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Case Study: Fit Evaluation of Protective Gloves Made of Elastic and Non-elastic Textile Materials

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Abstract
The main objective of the study was to evaluate two fit testing methods for protective gloves using anthropometric measurements. The gloves differed in terms of textile materials (woven fabric without elastomeric fibres and knitted fabric with elastomeric fibres), with and without size allowances, respectively. The evaluation method proposed may supplement the standard glove fitting procedure given in Standard EN 420:2003+A1:2009. The standard specifies only a method for measuring hand circumference and length, while the Authors used an original approach to measure the length and width for the purposes of glove fitting. The objective of the case study was to determine the optimum size difference between the protective glove and the user's hand. The methodology developed shows how to evaluate gloves made of woven or knitted fabrics with or without elastomeric fibres in the context of glove fitting, which has direct implications for user comfort and the safety of manual work.

Key words: *protective gloves, textile materials, fit evaluation.*

Introduction

One way of improving worker comfort is to provide gloves that are appropriate in terms of their protective and ergonomic properties [1]. Of particular importance is glove fit, which is essential to ensuring dexterity, precision, and firmness of grip while performing occupational tasks [2]. Gloves often need to provide simultaneous protection against multiple hazards and incorporate materials of different area densities with a view to improving user comfort. In the case of many of those hazards, it is important to minimise donning and doffing time and prevent the separation of glove layers (e.g., in firefighting gloves), which is also directly related to glove fit. Too small gloves not only induce user discomfort, but may additionally accelerate loss of protective function. On the other hand, too large gloves may not offer adequate protection, while also hindering the performance of occupational tasks [3-6]. The type of occupational hazard determines glove design as well as glove materials, including their area density [7]. Depending on the degree of precision required, workers may use more or less well-fitting five – or three-fingered gloves or mittens (***Figure 1***). Gloves protecting against light and moderate mechanical injuries are usually made of leathers and woven fabrics, or woven and knitted fabrics partially or wholly coated with plastic or rubber. Such gloves may also be made of fabrics knitted from polyester, nylon 6, polyamide, aramid, Ultra-High Molecular Weight Polyethylene, and core-spun yarns. Hand protection products designed to protect users from heavy mechanical damage are made of steel meshes. In turn, heat-protective gloves consist of multi-layer woven or knitted systems incorporating Kevlar®, Nomex®, Twaron®, Preox®, PBI, as well as cotton and woolen yarns impregnated with fire-resistant agents. Other materials used for these applications are rigid aluminised fabrics and heat resistant leathers. Thermoinsulating inserts are typically made of nonwovens, acrylic or

Figure 1. *Examples of glove designs determined by type of hazard: a) fitted gloves made of polyamide fibres highly resistant to cuts, protecting against light and moderate mechanical injuries, b) large mittens made of several layers of fabrics including an insulating heat-resistant nonwoven (source CIOP-PIB).*

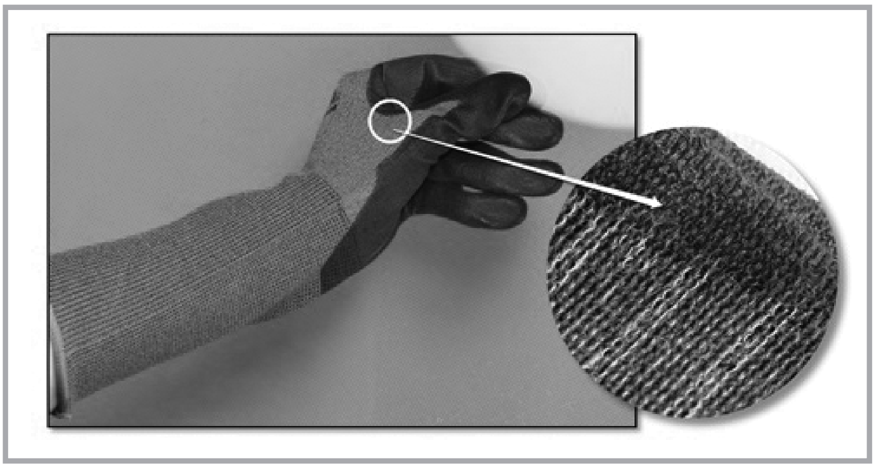


Figure 2. *Cut-resistant gloves made of knitted fabric from strong polyamide fibres with the addition of elastomeric fibres, ensuring an ergonomic glove fit (source: CIOP-PIB).*

