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A user-centred development process for an equipment vest for the Swedish police force

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Abstract: The aim of this paper is to describe a user-centred development process for an equipment vest for police officers on active duty. Development and evaluation of the vest were conducted through a multidisciplinary collaboration between the police organisation and external researchers with expertise in ergonomics and biomechanics. The development process was initiated with a user needs analysis, followed by pilot testing of the initial vest prototype. In the extensive usability test, 95 police officers participated. Interviews, focus group discussions, and pressure measurements were conducted to assess the vest's functionality, impact on physical load, safety aspects, and signal value. Throughout the process, several important aspects were identified. Researchers delivered results iteratively to the designers and project manager. The results from the user evaluation guided further development, resulting in an equipment vest tailored to the needs and requirements of Swedish police officers on active duty.

Keywords: user-centred; development process; equipment vest; police forces; multidisciplinary collaboration; ergonomics; biomechanics; usability test; physical load.

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1 Introduction

Musculoskeletal disorders are common among police officers, with lower back pain being the most frequently reported (Larsen et al., 2018). The regulated equipment that police officers wear during daily work has been identified as one of the contributing factors to the high prevalence of lower back pain (Ramstrand and Larsen, 2012). Most police officers, working on active duty, wear a duty belt around the waist, including equipment such as radio, weapon, baton, handcuffs, OC spray (pepper spray), etc., which is bulky, imposing an unfavourable load on the lumbar spine (Hsiao, 2023). The bulkiness of the duty belt leads to unfavourable postures when sitting in, or driving, a police vehicle. Movement of the belt, relative to the body, is also reported as being problematic, especially during foot patrolling and running (Ramstrand and Larsen, 2012). Most police officers also carry a ballistic vest, typically worn closest to the body under the uniform. The ballistic vest has bullet resistant panels in the front and back. This additional layer of equipment has been identified as a challenge in regulating body temperature (Ramstrand and Larsen, 2012). The combined weight of the duty belt and ballistic vest is approximately 9 kilograms.

A possible way to increase body temperature comfort could be to wear the ballistic vest over the uniform. A way to improve unfavourable physical load for police officers is to redistribute the equipment from the duty belt onto an equipment vest (Larsen et al., 2016). Larsen et al. (2019b) investigated the effect of different load carriage designs on in-vehicle sitting pressure and self-rated discomfort among police. The study found that an equipment vest decreased musculoskeletal discomfort and was suggested as an intervention to improve the physical work environment among Swedish police working on active duty (Larsen et al., 2019b).

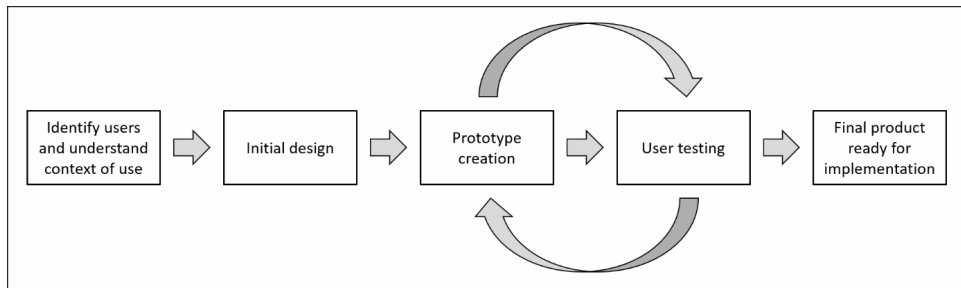
Up until now, the Swedish Police Authority has used a number of different equipment vests to redistribute equipment that is otherwise worn on the duty belt. However, the vests are produced by different manufacturers, and the designs of the available models are not in accordance with the Swedish Police Authority's uniform regulations (Polismyndigheten, 2018). Furthermore, these equipment vests are only worn by special units in the police force where the need for an equipment vest has been deemed essential for the specific work situations. However, police officers on active duty had expressed a need for alternative solutions to carry their equipment beyond the traditional duty belt. Furthermore, drawing from prior research on musculoskeletal pain and equipment utilisation within the Swedish police (Larsen et al., 2018; Ramstrand and Larsen, 2012; Larsen et al., 2019b), a desire among police officers emerged to develop an equipment vest that would be suitable for all active-duty police officers.

Therefore, in 2019, the Swedish Police Authority initiated a project to develop and evaluate an equipment vest that allows for redistributing equipment from the duty belt, whilst also integrating the ballistic panels from the current ballistic vest. The development unit at the department of national operations was assigned to lead the development of the vest. The goal of the project was to develop an alternative load carriage system for Swedish police officers in order to minimise the risk of musculoskeletal disorders. In the development process, the following aspects had to be taken into account: functionality, physical load, safety and signal value. To account for all aspects, it was decided at an early stage that the development and evaluation of the vest should be conducted in a multidisciplinary collaboration between the police organisation, the future users of the vest and external researchers, with competences in

ergonomics and biomechanics. Involving external researchers with non-profit interests in the development and evaluation of the equipment vest introduced an objectivity to the whole project, which was governed by the Swedish Police Authority. The research team included four researchers, of which two (L.L. and R.T.) had collaborated previously with the Swedish police organisation in several research projects concerning biomechanics of load carriage systems and work environment (Ramstrand and Larsen, 2012; Larsen et al., 2016, 2018, 2019a, 2019b). To ensure a higher and broader competence in the research team, two researchers (K.E. and T.N.) with specialist competence in ergonomics/human factors were also involved in the project.

