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Testing of Protective Gas Masks with an Emphasis on Subjective Opinions

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Abstract: This article focuses on the testing and evaluation of gas protective masks based on subjective aspects, since most studies focus on objective indicators without ascertaining the opinions of those who use gas protective masks. Three types of modern anti-gas protective masks were selected for testing. Multi-criteria decision making and the expert method were used to develop the criteria. Mathematical relationships were used to evaluate the test results. For the purpose of testing, a methodological procedure was developed that integrates the established subjective criteria. The test results identified the key parameters in evaluating gas protection masks; at the same time, the results pointed out the possible shortcomings of the OM-90 anti-gas protective mask and its use in the civilian sector. By evaluating the data, the most appropriate gas protective mask was selected that best met the subjective criteria. The study provides insightful findings for decision support in the field of civil protection material but also protective equipment of rescue units. It is the subjective assessment that is essential in a comprehensive evaluation of the quality of gas protective masks, as the user himself often perceives the quality of the product differently from the manufacturer.

Keywords: gas protective mask; subjective assessment; testing; quality; civil protection; safety

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Citation: Kubás, J.; Kollár, B.; Tonhauser, M.; Ristvej, J.; Petrlová, K.; Blažková, K. Testing of Protective Gas Masks with an Emphasis on Subjective Opinions. *Appl. Sci.* **2024**, *14*, 7179. https://doi.org/10.3390/app14167179

Academic Editor: Dibyendu Sarkar

Received: 15 July 2024
Revised: 4 August 2024
Accepted: 13 August 2024
Published: 15 August 2024

1. Introduction

This paper presents the results of research focused on the assessment of design specifics of protective equipment, which is implemented at the Faculty of Safety Engineering, University of Žilina, with the support of other departments. The subject of the research is mainly the testing of protective equipment used by the units of the integrated rescue system and civil protection units of the population. The research focuses on the objective characteristics of protective equipment but also on the characteristics that are perceived by its users. It is therefore a subjective assessment, similar to the study focused on protective clothing [1]. Here, attention has been given to the establishment of test criteria for the purpose of subjective evaluation as part of an overall assessment of the quality of protective anti-chemical and anti-gas clothing [1,2]. This paper builds on the authors' research activity and focuses on the testing of protective gas masks with an emphasis on subjective evaluation.

Subjective evaluation is particularly important in the area of decision-making on the choice of an appropriate protective measure. The objective characteristics of the protective equipment predetermine the area, the environment, and the use of the protective equipment. However, once these characteristics have been determined, the views of the users of the protective equipment must also be taken into account [1]. Subjective evaluation and monitoring of users' opinions have been the subject of several studies worldwide. A Finnish study focused on the subjective perception of the wearer of insulating protective clothing. Testing has highlighted the impact of protective clothing on the workload and performance of wearers of the clothing, which absolutely must be taken into account [3]. Son et al. [4] point out in their study the importance of subjective opinions and insights of personal protective equipment users. Their aim was to identify appropriate test methods to investigate the impact of personal protective equipment on the mobility of firefighters. The findings provide guidance for the development of improved and comfortable protective equipment [4].

Bourassa et al. [5] have addressed testing of the effect of a protective gas mask on the physiological functions of its wearers. Specifically, they performed four measurements on a sample of respondents. These measurements were conducted without the gas mask and with the gas protective mask at rest and during exercise. The authors focused on measuring exertion index, breathing patterns, and gas exchange. The study demonstrated increased physiological stress on the respondents both at rest and during exertion. Thus, the protective gas mask affects the respiratory stress described by its wearers. The data obtained can be used to inform retrofitting and modification of protective mask designs. However, the authors did not address other technical characteristics, such as visibility in a protective mask or sufficient fit. The evaluations also did not include the views of its users [5].

The tightness of the protective gas mask in relation to the respondent's face type and the prevalence of stubble in respondents has been the subject of research by Hylak [6]. The author's testing was able to confirm the assumption that the unshaven face of the rescuer may have a negative impact on his health in relation to the weaker tightness of the face shield mask. The author also tested the possibility of using a filter-ventilation unit instead of a protective filter [6].

In their study, Su and Li [7] addressed the design of a new prototype protective filter for gas masks. The measurement results confirmed its functionality and the reduction of inhalation resistance [7]. Delice et al. [8] addressed testing of gas protection masks with respect to their suitability during first aid administration. Using a simulation of patient intubation, they tested the suitability of the protective mask, focusing on the fit of the filter. Responders were divided into groups, with one group using no protective mask, the second group using a protective mask with the filter placed in the front, and the last group having the filter placed on the side of the protective mask. The results showed that for this purpose, the use of a protective mask with a filter placed in the front is preferable. A filter placed in the lateral part reduces the mobility of one of the rescuer's hands. However, the study focused only on the selected characteristic of the protective mask as well as the specific activity [8].

The team of authors addressed the potential use of full-face gas protection masks used in the military in the context of the SARS-CoV-2 pandemic. Testing focused on evaluating the Airboss Low Burden Gas Protective Mask in comparison to disposable protective drapes. The aim of the study was to determine whether the protective mask used in the military environment is suitable for use in the civilian sector. The testing was based on ten evaluation criteria. These criteria were, for example, ease of donning, initial comfort, fogging, sealing, or subjective confidence in its protection. A relatively large sample of 61 respondents participated in the testing. The test results confirmed the suitability of the use of full-face gas protection masks used by the military in hospital and civilian environments. The use of this type of protective mask also reduces the cost of procuring disposable protective drapes and overall logistics. Gas protective masks can be easily disinfected and reused [9].

Sýkora and Hylák [10] conducted a subjective evaluation of three Czech and nine foreign protective masks. The subjective criteria included the size of the field of vision, distortion of the view through the mask, vision under the feet, tolerability of the inner half mask, qualitative characteristics of the clamping system, manipulability of the clamping system, the effect of the filter on the user's vision through the mask, the subjective tightness of the mask, whether the mask fits well on the face, intelligibility when speaking, and respiratory resistance. A disadvantage of this evaluation was that the individual subjects who tested the gas masks did not in all cases have a satisfactory protective mask size [10].

However, the above studies provide sufficient evidence to confirm the importance of subjective testing and assessment. The inclusion of subjective evaluation of personal protective equipment and products in general is one of the prerequisites for a comprehensive quality assessment. Quality management, according to the STN EN ISO 9000:2016 [11] series of standards, is a prerequisite for product conformity assessment [12,13]. Quality control, according to ISO standards, is also required by Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC [14]. Protective masks fall under personal protective equipment and are used to protect the face, eyes, and respiratory organs. According to that Regulation, such equipment should be designed in such a way that any restriction of the field of vision, face, or respiratory organs is reduced to a minimum. At the same time, these devices should be designed to prevent chafing and ensure that the clamping systems do not cause problems for users for the needs of rapid deployment and use [14]. The aforementioned properties can also be tested using subjective criteria.

From the above review of studies focusing on the testing of gas protection masks, it is possible to infer some gaps in research focusing on subjective parameters and evaluation. Relatively little attention has been paid to the testing of subjective characteristics. The objective side of the evaluation of protective equipment plays a more significant role [1], but to ensure a comprehensive evaluation, it is essential to consider the subjective side as well [12,13]. The analyzed studies dealing with subjective evaluation had several shortcomings. For example, [8] focused on one specific activity, and only one parameter was monitored. The study focused on a simulated clinical task in the context of SARS-CoV-2, yielding interesting results, but only one type of protective gas mask was compared with disposable drapes [9]. In the area of comprehensive testing focusing on the subjective side of the evaluation, a study entitled focus subjective testing of domestic and foreign protective masks can be an inspiration. However, the shortcomings of this study are its relatively long history of testing and, in particular, the fact that individual respondents did not possess a suitable size of protective mask [10].