woolen knitted fabrics, artificial fur, or polyamide foam. In turn, gloves providing simultaneous protection from several hazards contain multiple layers of the aforementioned materials. In the case of exposure to noxious chemical substances, protective gloves are made of a variety of rubbers (e.g., natural, polychloroprene, polyacrylonitrile, butyl, and Viton rubber) and plastics (e.g., polyvinyl chloride, polyvinyl alcohol, polyethylene, and Hypalon).

Protective glove designs have incorporated many of the emerging textile technological solutions initially developed for sports products. Indeed, the popularity of modern sports gloves (e.g., for martial arts, water sports, winter sports, cycling, climbing, etc.) has inspired the users of protective gloves, who increasingly expect comparable levels of comfort in the workplace. Thus, the intensive development of materials technology and design advances initiated in sports products have led to the introduction of new ergonomic solutions in protective gloves [8]. As a result, commercially available protective gloves exhibit a strong affinity to the design and technologies used in sports gloves, especially in terms of fit-improving elastomers. The incorporation of elastic textile materials (knitted fabrics and woven/knitted fabrics containing elastomeric fibres) between the fingers or in the dorsal part of the glove ensures a safe fit and an ergonomic grip (***Figure 2***). The strategically positioned elastomeric parts improve manual dexterity during the performance of tasks and improve tactile sensation during object gripping and moving. Thus, the design of protective gloves largely depends on their intended purpose and the degree of protection they are expected to offer. In turn, the type of fabric used depends on the raw material, yarn, fibre, weave, fabric structure, chemical finish, etc. Currently, protective gloves employ state-of-the-art fibres, ranging from carbon and aramid fibres to unconventional elastomers, which have considerably altered and modified glove fit [9].

Improvement of the functionality of protective gloves implies the development of fit assessment methods. The current requirements contained in the standards designed to assess the compliance of such personal protective equipment (PPE) with Directive 89/686/EEC (as of April 21, 2018 Directive 89/686/CEE becomes replaced by Regulation (EU) 2016/425 of the European Parliament and of the Council) also concern sizing with respect to mean anthropometric data. Actually, only the minimum length of gloves is measured by a method specified in the standard [10]. The length of the glove is measured by suspending it from the middle finger on a ruler with a rounded tip matching the tip of the finger. The minimum glove length recorded in this way is compared with the sizing table to determine the glove size.

In terms of ergonomics, it is necessary for measurement methods to reflect the work environment in which the protective gloves are used [11]. In this context, one should consider the anthropometric factor to ensure optimum PPE fit to the dimensions of the human body. For instance, an anthropometric atlas provides specific data on the anatomical features relevant for sizing and is the most widely used reference for this purpose [12-15]. The atlas contains outlines of the human body, with each feature denoted by a number corresponding to values contained in tables. Anthropometric data are given for three cases: the median (50 th percentile) as well as the bottom (5 th) and top (95 th) percentiles of the population, both for males and females. For clarification purposes, it should be noted that 5% and 95% of the population fall below the sizes given for the 5 th and 95 th percentiles, respectively. The top and bottom percentiles are also known as the threshold percentiles. A good fit of protective gloves is of paramount importance as they should enable workers to reach a high degree of manual dexterity.