User-centred design is a broad term used to describe design processes in which users are involved (Abrams et al., 2004). Such design is most often described in the development of interactive systems (Abrams et al., 2004; ISO, 2019). However, the approach, principles and the variety of methods used in user-centred design can be applied in all product development when ergonomic principles shall be applied to a product (Dwivedi et al., 2012; Leonard et al., 2006). Using a user-centred approach in the development process makes it easier for designers and researchers to better understand the needs and preferences of the users of the product/intervention and to ensure the creation of products that meet users' needs (IDEO, 2015; Lowdermilk, 2013). This is an iterative process in several phases that includes understanding the work system and users' needs, product development testing and evaluation of designs and prototypes, which finally results in a design solution ready for implementation (Figure 1) (Leonard et al., 2006; ISO, 2019). User-centred design includes different key principles; for example, understanding the user's needs and work practice; active user participation throughout the project; early prototyping; continuous iteration of design solutions; multidisciplinary teams and integrated design (Gulliksen et al., 2003).

Figure 1 Illustration of the user-centred development process



Source: Inspired by ISO (2019)

Physically demanding occupations, such as military, police and firefighters, require equipment to be carried on the body; thus, it is important that the carrying system fulfils their special contextual needs. However, how user-centred design processes are applied in the development processes for equipment in those occupations is rarely described and reported in the literature. In 2004, a Canadian study described how a load carrying system for military personnel was developed by a multidisciplinary team consisting of designers, human factors specialists and biomechanics specialists, whilst incorporating the end users in the design process (Stevenson et al., 2004). The study summarises how the biomechanical testing contributed to the development of the load carrying system design,

but the iterative design process was not described (Stevenson et al., 2004). Literature on empirical descriptions on how a user-centred design process is carried out (e.g., resources involved, methods used, outcomes considered) within organisations whose users have high demands on their personal equipment are lacking. Development and implementation of new specialised equipment, e.g., carrying systems, imply large costs for an organisation and will only be utilised if it fulfils the criteria set by the end user. Therefore, it is imperative that the equipment is well tested and evaluated in a substantial way before a decision on implementation is made.

The aim of this paper is to describe how a user-centred development process was used within the Swedish police organisation in the development of an equipment vest with integrated ballistic protection for police officers on active duty.

This paper will provide an overview of the user-centred development project, the project organisation, as well as the different phases and methods used in the user-centred process. Since the project is comprehensive and includes several sub-studies, more detailed presentations targeting specific aims explored during the process will be reported in separate papers (Larsen, 2022; Eliasson, 2022). Section 2 below describes the contextual factors of the project, the project organisation, and the context for Swedish police officers on active duty. Section 3 highlights the phases in the user-centred development in which different methods are used for data collection. Finally, Section 4 discusses the lessons learned from this project and presents the conclusions of the project from the researchers' perspective.

2 Context

2.1 Regulation of uniforms

All uniforms as well as all equipment worn by Swedish police officers are to be harmonised and are regulated by the Swedish Police Authority (Polismyndigheten, 2018). Swedish police are required to appear homogeneous and recognisable. Any changes in uniforms and equipment need to be aligned with the regulations. Sometimes these changes need to be preceded by a risk and safety assessment, which imposes restrictions and specific demands in the development process.

2.2 Project organisation

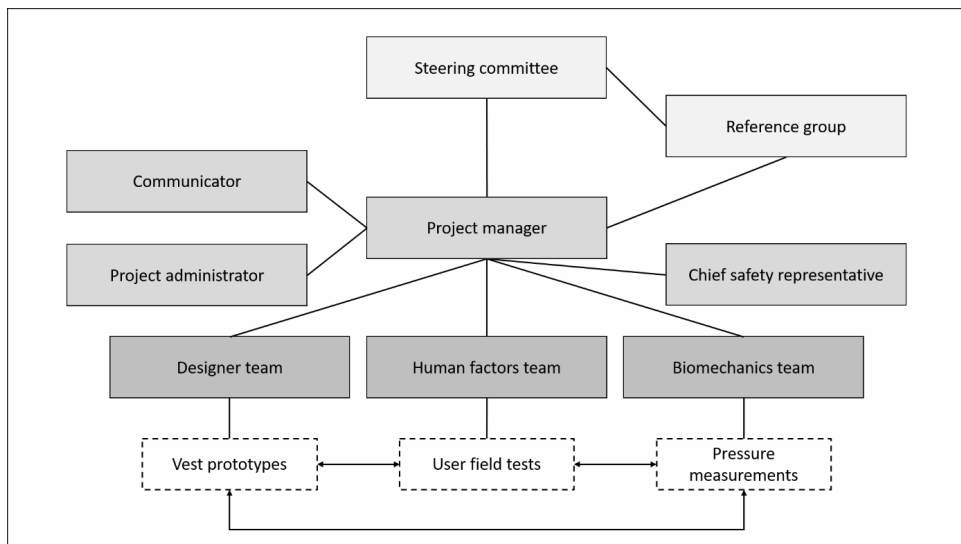
Between 2018–2020, the Swedish Police Authority allocated additional funding (50 million SEK/year) targeting work environment improvements (Polisförbundet, 2021). The development unit at the department of national operations received funding for the development of a new equipment vest with integrated ballistic protection. A project manager was recruited to organise and lead the project and put together the project organisation. The project manager had a background as a physiotherapist, ergonomist and work environment specialist, with broad experience of project management in several organisations, including the Swedish Police Authority and the Swedish Armed Forces. The project organisation comprised a steering committee, an operating group and a reference group. The project had a set timeline and was well anchored in the authority's top management.

The steering committee included three managers from the National Operative Department, with responsibility for the development unit, police equipment and national coordination. The steering group also included the purchasing manager from the finance unit, as well as a work environment specialist from the human resources department and a representative from the Police Union.

The project's operating group was a multidisciplinary group (Figure 2). The project manager had access to a project administrator, who provided support for various practical issues, and a communicator who actively communicated about the project to the police organisation throughout the project. Furthermore, a chief safety representative assisted the project manager with knowledge regarding the police work environment. The design team employed at the development unit and the external research team (human factors researchers and biomechanics researchers) developed and evaluated the vest. The operating group had regular meetings during the process.