The pilot testing of protective masks in the conditions of the Faculty of Safety Engineering focused on the assessment of three generations of protective masks. These were protective masks of the CM-4, CM-5, and CM- 6 types, also known as Guzu CM-6 [15,16]. However, the pilot testing did not have a clearly established methodological procedure and the individual criteria were still subject to consultation with experts. The low number of respondents was also a disadvantage of this testing. Part of the testing also included the determination of face type. However, this parameter later proved to be a complication as it is quite difficult to obtain a sufficient number of respondents representing each of the facial types [16].

The aim of the authors of this paper is to present a new methodological procedure for testing gas protection masks with an emphasis on the subjective evaluation of their users. The methodological procedure allows comprehensive testing of design parameters using subjective opinions of users. The testing also includes a method for evaluating the results obtained from the testing. The procedure allows the selection of the most satisfactory gas protection mask from among the masks selected for testing. The methodological procedure is particularly suitable for the needs of the decision-making process on the inclusion of the selected mask in the material of rescue units and civil protection units as well as in civil protection warehouses for the needs of population protection. The results are also suitable as a basis in the process of development or modernization of the design of gas protection masks. The research also provides an extended answer to the question of whether protective gas masks used in the military environment are suitable for use in the civilian sector.

2. Materials and Methods

Three types of gas protection masks were selected for testing purposes. Namely, they are Guzu CM-6 protective mask (Gumárne Zubří a. s., Zubří, Czech Republic), STS Shigematsu CF01 protective mask (SHIGEMATSU WORKS CO., LTD., Tokyo, Japan), and

OM-90 protective mask (Gumárne Zubří a. s., Zubří, Czech Republic), which is specially manufactured for the needs of the army [15,17–20]. These are modern types of full-face gas protection masks. The OM-90-type protective mask was chosen mainly for the effort to assess the suitability of its use in the civilian sector and in the field of civil protection of the population.

A total of 58 respondents took part in the testing, of which 35 were male and 23 were female. All respondents were aged 20–21 years. Many of them had experience with protective masks prior to testing. All respondents participated in the testing voluntarily. Prior to the final testing, all respondents were familiarized with the different protective masks, the correct procedure for putting them on, as well as the methodological procedure for testing. The dataset obtained from the testing is available upon request from the authors.

2.1. Characteristics of Selected Gas Masks

The STS Shigematsu CF01 protective mask is a Japanese mask providing respiratory protection. This mask is made of thermoplastic elastomer which makes it weigh only 360 g. The panoramic visor made of polycarbonate provides the wearer with an excellent view. The mask is designed for use with protective clothing and a helmet. It has a see-through membrane that facilitates communication with the environment. It is available in three sizes (S, M, L) to adapt to the specific user. The fastening system is based on the principle of six-point straps. A bayonet filter is provided for this type of mask, and its location is on both sides of the mask. The protective mask complies with EN 136:1998/AC:2003 [21] (Class 1), which specifies minimum requirements for face masks for respiratory protective equipment. The STS Shigematsu CF01 protective mask is shown in Figure 1 [18].

Figure 1. STS Shigematsu CF01.

The Guzu CM-6 protective mask is made by a Czech manufacturer and is mainly used in industry, agriculture, chemical and nuclear industries, civil protection units, rescue fire brigades, police units, etc. The material used in this type of mask is bromobutyl rubber, which is harmless to health. The weight of the mask itself is 560 g. The panoramic visor made of polycarbonate provides the user with excellent spatial orientation with minimal distortion. For users who are dioptrically challenged, special spectacle inserts can be used. The clamping system of the mask is based on the principle of five-point rubber-textile straps. As an accessory, the protective filter can be used on both the right and left sides. The mask provides protective functions in the range from −30 °C to +70 °C and meets the requirements of EN 136: 1998/AC:2003 [21] (Class 3). The Guzu CM-6 protective mask is shown in Figure 2 [15].

Figure 2. Guzu CM-6.

The OM-90 mask is actively used by the Czech army. The weight of this mask is 500 g and it is mainly characterized by its resistance to the penetration of poisonous and other dangerous substances. It has a special two-part visor, which allows the use of optical sighting systems and is also compatible with basic military optical instruments and weapon systems. The mask, together with the use of the OF-90 protective filter, provides a high degree of protection. The lens glass used in this type of mask is highly impact- and scratch-resistant. In the event that the wearer of the mask is in a contaminated area, the intake of liquids is made possible by a special device with which the protective mask is equipped. The functional reliability of the mask is in the temperature range from −30 °C to +70 °C and meets the requirements of EN 136:1998/AC:2003 (Class 3). The OM-90 protective mask is shown in Figure 3 [17].

Figure 3. OM-90.

The following Table 1 shows an overview of the technical characteristics of individual gas masks [15,17,18]. This overview can be used for the purpose of compiling objective criteria.

2.2. Evaluation Criteria for Gas Masks

To establish the subjective criteria, as well as to determine their weights, it was necessary to reach out to practitioners and academics. These experts have practical experience with gas protection masks, either in specific interventions or exercises. They also have theoretical knowledge of protective masks. The 4 most suitable experts who have the most experience were chosen by selection, as some of them also work in several organizations in which they come into contact with the given issue. They come from the backgrounds of the factory fire brigade, the Ministry of the Interior of the General Directorate of the Fire Brigade of the Czech Republic and the Institute of Public Protection, academia, and voluntary organizations in the field of civil protection of the population. The subject of the interviews with the selected experts was to determine the criteria and the method of testing.

The selected experts were not influenced by each other's opinions as the principles of the Delphi technique were used. The subjective criteria established are presented in Table 2 along with the assigned weights.

Table 1. Technical characteristics of selected protective masks.

Parameter	Type of Protective Mask		
	STS Shigematsu CF01	**Guzu CM-6**	**OM-90**
Weight	360 g *	560 g	500 g **
Number of sizes	3	1	3
Visor	panoramic	panoramic	two-part
Effective field of view	unknown	70%	73%
Binocular field of view min.	unknown	80%	34%
Speech clarity	unknown	95%	95%
Filter type	bayonet	Rd 40 × 1/7″	Rd 40 × 1/7″
Clamping system	rubber-textile straps	rubber-textile straps	rubber-textile clamp
Liquid intake system	no	yes	yes
Collar material	thermoplastic elastomer	thermoplastic elastomer	bromobutyl rubber
Visor material	polycarbonate	polycarbonate	tempered glass
Sealing line	yes	yes	yes
Temperature tolerance from—to	unknown	−30 °C to +70 °C	−30 °C to +70 °C
Eye protection	yes	yes	yes
Respiratory protection	yes	yes	yes
Possibility of connecting filters (number)	2	2	2

* It is the stated maximum weight of the mask regardless of its size. The smaller mask size will weigh less than 350 g. ** It is the stated average weight of the mask. The smallest mask size weighs approximately 475 g and the largest mask weighs approximately 530 g.

Table 2. Subjective evaluation criteria and criteria weights.