Occupational exposure of workers' hands entails the need to ensure an appropriate level of protection by means of sufficiently resistant gloves. It should also be remembered that gloves should be well-fitting to enable good manual dexterity during the performance of routine manual tasks. From the point of view of worker safety, poorly fitting gloves may lead to workplace accidents due to restricted movement. For instance, Tremblay-Lutter et al. noted that such gloves (especially those ill-fitting in the region of the fingers) impair dexterity largely due to the materials used [16]. In turn, Muralidhar et al. [17] focused on gloves providing selective protection in which varying levels of protective material may be introduced in different parts of the glove to ensure protection where it is most needed while affording superior manual dexterity. However, the largest body of research into the effects of glove material (thickness, number of layers) on fit concerns all-rubber gloves for chemical protection (in the chemical industry, chemical labs, beauty parlors) and biological protection in medicine (used by surgeons, dentists, nurses, veterinarians) [18-20]. According to Hsiao et al., there is currently no adequate sizing scheme for protective gloves, while those based on the PPE standards seem insufficient. In their study of 863 male and 88 female firefighters in the United States, as many as 24% to 30% of men and 31% to 62% of women reported problems with glove fitting (the study encompassed an age-, race/ethnicity-, and gender-stratified sample, and fourteen hand dimensions were measured to develop an improved sizing plan for protective gloves) [21].

Although protective gloves are indispensable in the workplace to protect workers against hand injury, they may adversely affect other safety-related issues, such as task completion time, precision, tactile sensitivity, strength, manual dexterity, and range of motion. Therefore, reliable fit testing protocols are of great importance for glove manufacturers with a view to product improvement. Indeed, it seems critical to determine how to best fit protective gloves made of various elastic or non-elastic materials.

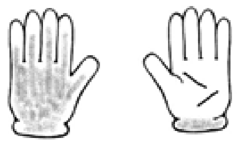
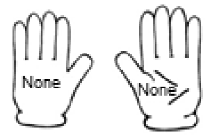
The objective of the study was to verify fit testing methods using manual anthropometric measurements for two types of protective gloves made of elastic or non-elastic textile materials. The original research was designed to determine the optimum size difference between the protective glove and the user's hand. The problem is presented on the basis of a case study of the fit evaluation of gloves made of materials very different in terms of their elastic properties.

Materials

The samples studied included work gloves offering protection against mechanical factors (variant A) and both mechanical and thermal factors (variant B). The gloves were described in terms of the following features (***Table 1***):

- basic information about product type and purpose, including number of fingers,
- type of glove material,
- location of elastomeric fibres in the glove in the dorsal and/or palmar regions,
- number and type of all materials in the dorsal region: number and arrangement of layers, including the liner, insert or filler, and external layers.

Table 1. *Characteristics of sample gloves made of elastic and non-elastic textile materials studied.*

Glove designation		Variant A Elastic textile materials	Variant B Non-elastic textile materials
Photograph			
Glove type		Five-finger gloves	
Glove material	Dorsal aspect	Polyamide knitted fabric with elastomeric fibres	Cotton woven fabric with out elastomeric fibres
	Palmar aspect	Polyamide knitted fabric with elastomeric fibres coated with polyacrylonitrile rubber	Cotton lining without elastomeric fibres and synthetic leather
Presence of elastomeric fibres		Yes Dorsal aspect Palmar aspect  Location of elastomeric fibres (shaded)	No Dorsal aspect Palmar aspect  Location of elastomeric fibres (none)
Purpose		Protection from mechanical hazards	Protection from mechanical hazards and low temperature