A reference group was also part of the project organisation, comprising seven police officers representing the following seven police regions in Sweden; Syd, Stockholm, Mitt, Väst, Öst, Bergslagen and Norr (Polismyndigheten, 2022a). Furthermore, the reference group also included one person representing specially trained police instructors; one representative from the department of national operations and one safety representative. These representatives had to be active as a police officer on active duty and have good experience of police work. Their role was to provide feedback to the work presented by the operating group and give input based on work-based experience.

Figure 2 Project organisation and interactions between the functions



2.3 Swedish Police on active duty

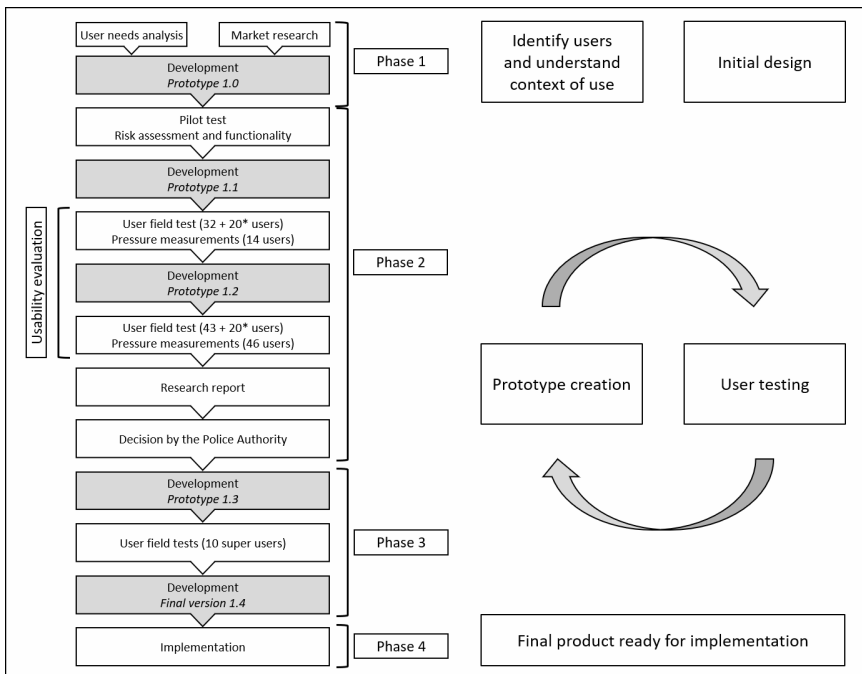
Police officers working on active duty need to be prepared and well equipped for all unforeseen events. Often, this occupational group is the first on site at acute incidents. This puts high mental and physical demands on the individual as well as the functionality of the equipment worn by the police officers. Despite the episodic intensity of police

work, most of the working time is spent sedentary, and the activity level can be compared to that of blue-collar workers (Ramey et al., 2014). The sedentary time typically entails sitting in/driving police vehicles or conducting administrative work at the police station. Police officers working on active duty are enrolled in different systems of shift work, and time to recover between work alterations is a factor affecting the well-being of police officers. Optimising the equipment of active-duty police is a priority to enable high functionality in all work situations.

3 The user-centred development process

The user-centred development process constituted four phases (Figure 3), whereof this paper describes phases 1 to 3. The first phase was solely conducted by the Swedish Police Authority. The aim of this phase was to identify specific user needs and make a decision on whether to develop and test a prototype. Since the Police Authority wanted an external evaluation of the vest, the researchers were assigned to conduct a usability test. The usability tests, constituted phase 2 and during this phase vest prototypes were iteratively developed and evaluated. The phase concluded with a report presented to the decision makers. The report represented a crucial decision point to determine whether the vest development should proceed. The Police Authority decided to proceed, whereof phase three was entered, which included final iterations to finalise the product.

Figure 3 Description of the development process of the equipment vest in relation to a use-centred development process



Note: Description of the last phase, implementation, is not included in this paper, since it has not yet been conducted.

3.1 Phase 1: user needs analysis, market research and initial design

Earlier research projects conducted in collaboration with the Swedish Police Authority (Ramstrand et al., 2016; Larsen et al., 2016; Larsen et al., 2019b) identified a need for an equipment vest. However, in order to make an initial prototype, the design team at the development unit required further exploration of user needs and an investigation of existing vest types. This task was undertaken by the project manager, the design team and the chief safety representative. They collected data regarding needs by interviewing end-users, specifically police officers on active duty, to gather their perspectives on how an equipment vest could fulfil their needs. These interviews also aimed to provide a deeper understanding of the work environments in which police officers operate, highlighting the need for the vest to be adaptable to various situations. Given the authoritative nature of police work, the Police Authority imposed certain criteria that the vest design needed to adhere to. These criteria included maintaining a high safety standard, ensuring harmonisation with the rest of the uniform, and avoiding any interference with the police's distinctive identity that is, the vest should not convey a military appearance. The analysis of user needs and together with the requirements from the Police Authority resulted in a requirement specification (Table 1). Market research was conducted to gather information from other countries regarding different equipment vest applications, as well as research regarding optimisation of fabrics, modular equipment fastening systems, and design solutions. The market research served as inspiration for the vest design. However, no existing vest optimised for the Swedish uniform regulations (Polismyndigheten, 2018), or for the ballistic plates used by the Swedish police could be identified. Furthermore, by developing their own vest design, which is owned by the Police Authority, they avoid being locked into procurement agreements. Consequently, it was decided that the Swedish Police Authority should develop its own equipment vest. Based on the identified needs and requirements the prototype vest 1.0 was developed.

Table 1 Needs requirements and usability factors identified as important in the development of the equipment vest.