No.	Criterion	Weight
1.	Breathing in a protective mask	0.17
2.	Handling the clamping system	0.15
3.	Comfort under physical exertion	0.13
4.	Field of view	0.13
5.	Distortion	0.09
6.	Comfort in a protective mask	0.09
7.	Clarity of speech	0.08
8.	Seeing underfoot	0.08
9.	Time-consuming to put on a protective mask	0.04
10.	Changing filters	0.03
11.	Overall evaluation of the protective mask	0.02

The weights of the subjective criteria were determined based on the ranking method. The importance of the subjective criteria was determined by the aforementioned practitioners, who ranked each criterion in order of importance, with number 1 being the most important criterion and number 11 being the least important criterion. The importance of criterion i according to rater j is calculated from the relation:

$$v_{ij} = \frac{a_{ij}}{\sum a_{ij}}, \quad (1)$$

where a_{ij} is the score of criterion i by evaluator j, calculated from the ranking of that criterion by that evaluator according to the formula:

$$a_{ij} = k + 1 - p_{ij} \quad (2)$$

where k is the number of criteria and p_{ij} is the ranking of criterion i by rater j. The resulting weight of criterion i is computed as the average of the weights of the experts:

$$v_i = \frac{\sum_j v_{ij}}{q}, \quad (3)$$

where q is the number of experts.

2.3. Method of Data Evaluation

Respondents who took part in the testing answered each criterion using a questionnaire. The answers represent a numerical scale. Values are then assigned to each number. This scale is shown in Table 3 below.

Table 3. Scoring of questionnaire responses.

Possible Answer	Points Awarded
1	0
2	0.25
3	0.50
4	0.75
5	1

Protective masks that have been tested according to specified subjective criteria will achieve a final rating based on the score achieved. In the first place, there is a need to determine the ranking of the variants according to the given criteria. Based on the scores obtained, the ranking (*rij*) is determined and the protective mask which has obtained the highest score is given the first place. The criterion of the time required to put on the protective mask will be evaluated according to the average time, i.e., the protective mask with the shortest time will be ranked first.

The score (*qij*) of the *i*-th mask according to the *j*-th criterion is obtained by the following relation:

$$q_{ij} = m + 1 - r_{ij}, \quad (4)$$

where m is the number of masks and (r_{ij}) is the ranking of the i-th mask according to the j-th criterion determined by the scores obtained. We obtained the resulting early rank of each protective mask by multiplying the score q_{ij} with the weights of each criterion.

$$S_v = \sum q_{ij} * v_i \quad (5)$$

For better clarity, the resulting values can be normalized by dividing the sum of the individual protective mask scores by the sum of the individual protective mask scores.

2.4. Methodological Procedure for Testing Gas Protection Masks

The testing methodology integrates the established assessment criteria. At the same time, it has been set up to make testing fast and efficient. The accessories required for testing protective masks are:

- Gas protection masks;

- Accessories for protective mask (filter);
- Timekeeping;
- Questionnaire;
- Assistant.

The CM-6 and OM-90 protective masks have two threads for connecting the protective filter; however both were tested with one protective filter, and the STS Shigematsu CF01 protective mask was tested with bayonet filters on both sides of the protective mask. The test person completes the questionnaire with the help of an assistant who reads and completes the questions as the test person answers the questions.

Step 1: Gas masks (3 types) are prepared on the table. The assistant prepares a mobile phone and a timer. It is necessary that both persons know the instructions for putting on the protective mask and handling the clamping system. The tester starts to put on the protective mask, and at the same time, the assisting person starts the timer. The gas protection mask is donned in accordance with the instructions and with the necessary accessories in the shortest possible time. Once the test person has the mask on, the timing is completed and recorded on the questionnaire.

Step 2: The test person examines the field of vision by looking around the area and focusing on the overall visibility in the mask, whether he/she can see objects in the vicinity of 180 degrees. He or she then focuses on a specific object and assesses whether he or she sees the object clearly or blurrily. Based on this examination, he or she rates the field of view of the protective mask on a scale of 1 (worst) to 5 (best).

Step 3: For the distortion question, the test taker chooses at least 2 objects to observe their possible enlargement or reduction. The observation of such a phenomenon means that the protective mask distorts the image. On the basis of this examination, he/she rates the distortion of the protective mask on a scale from 1 (worst) to 5 (best).

Step 4: The tester evaluates the mask to see if it fits comfortably on his/her face or, conversely, if it is oppressive and does not fit his/her face at all. Based on this examination, he or she rates the protective mask on a scale of 1 (worst) to 5 (best).

Step 5: The tester examines, looking down at the feet and with a short walk, whether the underfoot support is clear and satisfactory or unsatisfactory. Based on this examination, the person rates the vision underfoot in the protective mask on a scale of 1 (worst) to 5 (best).

Step 6: The test person manipulates the clamping system, tries to loosen and tighten the mask back according to the handling instructions. Based on this examination, he/she rates the handling of the clamping system on a scale of 1 (worst) to 5 (best).

Step 7: For the breathing question, the test subject will consciously and deeply inhale and exhale slowly for at least 30 s. Based on this exploration, he/she will rate whether he/she is breathing poorly or well in the protective mask on a scale of 1 (worst) to 5 (best).

Step 8: The assistant assesses and records his/her response to the speech intelligibility questionnaire. The test taker introduces him/herself aloud (name and surname), states his/her age and place of residence. The assisting person rates whether the speech intelligibility in the protective mask is poor or good on a scale from 1 (worst) to 5 (best).

Step 9: The test person removes the mask from his/her face. He/she tries to replace the filter according to the filter handling instructions. Based on this examination, he/she rates whether the filter change is difficult or easy on a scale of 1 (worst) to 5 (best).

Step 10: For the question on the questionnaire focusing on comfort under load, the tester will perform a load test, which will consist of performing 15 squats. Based on this physical test, he/she will rate how comfortable he/she was with the load on a scale of 1 (worst) to 5 (best).

Step 11: The tester will rate the protective mask as a whole, whether it is satisfactory or unsatisfactory on a scale of 1 (worst) to 5 (best).

A questionnaire was created to record respondents' answers and shared online. It included instructions for respondents during testing along with the testing procedure. Any comments or opinions of the respondents could be recorded in an open-ended question at the end of the questionnaire. The questionnaire created can be found in

Appendix A. The methodological procedure for testing the gas protection masks is shown in the following Figure 4.