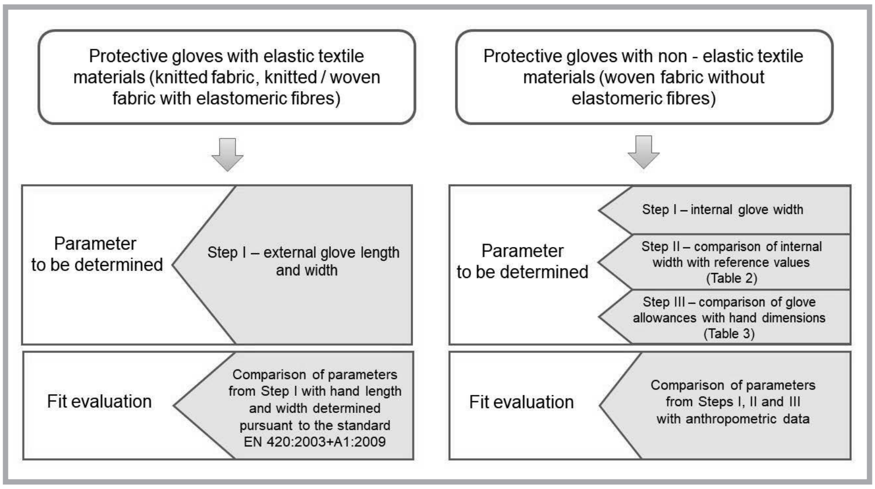


Figure 3. *Two procedural variants for glove fit evaluation developed in this study.*

Research methodology

The study evaluated the fit of two protective glove variants selected for the materials used in them. Due to the fact that glove stretchiness arises not only from the presence of elastomeric fibres, but also from the very properties of knitted materials, the following classification of gloves is hereby proposed for the purposes of glove sizing:

- gloves made of elastic textile materials (knitted fabric, knitted/woven fabric with elastomeric fibres).
- gloves made of non-elastic textile materials (woven fabric without elastomeric fibres).

The size of elastic gloves (variant A) was measured pursuant to Standard EN 420:2003+A1:2009 [10]. In turn, the size of non-elastic gloves (variant B) was measured on the basis of data from an anthropometric atlas, taking into account fabric allowances [12]. This difference results from the fact that elastic gloves offer very good fit, and thus no allowances are needed. The measuring procedures for protective gloves A and B are given in ***Figure 3***.

The external dimensions of elastomeric gloves (variant A) were measured using a semi-rigid ruler (Format Professional

Table 2. *Minimum glove length and width for different hand sizes.* ***Note:*** ** Requirements concerning minimum glove length pursuant to the standard EN 420:2003+A1:2009 [10]. ** Requirements concerning minimum glove width were determined based on CIOP-PIB studies taking into account sizing guidelines with respect to the palm circumference according to EN 420:2003+A1:2009 [10].*

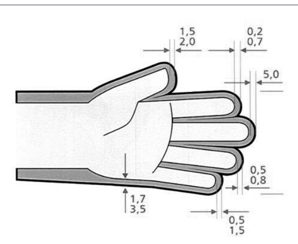
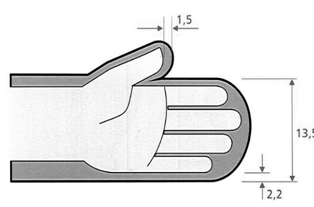
Hand size	Minimum glove length based on the length of the hand of the corresponding size, mm*	Minimum glove width based on the circumference of the hand of the corresponding size, mm**
6	160	80
7	171	92
8	182	105
9	192	118
10	204	130
11	215	143

Table 3. *Minimum and maximum internal glove width (requirements were determined based on literature references 10 and 12).*

Internal glove width	
Glove size	Minimum and maximum width, mm ($V_{min} \div V_{max}$)
6	74-76
7	80-89
8	86-102
9	92-115
10	98-127
11	104-139

Figure 4. *Digital inside caliper used for measuring the internal dimensions of protective gloves.*

Table 4. *Allowances added to hand dimensions in protective gloves [12].*

Five-finger gloves
The diagram shows mean and maximum allowances [cm] added to hand measurements

Width allowance: maximum: (+ 3.5 cm), mean: (+ 1.7 cm)
Mittens

Width allowance: (+ 2.2 cm)

Quality, Germany). The measurements were compared with the minimum values for different hand sizes (***Table 2***). Since the gloves met the minimum requirements, they were qualified for the next evaluation step.

The standard EN 420:2003+A1:2009 [10] specifies only a method for measuring hand circumference and length. The Authors used an original approach to measure glove length and width (***Table 2***) with a view to determining the optimum size difference between the protective glove and the user's hand. Here, the reference values were the minimum glove length given in EN 420:2003+A1:2009 [10] and the minimum width of the glove fitted to the hand [12].