<i>Authority and user needs and usability aspects</i>
<ul style="list-style-type: none"> • Provide comfort in a wide temperature range, from hot summer conditions (above 20°C) to extreme winter cold (down to -25°C or lower). • Suitable for all police officers regardless of their role (e.g. patrolling police officers, mounted police officers, canine police officers etc.) • Include the ordinary ballistic plates but also enable insertion of hard armour plates in the same system when needed. • Enable a rapid change of conspicuity to allow police officers to quickly adjust conspicuity requirements (high or low) in various situations*. • Harmonises with the standard regulations for Swedish police uniforms. • Signals the police authority's vision: "Your police make Sweden safe and secure". • Facilitates sitting in vehicles.

Note: *Police officers may need to modify their level of conspicuity based on the situation. For instance, situations such as traffic citations might call for heightened conspicuity.

Figure 4 Vest prototype 1.1



Figure 5 Vest prototype 1.2



3.1.1 General description of equipment vest with integrated ballistic protection

The new equipment vest with integrated ballistic protection replaces the need for the ordinary inner ballistic vest worn closest to the body. The prototypes of the new equipment vest (Figures 4 and 5) included ballistic protection plates in the front and back and pockets for hard armour plates which can be inserted for further ballistic protection. Hard armour plates are thicker ballistic plates aimed to be added when greater protection is needed for the vital organs, e.g., against high velocity ammunition. In order to fasten equipment on the anterior side of the vest, different combinations of nylon straps, Velcro and modular lightweight load-carrying equipment (MOLLE) (Sampson, 2001) were used in the different design of the prototypes. MOLLE is widely used for load-carrying systems within the armed forces as well as the police forces (Sampson, 2001). Relocating equipment from the duty belt to an equipment vest introduces a risk of moving the musculoskeletal problems from the lower back to the shoulders. For this reason, the vest was designed with a flexible solution in the shoulder region for the insertion of a rigid arch into the shoulder straps, aiming to relieve the proximal part of the shoulder from the weight of the vest. The arches were made of composite material and could be manually inserted or removed from the shoulder strap during the test period. Three different sizes of arches were developed and made available for selection during the initial fitting of the vest prior to the start of the testing period. The shoulder straps were designed to be adjustable and fastened in the front with Velcro. Velcro placed underneath the straps ensured that the arches remained in place. Different suspension methods around the waist were tested in the three prototypes. The principle for suspension in the vests was a wide elastic band closest to the body to ensure a large contact area all the way around the waist. The outer layer of the vest was closed on the side or back of the vest with different solutions, depending on the prototype version. Given that the vest needs to be worn across varying temperatures and work environments typical for police officers, including vehicles, indoor and outdoor settings, various fabrics were tested in different iterations of the vest. Moreover, ensuring a comfortable fit while seated in a vehicle was crucial for the vest's design. To align with the Police Authorities' requirement for uniform harmonisation, the vest was crafted from fabrics that matched the rest of the dark blue uniform attire. Additionally, it was of paramount importance to convey the vest's purpose as standard equipment for ordinary Swedish police personnel, rather than giving off a military impression. This aspect, referred to as 'signal value', was carefully examined during the usability test interviews.

3.2 Phase 2 – pilot test and usability test

Since the Swedish Police Authority decided to develop its own vest, it was important that the user needs were regarded in the design. The Police Authority wanted to evaluate how the design met the overall requirements of functionality in the field, physical load, safety and signal value. However, to facilitate an iterative user-centred design process, it was crucial for the project management that evaluation was not separate from the design process. Instead, it needed to be continuous and integrated throughout the development of the prototypes. This approach ensured that user feedback drove the design forward. To guarantee unbiased evaluation, external researchers were appointed to join the project's operating group and assess the vest's usability. The team of researchers proposed a study design for the upcoming evaluation.

3.2.1 Pilot test – of functionality, risk assessment and study protocol

Prior to initiating the usability evaluation (Figure 3), a pilot test was executed to assess the functionality and identify potential risks associated with the vest, confirming that it would not hinder work activities. Additionally, a trial of the study protocol for the usability testing (Figure 6) was carried out. The pilot test played a crucial role, serving both as a risk assessment and as a milestone for approving further development. In conjunction with an overall functionality test, the Police Authority conducted a ballistic test on the prototype vest as part of the risk assessment process.

The pilot test was carried out in a training environment, involving ten police officers who were specialised as police instructors. The test encompassed specific activities such as shooting, running, and various physical techniques commonly employed in police work. These activities were selected to ensure that the vest did not impede or obstruct critical tasks. Furthermore, wearability and comfort were evaluated during the test day, as the police officers wore the vest throughout the day while engaging in different activities such as sitting, standing, and sitting in or driving vehicles. The design team and the human factors researchers observed the testing and thereafter led a group discussion. The discussion with the police officers resulted in a joint assessment that the concept of wearing an equipment vest with integrated ballistic protection was regarded as operationally safe. Thereafter, the police officers wore the vest in ordinary work for two weeks in order to further test overall functionality (including comfort and wearability). After the test period, the functionality of the vest was assessed through individual interviews and a group discussion with the police officers, following the study protocol that was developed and now tested for the study design of the usability evaluation. The study protocol included a specific plan for the usability evaluation, consisting of two studies: a field study (sub-study 1) and an experimental study (sub-study 2). Minor adjustments were made to the study design based on the pilot test.

Results from the pilot test were collected solely to provide input for the vest design and serve as the basis for decisions regarding the project's progression. The ten police officers who tested vest 1.0 were overall satisfied with the relief the vest provided in terms of reducing load on the hips and the lower back. However, various factors related to comfort and functionality were highlighted for consideration in the development of a vest model to be tested in a larger usability test. The suspension system was identified as an issue, as indicated by this quote from one of the police officers: "I never take it off [during the workday]; I find it too difficult to put on. By the time I've got it on, my colleagues have already left the building". The pilot test was conducted in May, and the version tested did not meet the users' needs regarding temperature comfort, as explained by the following quote: "it's too warm! I mean, seriously, I'm dying!". However, the fact that a vest was an appreciated solution for the police officers was not in question, as expressed by one officer: "the best in terms of equipment that I've worn!"