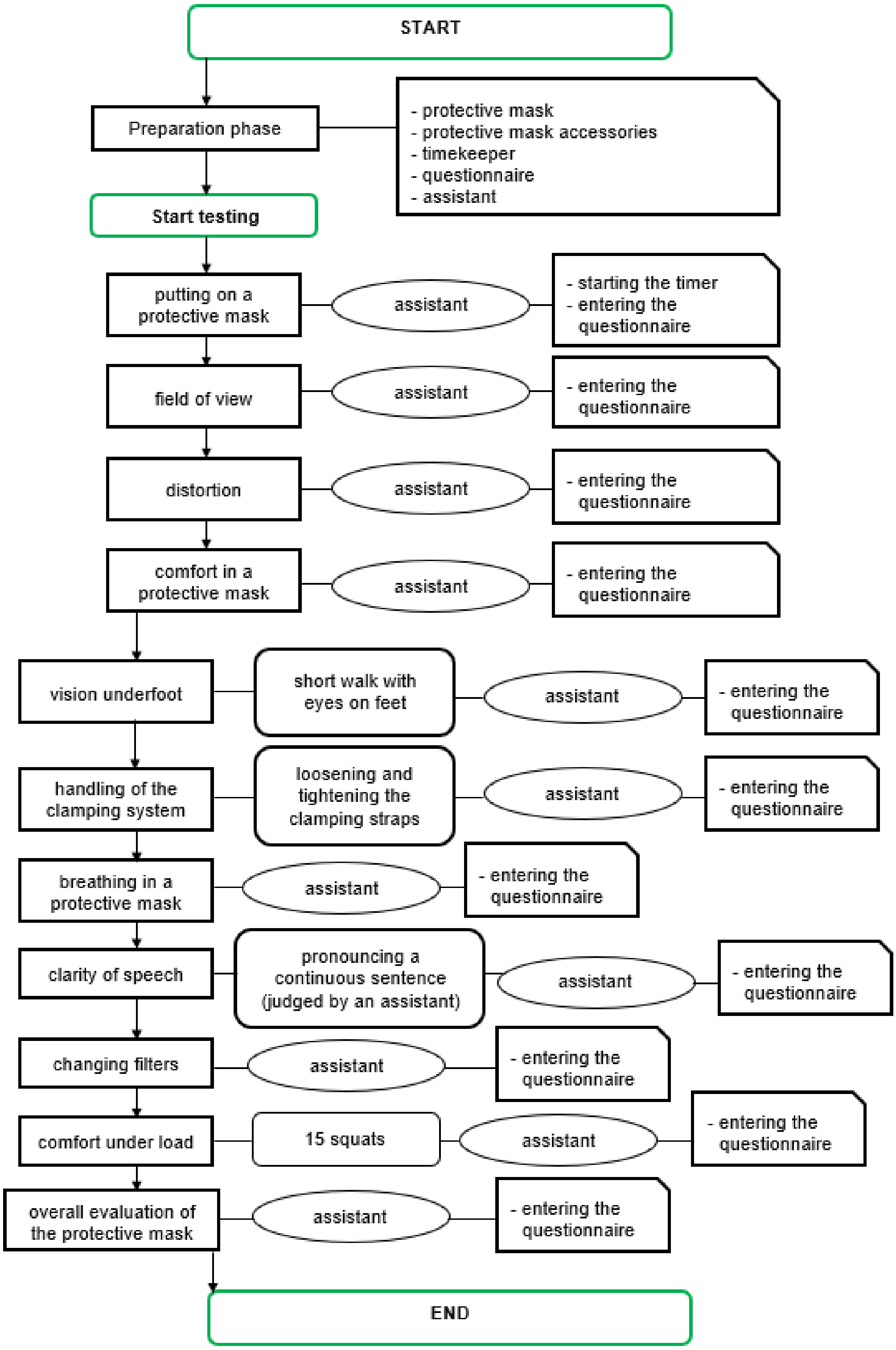

Figure 4. Methodological testing procedure.

3. Results

The final testing of gas protective masks took place at the Faculty of Safety Engineering, University of Žilina, and was attended by 58 respondents (students). It was a routine survey, and all participants took part in the testing voluntarily. Therefore, Institutional Review

Board (IRB) approval was not required. Respondents were familiarized in advance with the use of gas masks. Many of the respondents had practical experience. The results from the final testing of the gas protection masks are presented in Table 4 and Figures 5–14 below.

Table 4. Average time to put on protective masks.

Time to Put on a Protective Mask (h:min:s)	STS Shigematsu CF01	OM-90	Guzu CM6
Average	0:00:24	0:00:19	0:00:18
Median	0:00:18	0:00:15	0:00:15
The best	0:00:04	0:00:05	0:00:02
The worst	0:02:05	0:00:38	0:01:03

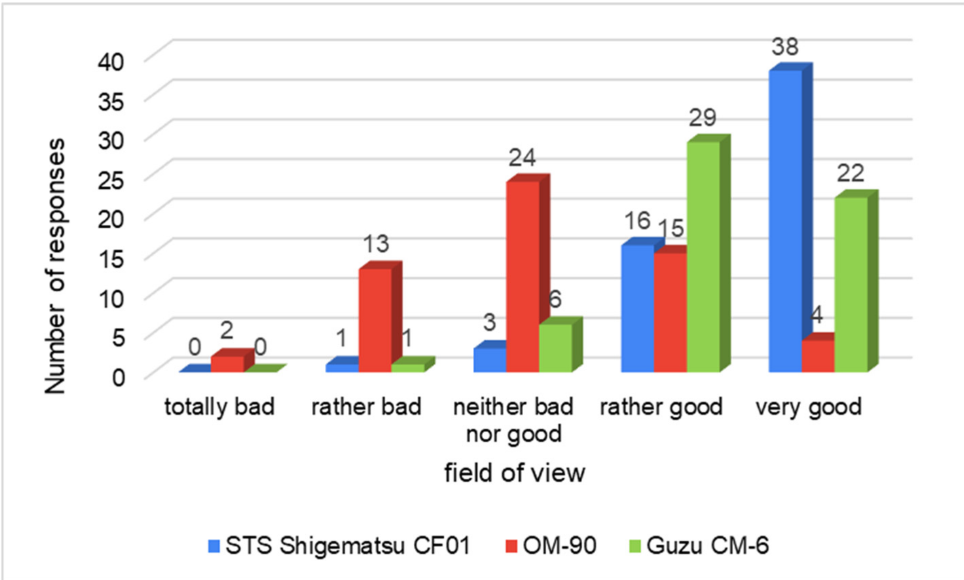

Figure 5. Graphical representation of the field of view evaluation.

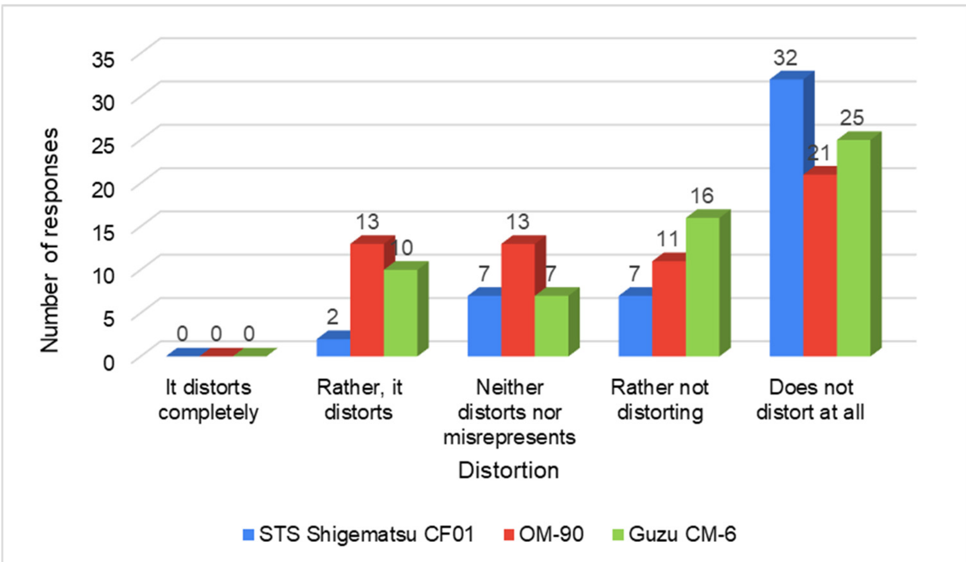

Figure 6. Graphical representation of the distortion evaluation.