The anthropometric properties of gloves made of non-elastic fabric (variant B) were determined in three steps. Our measurements were compared with anthropometric measurements conducted by the Institute in 2010 on a large population of users [12]. First, the internal width of gloves was compared with the min-max values given in ***Table 3***. Second, it was checked whether that internal width corresponded to a given glove size (whether it was not too tight). Finally, the size of allowances was taken into account.

This procedure was conducted to determine whether the external dimensions, after subtracting allowances, remained within the appropriate size range (***Table 3***), ensuring user comfort. The detailed protocol is described below.

Initially, the internal glove width was measured using a digital inside caliper (Uni-Max, Czech Republic). The caliper was placed in the glove below the finger line (***Figure 4***) and gradually spread open until resistance was felt. The result was the smallest recorded value rounded to the nearest 1 mm. In the second step, it was determined whether the internal glove width was within the min-max range (***Table 3***) established on the basis of anthropometric data on hand length and width [10, 12, 15].

The third step involved the evaluation of allowances by comparing step II results with the table specifying mean and maximum allowances (***Table 4***) [12]. According to the atlas, mean allowances refer to allowances in leather and fabric gloves, while maximum allowances refer to those in thermoinsulating gloves (or other hand protection products consisting of multilayer systems). Subsequently, the allowances were subtracted from the internal width of the gloves. The glove passed this measurement if the resulting difference was within the min-max requirements for a given glove size. Then, the measurements were compared with the minimum values obtained based on hand size. Gloves for which the results indicated a good fit were deemed to pass all three steps of the evaluation process.

Results and discussion

Prior to discussing the results of the present study, its limitations related to the small number of measurements and glove types should be acknowledged. Nevertheless, the paper concerns an issue that is significant from a utilitarian point of view and addresses the needs of workers, many of whom complain that protective gloves selected pursuant to the standard EN 420:2003+A1:2009 [10] do not fit well. Hence, it is necessary to conduct research into an appropriate methodology with respect to the requirements of that standard. To ensure work safety, glove sizing should also take into account allowances which are not covered by EN 420:2003+A1:2009 [10]. The gloves in-

__Table 5.__ Measurement results and glove size evaluation (variant A).

External length and width							
Size stated by manufacturer	Glove no.	Glove length measured	Glove length	Measurement uncertainty k=2, confidence approx. 95%	Glove width measured	Glove width	Measurement uncertainty k=2, confidence approx. 95%
		mm	mm	mm	mm	mm	mm
10	1	268	268	± 0.5	133	133	± 0.5
	2	268			133		
Interpretation						Pass	

__Table 6.__ Measurement results and glove size evaluation (variant B).

Step I	
Internal width (I_w)	(116 ± 0.5) mm
Step II	
Minimum and maximum values ($V_{min} – V_{max}$)	98-127 mm
Step III	
Allowance (A)	17 mm
Internal width less allowance $I = I_w A$	99 mm
Interpretation	**Pass**

cluded in the present study are examples of five-finger gloves with and without allowances. Allowances are not used in gloves made of knitted fabrics and woven fabrics with elastomeric fibres, as such gloves are characterised by a better fit. On the other hand, gloves made of woven fabrics without elastomeric fibres need to have allowances in the fingers to compensate for any fitting discrepancies. Work in such gloves increases occupational hazards due to impaired dexterity, a less stable grip of objects, and the risk of the allowances being caught in the moving parts of machinery. The method of calculating the size of allowances presented is based on an anthropometric study conducted by the Institute on a large working population concerning, amongst others, hand length, width, and thickness [12]. The results for knitted five-finger gloves made of elastic textile materials (variant A) do not include allowances (see ***Table 5***). On the other hand, mean and maximum allowances were defined for five-finger gloves made of non-elastic materials (variant B, see ***Table 6***). Thus, two different approaches were used for two types of gloves, as an allowance determination method for elastic gloves (variant A) would lead to zero results (no allowances).