The project manager presented the findings from the ballistic tests, the risk assessment and functionality test to the steering committee. Subsequently, the committee decided to proceed with the design project, and conduct further testing and evaluation of the concept; an equipment vest with integrated ballistic protection, by involving a larger group of police officers in their daily work. Taking into account the feedback received from the ten participants in the pilot test, vest prototype 1.1 (Figure 4) was developed for the comprehensive usability test. The prototype 1.1 was made by the same fabrics as the 1.0 model, but modifications were made to enhance the fit. Additionally, the Velcro

suspension system was improved and more fastening points for equipment pouches were added to the model 1.1.

3.2.2 Usability evaluation

The usability testing included an evaluation of how the design met the overall requirements of functionality in the field, physical load, safety and signal value. Functionality included evaluation of usability aspects, comfort and physical load. Safety included evaluation of whether the equipment vest allowed for flexibility regarding conspicuity (with the goal of ensuring the safety and security of the public and employees). Evaluation of the signal value concerned opinions from the public shared with police officers regarding the change in their appearance. Additional design aspects to be considered for the on-going vest development included:

- fabrics of the vest (which needs to meet the requirements of, e.g., resisting fire, different weather conditions and sufficient ventilation during wear)
- suspension of the vest (for speedy removal and for a snug fit)
- placement of different equipment details on the vest (by using modular lightweight load-carrying equipment-system)
- design a system for easily adapting conspicuity (e.g., enhancing visibility for assignments in traffic or at major sporting events)
- design of shoulder straps (e.g., whether removable arches should be included).

Hence, the usability evaluation encompassed not only an overall assessment of the concept but also served as a crucial component of the user-centred design process. Information gathered from the ongoing data collection was regularly reported to the designers, enabling them to make improvements to the vest.

3.2.2.1 Study design usability evaluation

The usability testing comprised two sub studies. Sub-study 1 consisted of a field study that explored users' experiences with the vest in their daily work. Sub-study 2 involved an experimental study to quantify the load on the shoulder region of the vest (expressed as contact pressure). These two types of studies complemented each other, providing both qualitative and quantitative assessments of the vest. As musculoskeletal discomfort was a driving factor for the development of the vest as a complementary equipment concept to the duty belt, it was essential to thoroughly evaluate the risk of shifting the load from the hips to the shoulders. The studies used in the usability evaluation received approval from the Swedish Ethics Review Authority (D-nr 2021-01549). An overview of the study design of the different sub studies is presented in this section.

3.2.2.2 Recruitment of participants

Participation in the usability test (sub-studies 1 and 2) required full-time employment as an active duty police officer. A representative distribution between men and women, a spread regarding anthropometry and number of years on active duty, was sought. To create awareness and a sense of involvement, it was important for the project

management to inform the whole organisation about the development work on the new equipment vest. Information about the project was communicated on the intranet, and through direct information to the regional offices. Police officers from the Syd, Stockholm, Mitt, Väst, and Norr regions, collectively representing five out of the seven total regions, participated in the usability testing. Police officers registered their interest in participating in the study, and the design group selected participants based on their registrations. The aim was to include a range of anthropometric variations to test different vest sizes. Therefore, the participant selection process was strategic. The assortment of vest sizes created for the usability test was determined by statistics provided by the uniform and equipment storage, focusing on the sizes most commonly used police officers on active duty. Either a designer or a person instructed by the designers personally met the police officers to determine the suitable vest size and arch size for each individual. It is important to note that the participants can only be accessed through the Swedish Police Authority and that the data collection was only possible to conduct while the police officers were on duty.

3.2.2.3 Sub-study 1 – user field test

The user testing was conducted as a field test in which police officers wore the equipment vest with integrated ballistic protection during work for a test period of at least four weeks. The user testing was carried out in five of the seven different regions in Sweden. In total, 95 full-time police officers (26 female/69 male) participated. Information about the participants is presented in Table 2. Data was collected before, during, and after the test period, as illustrated in Figure 6. The individual structured interviews conducted both before and after the test period, aimed to evaluate the differences in comfort between duty belt and the vest. Furthermore, the participants reported in a daily work diary the activities they had done during working hours, the comfort of their vest during the day, any musculoskeletal discomfort experienced, and whether the arches were used. The instructions to the participants were that they should wear the vest during all work shifts and with the arches inserted for approximately 50% of their work shifts. The participants were randomised to start either with the arches or to insert them after half of the evaluation period (approximately after two weeks of work). On the starting day (Figure 6), the participants received training on wearing the vest and how to equip it. However, the specific equipment and its placement within the vest varied based on personal preferences. The training involved similar tests as those used in the pilot test, aiming to make the participants feel confident and secure in their equipment setup. Vest 1.1 was worn by police officers in regions Stockholm and Mitt. The police officers in region Norr had the opportunity to wear both vest versions 1.1 and 1.2 during an extended test period. This specific group could report to the operating group about differences experienced in the vest design. In regions Syd and Väst, model 1.2 was tested. When the test period was over, the participants were invited to an evaluation day. During that day, the participants evaluated how they experienced the usability of the vest. The user evaluation was conducted through individual structured interviews but also with focus groups interviews. In total, eight focus group interviews, with 6–8 participants in each group, were conducted in regions Stockholm, Mitt and Norr after the test period; in regions Syd and Väst, only individual interviews were conducted as data saturation was reached for the focus groups. The focus groups interviews aimed to discuss and evaluate the overall experiences of the usability; functionality, comfort, safety and signal value of