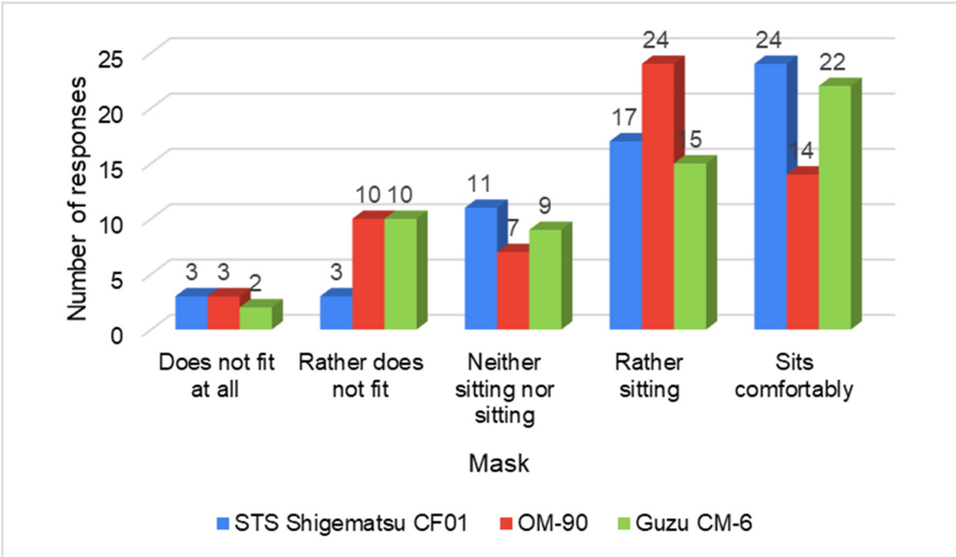

Figure 7. Graphical representation of the comfort rating of the protective mask.

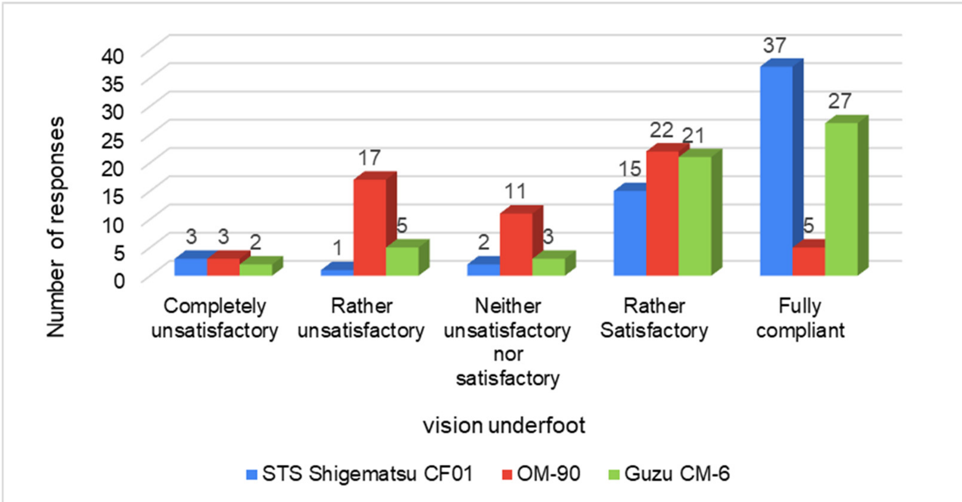

Figure 8. Graphical display of underfoot vision assessment results.

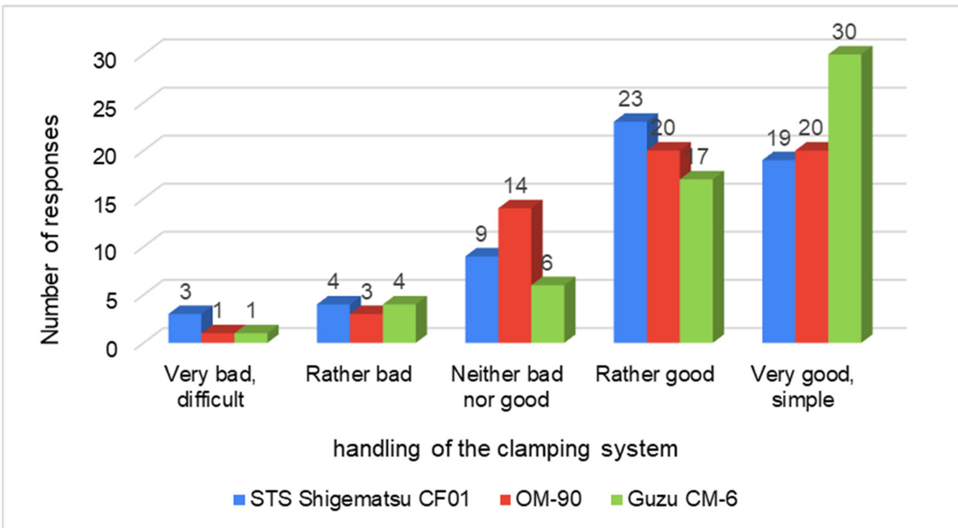

Figure 9. Graphical display of the results of the clamping system evaluation.

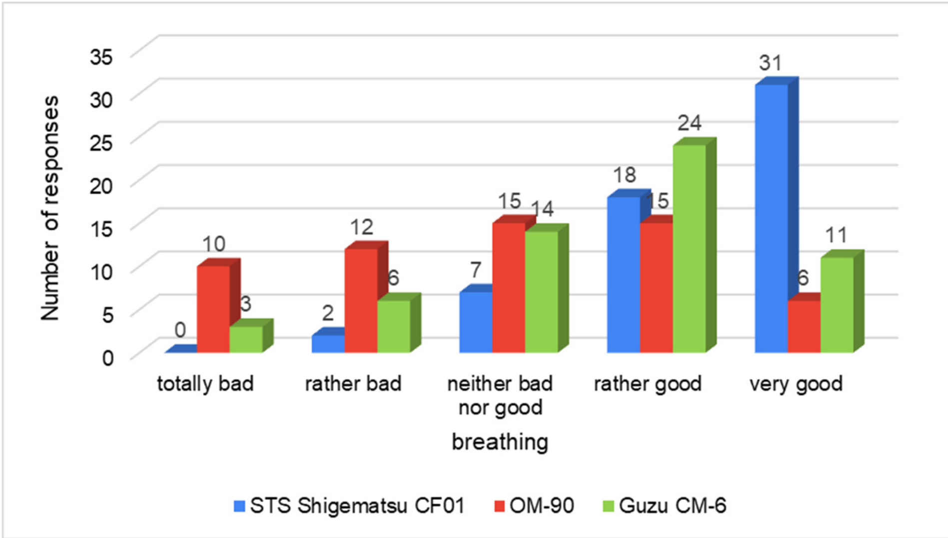

Figure 10. Graphical representation of breathing evaluation in a protective mask.

