manual cleaning. Therefore, obtained digital body dimensions displayed a substantial amount of accuracy and converged almost perfectly to the actual body dimensions of the respective person. In contrast, body measurements determined by the smartphone app do not derive from direct measurements of the actual human being scanned but are based on a mathematical approximation that leverages an anthropometric database created through a large number of body scans. Indicating information concerning age, height, and weight enables the system to assign a proband to a specific predefined target group. Body measurements that correspond to the scan are then calculated based on this assignment. Depending on the software provider, up to 30 body measurements can be used for size allocation.

Currently, 3D laser scanners are able to capture body dimensions with an accuracy <1 mm [10]. Moreover, such a laser scan takes not even a duration of 10 s per scanned position to complete. Measurements are valuable for the ergonomics sector as well as for the clothing sector [11]. However, data obtained through an actual 3D scanner hardly compares to data from smartphone applications or web-based software solutions for body measurements [4]. For the latter, accuracies range around <1 cm and thus, the data lacks precision for a throughout comparison. Nevertheless, data needed for size allocations require a smaller range of measurements than for instance data required for pattern construction or size code development. Hence, the prevalent accuracy range of mobile applications or web-based software fulfils its intended purpose.

To provide a comprehensive understanding of the smartphone application's results, the body measures derived from 3D Body scans were compared to the data estimated by the smartphone app using a regression analysis of three particularly important measurement areas. Results are presented for female and male participants for back length (Figure 10), chest circumference (Figure 11), and inner leg length (Figure 12). Regressions that entail an R^2 value close to 0 indicate that body dimensions determined by the app diverge to the dimensions measured by the 3D body scanner and thus engender a 'poor model fit', as it can be observed in the case of female back length in Figure 10. This indicates a substantial measurement error of the smartphone application and thus, disqualify these measurements for instance for design and development purposes. Regressions whose R^2 values are close to 1 represent a high degree of compliance between body dimensions obtained through smartphone application and 3D body scanner. Such models with a good fit can be seen in the case of chest circumferences (Figure 11) of both men and women. These cases exhibit a nearly linear relationship between both determination methods. It should be noted that even cases with a measurement disparity of several centimetres are largely within the range of a particular clothing size indicating their general value for allocation procedures. However, Figure 12, indicates differences between the application's and the 3D scanner's measures that could result in the allocation of an incorrect clothing size for this particular case. Nevertheless, these results provide further insights by highlighting body zones which the smartphone application struggled with and require therefore more attention by future researchers.

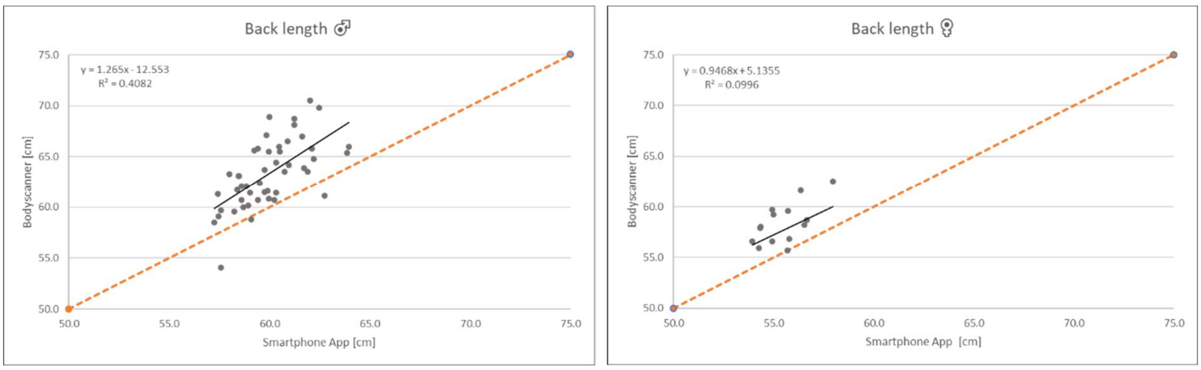

Fig. 10. Body measure "back length" derived from 3D body scanner vs smartphone application.