the vest. Questions regarding functionality included inquiries such as: ‘Tell us about your thoughts on the function of the vest in everyday work? When does it work better or worse?’ Comfort-related questions encompassed queries like ‘How does wearing the vest feel on your body?’ and ‘How does the vest feel when driving or being a passenger in a vehicle?’ Safety-related questions addressed participants’ sense of security with the vest and the placement of equipment. In terms of signal value, participants were asked if the public had made any comments or reflections regarding the vest. The structured interviews were analysed descriptively, and thematic analysis (Braun and Clarke, 2006) was used to analyse the focus group interviews. The complete results from this extensive data collection, aimed at evaluating the functionality of the vest and comparing it with the duty belt, will be reported elsewhere. The primary focus of this paper is to describe the user-centred development process and how users contribute to designing the vest, making it suitable for their needs while also meeting the requirements of the Police Authorities. The analysis of interviews revealed that police officers were highly satisfied with the concept of using an equipment vest in their daily work, as exemplified by this quote from a police officer in Region Mitt:

“The vest has been fantastic for the body, I think especially, and while driving as several have already said, it has made a tremendous difference.”

Complaints about warmth were frequently voiced by users of vest 1.1, leading to a fabric change in the subsequent model, 1.2. This modification resulted in improved ventilation and a more comfortable vest. As stated by a police officer in Region Norr:

“I have a much more consistent body temperature, and this is related to the fact that we face extreme temperature fluctuations, perhaps from minus 20 to plus 20 [degrees Celsius] –[the vest] it’s truly revolutionary...”

However, several issues were reported that drove further vest design enhancements. For instance, users highlighted safety-related issues, such as equipment pouches being too loose, making it difficult to quickly insert equipment. In some cases, police officers had to discard OC-spray after use because it was too complicated to put it back on the vest in specific situations. Another identified issue was inadequate conspicuity in traffic situations.

The Police Authority’s requirement to avoid conveying a military impression to the public did not pose a major concern. As expressed by a police officer in Region Stockholm, “the public hasn’t made any comments, and I haven’t perceived that they haven’t recognised that it’s a police officer; they haven’t misunderstood”. Another police officer mentioned, “the signal value is good; it looks more substantial with the vest, and that’s a positive aspect...” (Police officer Region Norr). A summary of the identified issues reported by users and their impact on vest design is presented in Table 3.

3.2.2.4 Sub-study 2 – pressure measurements

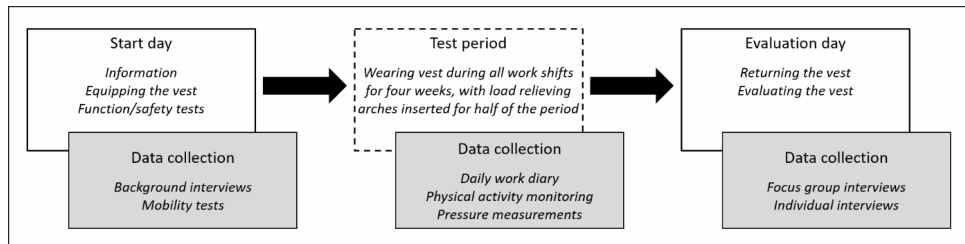
Sub-study 2 was an experimental study, which aimed to investigate the load, expressed as contact pressure between the equipment vest and the shoulder region, with and without arches. In addition, self-reported discomfort associated with wearing the equipment vest with or without the integrated arches was investigated. In total, 50 police officers (13 women/37 men), who also participated in the usability test, from the three regions (Stockholm, Syd and Väst), were included in the experimental study (Table 2). As there

is no standard application for measuring contact pressures in the shoulder region while wearing protective equipment and clothing, sensors originally designed for plantar pressure measurements were adapted and combined to fulfil this requirement. Pressure measurement sensors, TekscanTM, were affixed to the skin over the shoulder region, and participants wore their standard uniform and equipment vest over these pressure measurements sensors while performing the tests. The standardised tests were designed to simulate a high load on the shoulder region and included jumping and simulated driving while turning the steering wheel to its maximum end stop. Fourteen participants wore vest version 1.1, and 36 participants wore vest version 1.2. The sensors measured pressure against the body from the equipment vest with and without the arches in isolated, specific maximum stress situations. Pressure data were analysed in three anatomical regions representing the front, proximal and posterior areas of the shoulder region. All participants used the vest with and without the arches. Furthermore, data on perceived comfort during work were collected through structured interviews and were analysed descriptively.

Table 2 Characteristics of the study participants in the usability study and the sub-sample who participated in the pressure measurement study

<i>Participants in sub-study 1: user field test</i>	
Female/male	26/69
Body length, mean (min-max)	179 cm (162–201)
Body weight, mean (min-max)	80 kg (58–120)
Age, mean (min-max)	32 years (23–63)
Years as a police officer on active duty	5.8 years (0.5–33.0)
<i>Participants in sub-study 2: pressure measurements</i>	
Female/Male	13/37
Body length, mean (min-max)	180 cm (162–201)
Age, mean (min-max)	32 years (23–53)
Years as a police officer on active duty, mean (min-max)	5.7 years (0.5–26)