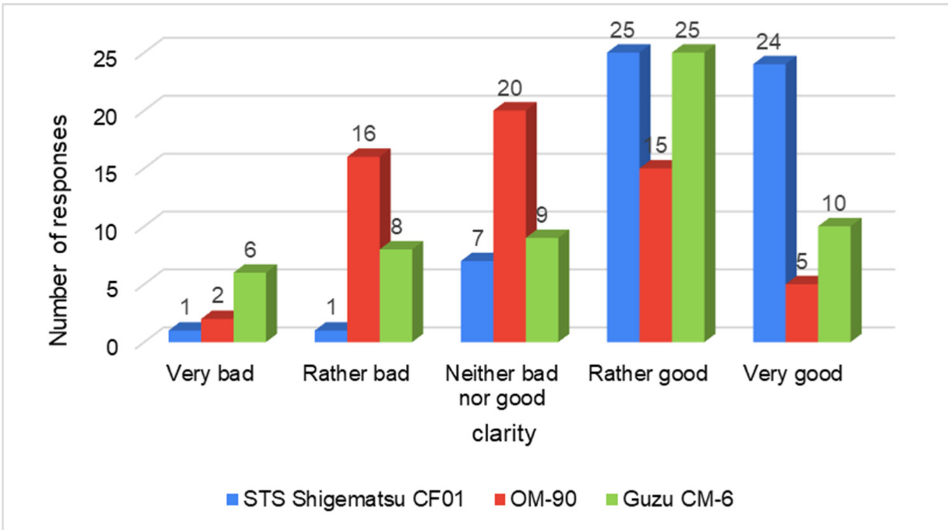

Figure 11. Graphical representation of the clarity rating of the protective mask.

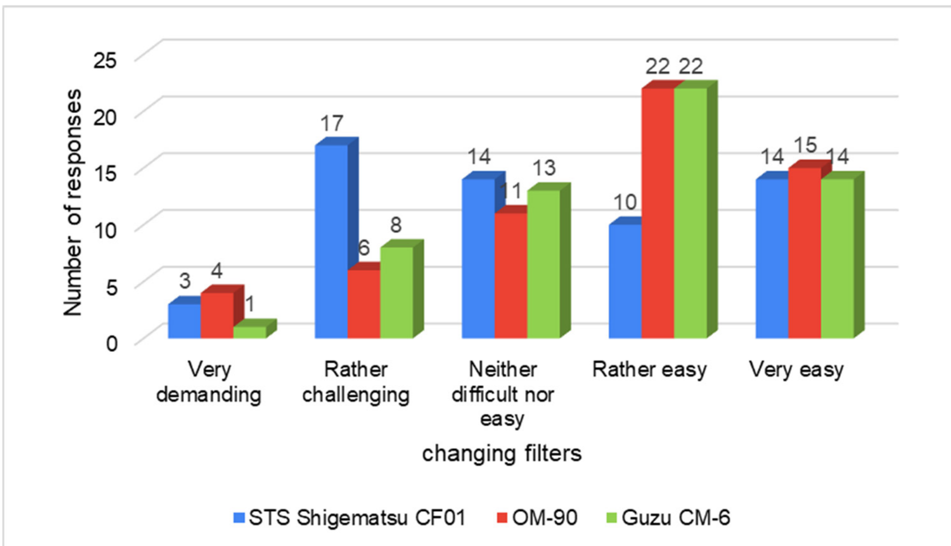

Figure 12. Graphical display of filter change evaluation.

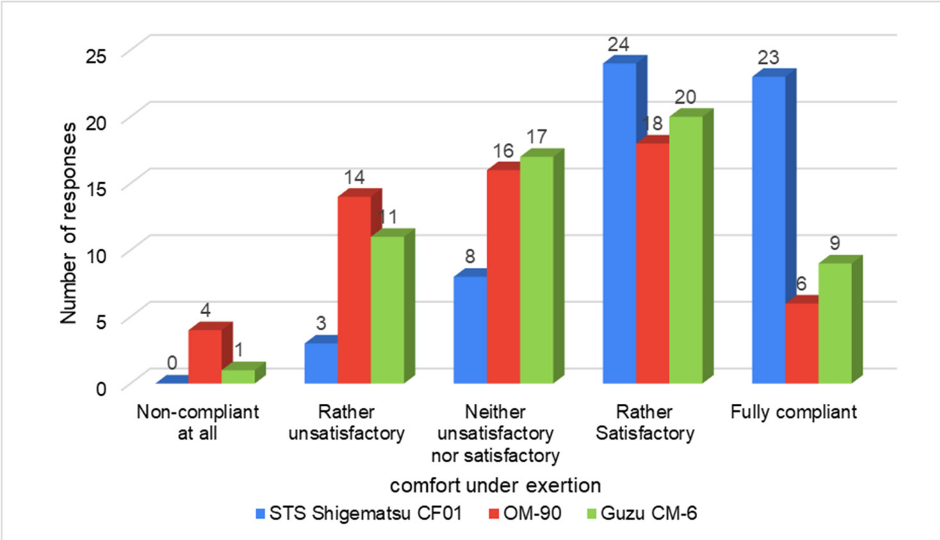

Figure 13. Graphical representation of the results of the exercise comfort evaluation.

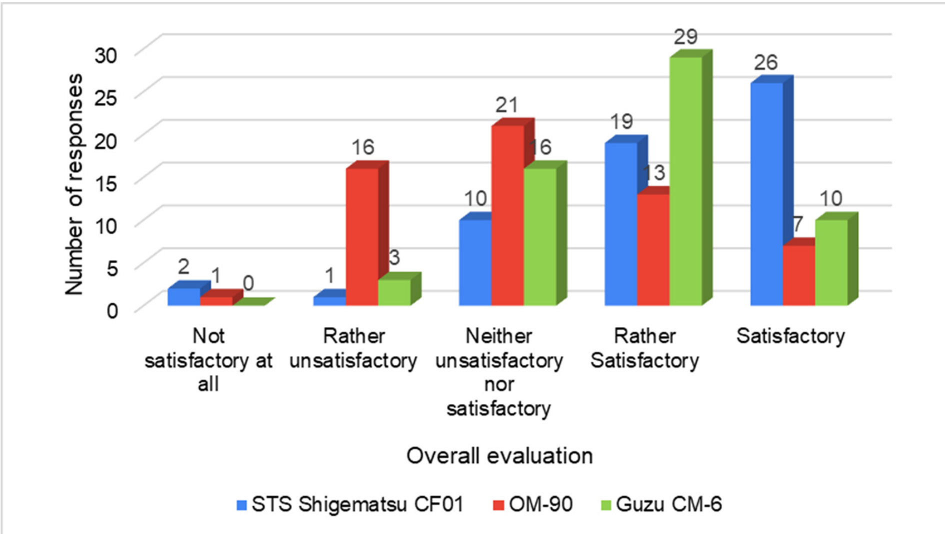

Figure 14. Graphical representation of the results of the overall evaluation of protective masks.

The fastest average time to don the protective mask was achieved by the Guzu CM-6 protective mask. The second fastest average time was achieved by the OM-90 protective mask with a difference of only 1 s compared to the Guzu CM-6 protective mask. The STS Shigematsu CF01 protective mask achieved an average time of 24 s, the slowest time to don a protective mask. This result may have been influenced by the different type of clamping system, with respondents preferring the type on protective masks from the Czech manufacturer. Figure 5 shows the results of the visual field assessment.

The best results were achieved by the STS Shigematsu CF01 mask, whose field of view was rated as very good by 38 respondents and rather good by 16 respondents. The field of view of the Guzu CM-6 mask was also rated positively by the majority of respondents. The worst results were achieved by the OM-90 mask, where only 4 respondents rated the field of vision as very good and 15 respondents as rather good. A total of 24 respondents could not rate the field of view of this protective mask and 15 respondents were inclined to rate the field of view negatively. The worst result of the OM-90 protective mask may be due to the fact that it does not have a panoramic visor. Binocular vision in the protective mask reaches only 34% [17], which is a significant difference compared to the other two protective masks. The results of the distorted vision testing by respondents are presented in Figure 6.