It should be noted that this is the first study to focus on this aspect of glove sizing. Most research focuses on the effects of gloves on user comfort, task completion time, precision, tactile sensitivity, strength, manual dexterity, and range of motion [22]. The development of glove fit methods has been described by several authors, but usually only with respect to two or three hand parameters, that is, length, circumference, and width. Viviani et al. [23] emphasised the advantages of manual anthropometric measurements over, e.g., 3D measurements.

In turn, Kwon et al. [24] identified key dimensions for the development of a glove sizing system (hand length, circumference, and breadth) by analysing the relationships between various hand measures and reviewing literature and industry practices. They also proposed the development of glove sizing systems based on those key dimensions. Rosenblad-Wallin [9] described a method for sizing mittens based upon an analysis of user populations and their hand measurements. New anatomically designed military mittens were developed according to users' needs as well as pursuant to the ergonomic and physiological requirements of dexterity and heat balance. A statistical study involving the anthropometric hand measurements of target users led to the choice of hand length and circumference as the basis for a new sizing system.

According to the literature, the three dimensions that are thought critical to glove sizing are hand length, circumference, and width. In turn, the basic standard concerning evaluation of protective gloves, EN 420:2003+A1:2009 [10], applies the same method for measuring different types of protective gloves. Thus, gloves that pass laboratory tests may still be uncomfortable to wear, that is, they may poorly fit the hand size for which they are designated. The problem is that textile materials differ greatly in terms of elasticity, which is determined by their structure and weave as well as by the fibre and yarn type. Due to the fact that personal protective products may contain knitted fabrics or elastomeric fibres, whose size varies between the unstretched and stretched state (on the hand), there is a real need to develop a new approach to glove fit evaluation. According to the standard, EN 420:2003+A1:2009 [10], one should measure the length of a freely suspended glove. However, in the case of elastic gloves, this would not be appropriate as they would fail to meet the requirements. Indeed, it seems that it would be more accurate to manually measure the internal dimensions of such gloves in a stretched state (as if worn on the hand).

The methodological approach presented addresses the problem above, that is, measurement of elastic gloves in an unstretched state. In the current study, it was found that glove sizing and fitting should involve an additional aspect linked to glove design. The sizing scheme proposed takes into account glove type and the presence or absence of knitted fabric or elastomeric fibres, and thus glove fit should be evaluated with two measurement methods. This is corroborated by reports from other authors. For instance, according to Flynn et al. [25] it is necessary to design alternative-sized PPE using new sizing and fitting methods; the resulting products of which should then be labelled as such.

The present study proposed two approaches. In the case of elastic gloves (Variant A), the external dimensions were measured pursuant to the standard EN 420:2003+A1:2009 [10]. The results (***Table 5***) indicate that the size of these gloves corresponded to the size class declared by the manufacturer. In the case of gloves made of non-elastic materials (variant B), the internal dimensions were measured. The results (***Table 6***) show that those gloves were also within the size range determined by means of anthropometric data, taking into consideration material allowances [12]. In the approach presented, hand circumference was converted into glove width (***Table 2***). In EN 420:2003+A1:2009 [10], hand circumference can be used only to assign glove size, which may generate the aforementioned problems concerning user comfort. The study determined allowances for non-elastic gloves which are critical in glove fitting. This method avoids situations in which the internal dimensions of the gloves would lead to assigning much larger glove sizes to the hand circumference. And it should be borne in mind that protective gloves must not be either too tight or too lose, or else they may contribute to risk at work [26].

The protocol developed can be used to evaluate gloves made of woven or knitted fabrics with or without elastomeric fibres in the context of glove fitting. In subsequent research, the authors intend to compare the methodological approach presented with the results of studies involving human subjects.

Conclusions

The study examined two fit testing methods using manual anthropometric measurements to evaluate protective gloves with allowances (made of non-elastic textile materials: woven fabric without elastomeric fibres) and without allowances (made of elastic textiles materials: knitted fabric with elastomeric fibres). The evaluation method proposed may supplement the standard glove fitting procedure specified in the standard EN 420:2003+A1:2009.

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