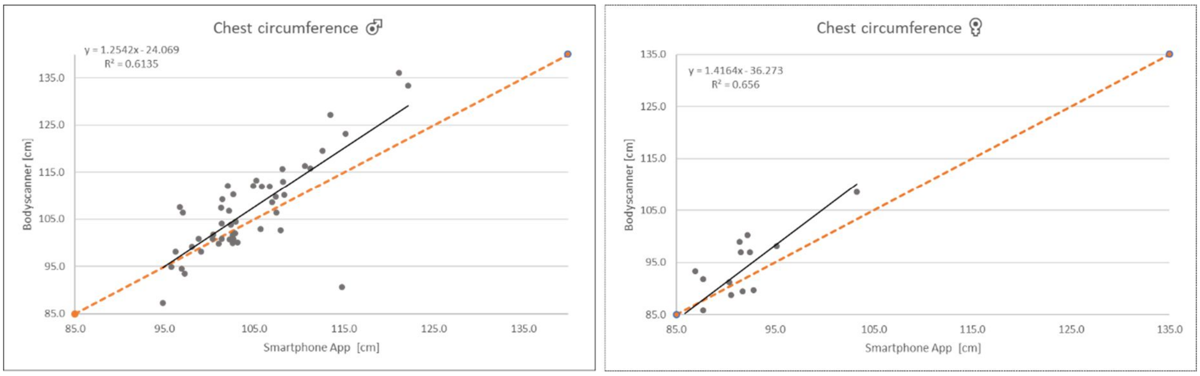

Fig. 11. Body measure “chest circumference” derived from 3D body scanner vs smartphone application.

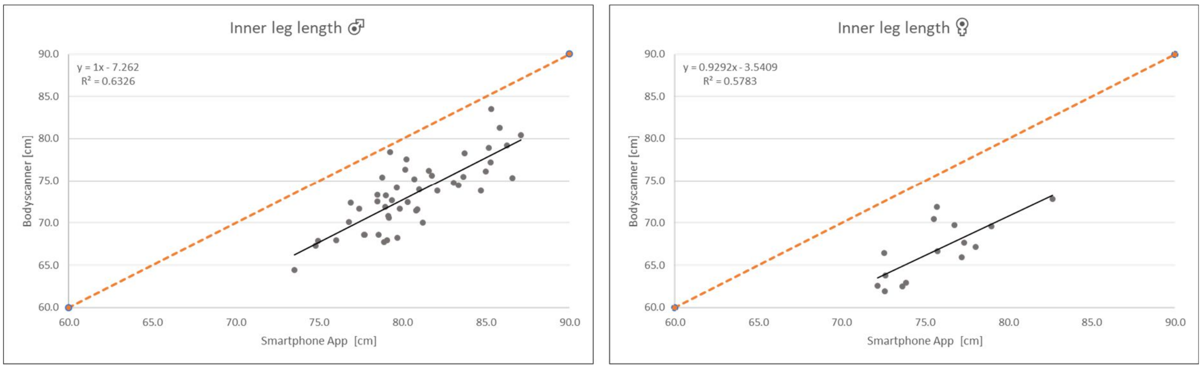

Fig. 12. Body measure “inner leg length” derived from 3D body scanner vs smartphone application.

4. Conclusion

Insights into the potential of smartphone applications are valuable for all organisations that face the issue of economic and ecological inefficiencies of human-product matchmaking regardless if they operate in an intraorganisational, a business-to-business, or a business-to-customer context. In contrast to several ‘civil’ solutions that are already on the market, this was an early approach to employ smartphone based technology in intraorganisational product-human matchmaking procedures for protective clothing. Overall, results show that smartphone camera based ‘scanners’ supported by sophisticated algorithms provide a powerful tool for objective outfitting. Thus, this experiment gathered strong evidence that relevant body dimensions can be purposefully captured by a smartphone camera and successfully transferred and processed by an algorithm based system to enable the automatic allocation of sizes. If used for this objective, smartphone applications that are already present on the market do not have to hide from stationary 3D body scanners. Moreover, body dimensions obtained through the smartphone application displayed appropriate accuracy to allow for them to be transferred and leveraged by tailors who are thus enabled to modify particular items if changes should be required. To enhance the size allocation process, more work is necessary in terms of machine learning and training of algorithms to pave the way for new generations of artificial intelligence that are able to accommodate specific customer needs, environmental circumstances, and clothing layers. Nevertheless, this has to be accompanied by revising outdated size codes and pattern constructions to improve the alignment of product characteristics with the particular requirements of the target group. Furthermore, these algorithms are only as good as the database they are fed from. Hence, a comprehensive data pool that encompasses an adequate range of age groups and morphotypes of the specific target group (in the present case a database that properly represents the German Armed Forces) is a pivotal success factor. Additionally, the heterogeneity in size codes used by different manufacturers impedes the performance of an automated size allocation system. Consequently, allocation algorithms would immensely benefit from a higher degree of industrial standardisation.

Although improvements are still possible from a technical point of view, findings suggest that smartphone-based body scanning will have a key impact on industry. Arguably, fit accuracy is a major issue for the clothing sector as individual preferences and environmental circumstances make a perfectly objective and dispassionate fit impossible to determine. Therefore, a differentiation between technology-driven objective fit and subjective fit, as perceived by the wearer, is necessary. On the one hand, addressing the discrepancy between objective and subjective fit creates a challenge for clothing engineers and software developers. On the other hand, it can also be seen as an interesting and fruitful opportunity for future research and the development of new business models.

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