For the distortion question, the test taker chose at least 2 objects for which he or she observed possible magnification, shrinkage, and other types of distortion. The STS Shigematsu CF01 protective mask again performed best in the distortion-focused criterion. The answer “does not distort at all” occurred in 32 respondents and the answer “rather not distorting” in 17 for this mask. For 2 respondents, the answer “rather distorts” was marked and 7 respondents could not judge the distortion in the protective mask. The answer “distorts completely” was not indicated by any respondent for either protective mask. The worst performing mask is the OM-90, for which 13 respondents chose the answer “rather distorts”. The Guzu CM-6 protective mask is between the OM-90 and the STS Shigematsu CF01 with overall results. The testing results are again probably most influenced by the type of visor. Figure 7 shows the results of the comfort ratings in the protective masks.

The evaluation of the comfort of the protective mask was focused on whether it presses on the individual parts of the face, whether it sits comfortably on the face or whether it fits snugly enough. The STS Shigematsu CF01 protective mask fit 41 respondents well. A total 11 respondents were unable to judge this criterion and 6 respondents did not find the mask comfortable on their face. The OM-90 face shield fits 38 respondents. The Guzu CM-6 face shield is the worst rated face shield under this criterion. Here, the shortcomings in fit that were already identified in previous testing [16] were confirmed. Figure 8 shows the results of the underfoot vision assessment.

The best possible visibility in a protective mask is important not only for the visibility of activities in an environment that is often cluttered, but also for the safety and protection needs of the wearer. The “completely satisfactory” rating for the STS Shigematsu CF01 protective mask received 37 responses and the “rather satisfactory” rating received 15 responses, meaning that the underfoot vision of this mask was satisfactory for up to 52 respondents. The second rating was achieved by the Guzu CM-6 mask. The underfoot vision of the protective mask does not suit 20 respondents, which means that this mask has the worst rating for this criterion. Figure 9 shows the results of the evaluation of the criterion focusing on the handling of the clamping system.

The Guzu CM-6 achieves the best rating for handling the clamping system. A total 30 respondents rated the handling of the clamping system as very good and easy. Conversely, only one respondent indicated that the handling was very poor and difficult. The second place was occupied by the STS Shigematsu CF01 protective mask, where 42 respondents rated the handling of the clamping system positively and 7 respondents negatively, but this represents the most negative ratings. The OM-90 protective mask has a relatively positive rating. The result of the STS Shigematsu CF01 protective mask can be compared with the result of the evaluation of the first criterion. It was the clamping system that achieved the worst rating that may have caused the slowest donning time. Figure 10 shows the results of the evaluation of breathing in the protective mask.

The test subject shall consciously and deeply inhale and exhale slowly for at least 30 s during the breathing assessment. The STS Shigematsu CF01 mask was again the first choice for this criterion. Not a single respondent gave the answer “very poor” for this type of mask, whereas 49 respondents gave a positive assessment of breathing in the protective mask. As many as 22 respondents found it difficult to breathe in the OM-90 protective mask and 9 respondents found it difficult to breathe in the Guzu CM-6 mask. The answer “neither bad nor good” was marked by 7 respondents for the STS Shigematsu CF01 protective mask, 15 respondents for the OM-90 mask, and 14 respondents for the Guzu CM-6 mask. Breathing in the OM-90 protective mask is rated as the worst. Figure 11 shows the results of the clarity ratings in the protective mask.

The worst-rated speech intelligibility is for the OM-90 protective mask, where 18 respondents rated it negatively and 20 respondents rated it positively. The STS Shigematsu CF01 protective mask is the best-rated protective mask. A total 49 respondents indicated that speech intelligibility in this mask is rather good or very good. For the Guzu CM-6 protective mask, 10 respondents indicated that speech intelligibility is very good and 25 respondents indicated “rather good”. However, quite a number of respondents indicated that speech intelligibility was poor. Figure 12 shows the results of the evaluation of the criterion focusing on filter replacement.

The worst results were achieved by the STS Shigematsu CF01 protective mask. A total 20 respondents found filter replacement or filter fitting difficult. Although the protective filters for the STS Shigematsu mask are smaller, lighter, and non-restrictive, the method of fitting them caused problems for users. The OM-90 protective mask achieved the best results with little difference to the Guzu CM-6 mask. Figure 13 shows the results of the evaluation of the protective masks according to comfort under load. Figure 14 shows the results of an evaluation focusing on the overall comprehensive evaluation of the individual protective masks.

The tenth criterion evaluated was comfort with the load, in which respondents had to perform 15 squats. The most satisfactory comfort under load is in the STS Shigematsu CF01 protective mask. Respondents rated comfort under load as satisfactory in the Guzu CM-6 protective mask at 29. The least satisfactory mask in terms of comfort under load is the OM-90, with 4 respondents selecting the answer "not satisfactory at all" and 14 respondents selecting the answer rather unsatisfactory. The best overall rating was assigned to the STS Shigematsu CF01 mask, which is consistent with most of the previous individual criterion results. A total 46 respondents are comfortable with the mask, 3 respondents are not comfortable with the mask, and 10 respondents stated that they are neither comfortable nor comfortable with the mask. The worst overall rating is for the OM-90 mask, which is not suitable for 17 respondents, 21 respondents are unable to judge this criterion, and 20 respondents are satisfied with this mask. This criterion, too, corresponds to most of the previously assessed criteria. The Guzu CM-6 protective mask ranked between the STS Shigematsu CF01 and the OM-90 mask based on the rating of this criterion. It can be argued that this criterion also matches the previous evaluations.

The overall final rating according to the above evaluation method is given in Table 5 below.

Table 5. Final evaluation of selected protective masks according to subjective criteria.

Type of Mask	Final Evaluation	Final Evaluation (Normalized)
STS Shigematsu CF01	2.55	0.43
OM-90	1.22	0.20
Guzu CM-6	2.22	0.37

The STS Shigematsu CF01 protective mask achieved the highest score, which means that it is the most satisfactory of the selected protective masks according to the subjective evaluation of the respondents. This mask is the lightest mask of those selected, which may have influenced several of the criteria set, such as comfort in the protective mask, similar to comfort under load. It is equipped with a panoramic visor, which is also an advantage in assessing, for example, field of view, distortion, and vision underfoot.

4. Discussion

The results of an evaluation of gas protection masks based on subjective criteria are useful when a decision needs to be made on the selection of a suitable protective mask. However, this is only one part of the overall evaluation [1]. The more important one will always include objective criteria and tests performed in specialized laboratories. The quality of the filters also plays an important role. However, subjective perception is also important. Similar tests that have investigated the properties of protective masks through subjective evaluations of respondents are, for example, [9,10,22,23]. This evaluation can be used when it is necessary to decide between two or more types of protective masks that have the same or similar technical characteristics and measurement results.

Another application of the presented testing and evaluation methodology is in the design and development of protective gas masks. This method makes it possible to detect deficiencies and identify parameters in which individual protective masks fall short. As an example, a study aimed at comparing protective masks with a binocular and panoramic type of visor can be carried out. It is the masks with the panoramic type of visor that allow better orientation according to the respondents [22,23]. On the other hand, in the same studies, respondents reported that the mask with a binocular visor was more comfortable [22,23]. These results can only be partially confirmed by our testing. For the comfort criterion, the OM-90 mask performed comparably well with other protective masks, but for the comfort criterion during the performance of the activity, the results were worse. However, as this is a subjective assessment, it is the discomfort caused by the orientation or weight of the mask that may have biased the results. Therefore, design, construction, and materials used appear to be a very important aspect resulting in the quality of protective masks perceived by users.