Figure 6 Data collection process



3.2.2.5 Researchers report – summary from usability testing

Phase 2 (Figure 3) was concluded with the research team reporting the findings from the usability test in a written report. Also, an oral presentation of the findings was given to the project management, which included the reference group and steering committee. The written report served as a basis for the higher police management to decide on the implementation of the vest within the organisation. The report encompassed findings related to the design aspects of the vest, as well as the comprehensive usability evaluation of the concept of wearing an equipment vest with integrated ballistic protection during active duty. The research team concluded that the usability testing and pressure measurements showed that an equipment vest with integrated ballistic protection was functional and user-friendly within the Swedish police force. Moreover, the findings from the usability testing supported that an equipment vest with integrated ballistic protection would be a new supplement to the regular uniform assortment. However, the report also included information to be considered with regard to advantages and disadvantages of both vest versions tested and that further development was needed if the vest was to be included in the uniform assortment (Table 3). For example, the researchers suggested that the arches should not be included in further versions; instead, other materials for padding the shoulder straps were recommended. In vest 1.2, a reflective visibility cape was integrated into the vest. The cape could be folded out when police officers needed to change conspicuity (e.g., during assignments in traffic or in major sporting events), and this was perceived as useful. However, when tested in the field, it also emerged that it was not sufficient in some situations, and it became clear that other accessories to increase conspicuity were needed as a complement. Furthermore, the suspension system as well as the adjustability for a well-fitted vest needed to be improved. The usability test had shown that a well-fitted vest was very important for the overall comfort and functionality. Hence, development of the vest's suspension was a key point to be addressed in the further development, especially if the vest was to be implemented as part of the uniform assortment. Ensuring the right size and instructions for adjustments to obtain a well-fitted vest were found to be key aspects of the potential implementation process. Therefore, the research team highly recommended an information package and training for personnel in the uniform and equipment storage sites throughout the organisation. Finally, the research team recommended a structured implementation and follow-up on the vest over time.

Based on the results from the usability testing and together with the results from the testing of the ballistic protection, the decision-makers at the Swedish Police Authority decided that the uniform assortment for police officers on active duty should be supplemented with an equipment vest with integrated ballistic protection but without arches. This decision resulted in revisions to the regulations for uniforms and equipment, so that an equipment vest was allowed for use by police officers on active duty (Polismyndigheten, 2022b).

Table 3 Issues identified by the users regarding function, comfort, and safety factors for improvement in the further development of the equipment vest

<i>Model</i>	<i>Issues identified</i>	<i>Improvement suggestions</i>	<i>Implemented changes</i>
1.1	Closing the vest is too complicated.	Improve the suspension system.	Replaced Velcro closures with snap buckles.
	The vest feels too warm and bulky.	Change to a more ventilated fabric.	Utilised a more breathable fabric.
	Adjusting the vest to tighten it around the torso is difficult.	Improve adjustability for a better fitting.	Made changes to enhance adjustability.
	The equipment pouches are too sloppy, making it difficult to quickly re-insert equipment with one hand after use. For instance, OC-spray was hard to insert after use.	The equipment pouches needed to be more stable.	Several variations of equipment pouches were made available for the police officers to choose from.
	The pocket is too tight to easily accommodate the reinforcement plate. One needed a colleague's assistance to insert the plate, and the top placement of the opening further complicated the insertion.	Enlarge the pocket for reinforcement plate insertion and consider adjusting the placement of the opening to facilitate easier insertion.	Modified the pocket to allow for easier insertion.
	External conspicuities products, such as reflective vest or bands, needs to be brought complementary.	Improve the flexibility to change conspicuity.	Integrated a reflective cape on the back of the vest for easy adaptation when needed.
1.2	Using snap buckles to fasten does not allow for a snug fit.	Further improvement of the suspension system.	The system with snap buckles was abandoned and a new Velcro system was developed.
	Same as mentioned above.	Further improvement of adjustability for a better fitting.	Additional changes were made to enhance adjustability.
	There are too few attachment points compared to vest 1.1, making it difficult to create space for all the equipment.	Increase number of attachments points.	More attachment points were implemented.
	There are no clear advantages with the arches, and sometimes it is complicated to insert them correctly.	Use padding for the shoulders instead of arches.	The system with arches was abandoned, and alternative solutions were implemented.
	The reflective cape is insufficient for ensuring visibility in certain situations.	More accessories for conspicuity were needed.	Additional accessories, such as reflective armbands, were produced as complementary items.

Note: The right column describes the implementation status of the suggested improvements in the next prototype.

3.3 Phase 3 – refined development of the vest

After the decision by the police management, further refinements of the vest based on the results from the testing of vests 1.1 and 1.2 could be undertaken. Vest 1.3, featuring new fabrics, improved suspension for a better fit, redesigned shoulder straps, and a reworked MOLLE system, was developed. During this phase, the evaluation was handled internally by the design team as the research team's assignment only extended to the reporting in the previous phase. However, the design team used a group of ten 'super users' who had tested the previous vest versions to evaluate vest version 1.3. Following the test period of two weeks, the super users provided feedback to the design team. The tested vest was perceived as good, no further changes were done to the final implementation-ready vest, version 1.4. However, due to procurement agreements change of fabrics were required. There are plans to implement the use of the vest in the Swedish police force during the coming years with a start in 2023.

4 Discussion and conclusions

This paper describes a user-centred development process for an equipment vest for the Swedish police force and how external researchers were involved in the evaluation. To the best of our knowledge, this is the first paper describing a user-centred design process in the context of a police organisation. The result of the user involvement is a well-tested and functional equipment vest to be used by police officers on active duty. In total, four iterations were needed between the designers and users of various vest prototypes before the final implementation ready vest version was agreed upon.

In this section, we, from the researcher perspective, will reflect about how we, as external partners, contributed to the project and important factors to consider in similar project organisations. First, a major part of this paper focused on the most extensive part of the project the usability evaluation, which was the second phase of the development process (Figure 3) and in which the researchers were involved in order to supply the police management with a non-biased evaluation. The researcher team possessed specific knowledge about the physical work environment of police officers on active duty as well as knowledge and experiences in ergonomics/human factor research in various work environmental contexts. Their competences in biomechanics, ergonomics, and overall work health were important for the evaluation. The police organisation gave the overall responsibility for the evaluation to the researchers, who planned the evaluation independently. The police organisation assisted with the recruitment of the participants and premises for meetings and testing. A mixed-methods approach, including objective measures (pressure measurements) and subjective measures (interviews, focus groups interviews), was used to collect data, which were necessary for the development process. Using such an approach gave provided valuable information regarding design aspects, as well as insights into the overall usability of the equipment vest and user experience and acceptance. Through this methodology, the researchers gained valuable insight and understanding of police officers' experiences of wearing the vest in their daily work, which they conveyed to the project manager and design team. The police officers appreciated external researchers conducting the evaluation; they trusted the competence of the researchers and thought it contributed to objectivity and rigour, ensured that their opinions were taken into account and reported in the project. As described by van

Oorschot et al. (2022), the researchers' role could be described as both facilitating and directing designers in the development process. However, the researchers themselves did not take on any design roles.