Adamson et al. [9] investigated the possibility of using military protective gas masks in the civilian sector. Specifically, this involved their use in hospital and pre-hospital environments by paramedics. We also tried to answer a similar question using the results of our testing. Army protective gas masks are designed primarily for the needs and activities performed on the battlefield. The results of our tests based on subjective evaluation confirmed their shortcomings compared to masks designed for the needs of firefighters and civil protection units. However, as in [9], we can conclude from the results that the OM-90 protective mask is competitive. Its use finds application especially in times of high demand for protective equipment in times of crisis [9,24]. It is therefore suitable for potential inclusion within civil protection warehouses but also medical facilities. The inclusion of decommissioned military gas masks that meet the requirements of the standards would avoid shortages during prolonged crisis situations [9], or during unexpected crisis events with releases of hazardous substances, such as accidents in Seveso and sub-threshold plants [25].

It is the companies using and storing hazardous substances that pose a significant threat to their surroundings and the people living there [26]. In addition, these companies also endanger their employees. In the conditions of the Slovak Republic, these enterprises must have trained units, which must be materially equipped [14,27,28]. Most of these enterprises are private companies and therefore decide on the means of protection of employees and units themselves. The presented method of testing and evaluation of gas protection masks can also serve the needs of these enterprises. The presented methodological procedure is time- and cost-saving. Testing can be carried out in cooperation with the employees of these enterprises and individual gas masks can be supplied by their manufacturers and dealers.

Taking into account the views from users of materials who carry out certain activities facilitates the improvement of safety in organizations. Users provide important insights into the strengths and weaknesses of the work equipment used. Their involvement promotes a culture of safety, increasing accountability and motivation to perform work to a high standard. In this way, it is possible to purchase appropriate work aids that contribute to the overall improvement of safety in the organization [29,30]. Ascertaining opinions on the working aids used will enable the crisis manager to make the appropriate decisions needed to purchase materials with a view to efficient use of financial resources [31,32].

5. Conclusions

This paper presents results from testing three types of protective masks using the proposed methodological procedure. This procedure integrates established criteria that are based on the subjective evaluation of the users of the protective masks. The results indicate the most suitable type of protective mask according to the subjective evaluation of the respondents. The disadvantage is that only three types of gas protection masks were tested. Similar testing would need to be carried out on more types of protective masks from different manufacturers in different countries. In this way, examples of good practice could also be identified. However, the present article presents the actual methodological procedure of testing and the method of evaluation. Part of the testing was to assess the possibility of using military gas protection masks in the civilian sector. The results of the testing point to their perceived shortcomings by the respondents, but they can be included as a suitable alternative in the event of a material emergency. The paper concludes by presenting the possible applications of the proposed method of testing and evaluation of gas protection masks.

Author Contributions: Conceptualization, J.K., B.K., M.T., J.R., K.P. and K.B.; methodology, J.K., B.K., K.P. and K.B.; software, J.K., B.K. and M.T.; validation, J.K., B.K., M.T., J.R., K.P. and K.B; formal analysis, J.K., B.K., M.T., J.R., K.P. and K.B.; investigation, J.K. and B.K.; resources, J.K, B.K. and J.R.; data curation, J.K., B.K., M.T., J.R., K.P. and K.B.; writing—original draft preparation, J.K., B.K., M.T., J.R., K.P. and K.B.; writing—review and editing, J.K. and B.K.; visualization, J.K., B.K., M.T., J.R., K.P. and K.B.; supervision, J.K. and J.R.; project administration, J.K., B.K. and J.R.; funding acquisition, J.K. and J.R. All authors have read and agreed to the published version of the manuscript.

Funding: Publication of this paper was supported by Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic—VEGA No. 1/0628/22; The Security Research in Municipalities with Emphasis on the Citizens' Quality of Life, by KEGA 043ŽU—4/2022; Implementation of knowledge from social, behavioral and humanitarian scientific disciplines in the preparation of students of the study field of security science; and by Grant System of University of Žilina No. 16963/2021 "Research into the readiness of municipalities to deal with emergency events with an emphasis on the safety of the inhabitants".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are presented in the study.

Conflicts of Interest: The authors declare no conflicts of interest. The views expressed, however, are solely those of the authors and not necessarily those of the institutions with which they are affiliated or of their funding sources. The authors are solely responsible for any errors or omissions.

Appendix A. Questionnaire

Testing protective anti-gas masks for needs of a unit's civil protection

1. Gender: *

Mark it with only one ellipse.

woman man

2. Temporal difficulty of putting on a protective gas mask STS Shigematsu CF01 (minutes:seconds) *

3. Temporal difficulty of deployment of a protective anti-gas mask OM-90 (minutes:seconds) *

4. Temporal difficulty of deployment of a protective anti-gas mask Guzu CM6 (minutes:seconds) *

5. Visible field (is it necessary to focus on the overall visibility; whether you perceive subjects in surroundings approx. 180 degrees; whether you see, for example, clearly or blurry) *

Rate it on the scale from 1 to 5 (1—the worst to 5—the best)

STS Shigematsu CF01/OM-90/Guzu CM6

6. Distortion (is it necessary to focus on the image or subjects; watch whether it goes; possibly increase or reduce image or subjects) *

Rate it on the scale from 1 to 5 (1—the worst to 5—the best)

STS Shigematsu CF01/OM-90/Guzu CM6

7. Mask (is it necessary to focus with it on; how you put your mask on your face; sitting and whether you need to it or not) *

Rate it on the scale from 1 to 5 (1—the worst to 5—the best)

STS Shigematsu CF01/OM-90/Guzu CM6

8. Vision of underfoot (when you look down underfoot, rate whether you see a satisfactory image or not) *

Rate it on the scale from 1 to 5 (1—the worst to 5—the best)

STS Shigematsu CF01/OM-90/Guzu CM6

9. Manipulation with clamping system (when tightening or releasing masks, rate whether it is a complex or simple manipulation) *

Rate it on the scale from 1 to 5 (1—the worst to 5—the best)

STS Shigematsu CF01/OM-90/Guzu CM6

10. Breathing (breathing good or bad with the protective mask) *
Rate it on the scale from 1 to 5 (1—the worst to 5—the best)
STS Shigematsu CF01/OM-90/Guzu CM6
11. Speech intelligibility (evaluate the intelligibility of speech in the mask, evaluated by the one from the pair who is not wearing the mask) *
Rate it on the scale from 1 to 5 (1—the worst to 5—the best)
STS Shigematsu CF01/OM-90/Guzu CM6
12. Exchange filters (is the manipulation of exchange filters difficult or simple) *
Rate it on the scale from 1 to 5 (1—the worst to 5—the best)
STS Shigematsu CF01/OM-90/Guzu CM6
13. Comfort load (does the mask's load suit you or limit you to such measures that it does not suit you at all) *
Rate it on the scale from 1 to 5 (1—the worst to 5—the best)
STS Shigematsu CF01/OM-90/Guzu CM6
14. Total rating of protective masks (focus on the protective the mask, on the whole is it satisfactory or not) *
Rate it on the scale from 1 to 5 (1—the worst to 5—the best)
STS Shigematsu CF01/OM-90/Guzu CM6
15. State your opinion (comments, observations, complaints, problems, shortcomings, options improvements) relating to issues of protective gas masks.
* means a mandatory answer

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