The key principles of an iterative user-centred design process (Gulliksen et al., 2003) were in focus throughout the development process. Since the equipment vest is essential for safety and functionality in police work, it was vital from the beginning that the project was developed, planned and conducted with a user-centred approach to accommodate the users' involvement in all phases. Initially, it was difficult to satisfy some of the requirements that the users had for the vest's design. Police work requires the adaptation to different body postures and activities (Ramey et al., 2014); consequently, police officers have high demands for a well-fitting vest and equipment and need to be able to put on/off and adjust the vest independently. The design of a suspension system for a speedy on/off and for a snug fit was a huge challenge throughout the different versions of the vest. Here, it became very clear how the user's involvement contributed to the design; several design iterations were needed before a useful and suitable design of the suspension mechanism was satisfactory for the users. In addition, the need to have a large area to place the equipment on the frontal part of the vest was hard for the developers to foresee. This was also a detail where the user's involvement was necessary for a noble design that is suitable for the police officers' needs. Furthermore, the fabric and temperature adjustment possibility of the vest was an aspect that could not be evaluated satisfactorily if the vest had not been tested in different regions, with different weather conditions, and in different work situations. Through the extensive testing, the selection of adequate fabrics was made early in the design process and could be tested and improved in following iterations. To have the right fabric is of great importance prior to large volumes of vests being produced.

Although user involvement in projects has benefits, it can be challenging (Kujala, 2003). This project was led by the Swedish Police Authority, through which the user involvement was sanctioned. More than 100 users were involved in pilot test and usability evaluation. Since the users were police officers on active duty, a thorough planning and organisation was needed to ensure the users were available on the start-up day, evaluation day and for the pressure measurements. A successful factor to achieve this was the project manager who coordinated the organisation of the different activities in the project. The reference group was helpful in anchoring the project in the different regions, and knowledge about the project was distributed throughout the police organisation by the communicator via e.g. the intranet and internal newsletters. As a result of this strategy, the project was well known in the whole organisation throughout the project period. The project manager worked in close collaboration with the designers as well as the researchers and the police managers in different regions and in the head office. The project manager also had deep knowledge about the context of the users, which facilitated the implementation of the project. The project was highly sanctioned and prioritised by the highest management in the police organisation, which is an important factor for successful participatory projects (Wilson et al., 1997, 2005). The time schedule for the project was well planned, lasting several months. The project had a set end date from the beginning, and all processes were to run in parallel during this period. Combining a practical product development with a rigorous research process can be challenging, since those separate processes may be happening at different speeds. In the present project, the experience was that the practical product development process was much faster. When the different processes are not in sync speed-wise, it increases the

risk of a shortfall in communication, which may cause irritation between the members of the operating group (here, researchers and designers). To handle this, it is extremely important that the members in the operating group have good knowledge of and respect concerning the different roles, a good communication between the involved teams and frequent recurring reconciliations are needed. Hence, the role of the project manager is of great importance from the overview perspective and the coordination. In the present project, the project manager's background, having competence in both ergonomics and human factors as well as experience of working with the police organisation, facilitated the communication. Comprehensive planning with frequent reconciliations during the process made room for adaptations at the speed of the practical product development process, making it possible for the researchers to gather and analyse data and deliver results iteratively. This contributed to the fact that the vest could be developed, tested extensively and evaluated thoroughly.

One can discuss whether it was necessary to involve so many participants in a product development project. This project resulted in a huge amount of data (information from the users); thus, many users had the possibility to give feedback and their point of view regarding the equipment vest and their needs for a functional product in the police officers' context. However, the users' opinions did not significantly vary between the different regions, so it would have been sufficient with fewer involved users. Lai et al. (2010) studied the role of user-centred design for project outcomes and found that more interaction with users does not correlate with better outcome (Lai et al., 2010). It is also reported that somewhere between 5–20 users are needed to discover all the usability problems in a design; however, user involvement should be based on the unique context of each particular study (Macefield, 2009). Consequently, it would have been cheaper for the project if fewer police officers were involved in the user testing. This is because then it would have been sufficient to produce only a few vests and fewer resources would have been used. However, the advantages of more police officers being involved were that the data were validated and different perspectives were taken into account. The involvement of about 100 police officers represents approximately 1% of the Swedish police force on active duty (Hagström, 2021). Many users gave feedback regarding their needs and the function and usability of the vest, which ought to result in a robust design. Further advantages of having so many users involved were that it created a commitment, and the participants moved from being 'only' participants to being active partners in the process. The design team could easily check changes in the design with the users. Furthermore, having so many users involved was also a way to consider the needs of the various regions. The police officers expressed that their participation brought a feeling of shared ownership.

In conclusion, the user-centred development process contributed valuable insights to the development of the vest. This approach provided a thorough basis for decision making and a well-accepted product among the users. This comprehensive project has shown the importance of a dedicated and multi competent project manager since the involvement of many actors, such as designers, managers, users and researchers, requires good coordination. It is anticipated that the description of this user-centred development process will serve as a guide for future development projects of occupational personal equipment. The overall outcome of this project is a new carrying system that will improve the physical work environment for police officers on active duty.

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