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Evaluation of a new ballistic vest design for compliance with Standard No. PN-V-87000:2011 using physiological tests

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Research into newly developed ballistic vests to be worn by police officers under clothing was carried out with air temperature conditions of +20 °C. A ballistic vest should incorporate protective features, comfort and ergonomics. The thermal strain on users who wore the vests was evaluated as an average and individually, after they had been conditioned in high (+50 °C), low (−40 °C) or neutral (+20 °C) air temperatures, while performing various occupational activities. Research involved six police officers aged 36–42 years, who wore civilian clothing used in moderate environmental conditions. During the tests, physiological parameters (internal temperature, local skin temperatures and amount of sweat secreted) were determined. The ease of doing exercises while wearing the vests, vest service and level of discomfort in use were assessed. Research showed that the vests tested, both as an average and individually, meet the requirements of Standard No. PN-V-87000:2011 (clause 4.5).

Keywords: ballistic vest; thermal strain; ergonomics

1. Introduction

The bulletproof vest is a special vest-like garment, and its task is to protect the chest from firearm-fired projectiles. Such items are used by police and military services, but also by personal protection services and private individuals in situations where their health and life may be at risk [1]. Soft ballistic panels, also known as basic inserts, are the main elements of ballistic protection and are the main protective layer against firearms and shrapnel [2]. Szołucha [2] states that ballistic soft insert manufacturers use essentially two types of materials – aramid fibres and high-molecular-weight ballistic polyethylene. Aramid fibres, or polyamide fibres, such as DuPont Kevlar and Teijin Twaron, have five times the tensile strength of steel with the same weight, and this difference is six times greater in water. Aramid fibres are thermally stable and do not melt. They also have self-extinguishing properties – when the fire source is stopped, they cease to burn. Low temperatures (approximately −50 °C), do not affect their resistance. Szołucha [2] indicates also that resistance of a vest to puncture with knives or similar close-quarter weapons is a separate issue. A projectile fired from a firearm does not penetrate the ballistic fibre of the protection panel, as opposed to a blade that penetrates the vest, just between the fibres, and is therefore more difficult to stop. There are special knife-resistant and/or needle-resistant vests; however, they seem to be a compromise between the level of resistance and user comfort, as they are usually much stiffer than classic protective vests [3–5].

Within the framework of a project, a multipurpose ballistic vest to be worn under clothing was developed for police officers [6–10]. The project consortium had to face a new, so far unknown, approach to the design of multipurpose ballistic vests to be worn under clothing, which included the customisation of these vests using 3D scanning techniques. Additionally, a group of officers was tested to determine the size subgroups, in accordance with police regulations and the legal issues related to personal data protection. Based on the results obtained, a modern prototype design for a multipurpose ballistic vest to be worn under clothing was developed. It was equipped with two inserts: (a) a basic bullet-resistant K2 class insert, with additional shrapnel protection properties (ballistic resistance limit V50 with a class of at least O3, in accordance with Standard No. PN-V-87000:2011 [11]); (b) an additional IIIA class insert in accordance with Standard No. NIJ 0101.04:2000 [12] that equips the vest with the protection against knives, needles and ice picks.

The purpose of research was to determine the possibility of using the vest in accordance with Standard No. PN-V-87000:2011 [11] (clause 4.5) and to evaluate the thermal strain on users who wore two models of ballistic vests to be worn under clothing, which were averaged (A) and individually (I) fitted, after they had been conditioned

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at high, low or neutral air temperatures, while performing various occupational activities.

2. Research methodology

2.1. Environmental conditions during the tests

The tests were performed in the climatic-walk-in-test chamber (Weiss System, Germany). The environmental conditions during the tests were as follows: air temperature +20.0 ± 0.5 °C, air velocity 0.4 ± 0.1 m/s and relative humidity 40.0 ± 2.5%.

2.2. Subjects

The research involved six police officers aged 36–42 years. The subjects were chosen for their similar physical endurance and similar body measurements: age 39 ± 2.5, body weight 86.3 ± 5.5 kg, height 182.2 ± 6.7 cm and physical endurance 36.4 ± 2.3 ml/kg/min. People with similar characteristics were selected in order to obtain unambiguous conclusions.

2.3. Clothing

Clothing used in moderate environmental conditions was selected for the tests. The clothing included underwear (cotton boxers, a special T-shirt to be worn under a ballistic vest), trousers with a belt, a long-sleeved shirt, socks and sports footwear. The clothing is shown in Figure 1.

2.4. Personal protection equipment or ballistic vests

The officers tested two variants of multipurpose vests to be worn under clothing, developed under the framework of this project:

- vests developed based on the individual body measurements of the officers (I);
- vests adapted to size subgroups from the identified group of officers (A).

Both vest types were developed from the results of the officers' body scans. As the vests were not developed in traditional sizes, their weight depended on the subject's body measurements. The weight of the vests tested was 3.7–4.2 kg. The general appearance of the ballistic vests is shown in Figure 2.

2.5. Measurements of physiological and physical parameters and subjective assessments

The following parameters were recorded continuously during the test:

- the internal temperature in the digestive tract monitored with a thermometric monitoring system (VitalSense, USA) and eight local skin temperatures monitored with i-Button wireless sensors (Maxim Integrated, USA), both measurements performed in accordance with Standard No. ISO 9886:2004 [13];

Figure 1. Clothing used in the test of ballistic vests to be worn under clothing: (a) without the vest; (b) with the vest and a shirt.

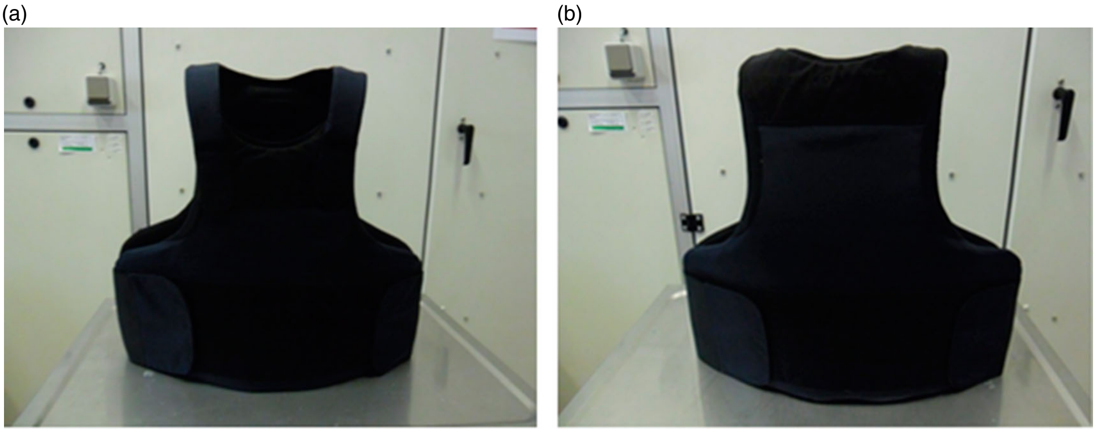

Figure 2. The ballistic vest to be worn under clothes developed in this project: (a) front; (b) back.

- the temperatures and humidity at two points on the inner surface of the ballistic vest (front and back), also measured with i-Button wireless sensors (Maxim Integrated, USA).

Before and after the test in the climatic chamber, both the subjects and each piece of their clothing were weighed using platform scales (Sartorius, Germany).

During the test, each subject had their ECG (Electrocardiogram) monitored and the test was supervised by a physician.

2.6. *Research procedure*

The examination of the feasibility of carrying out the following activities and the evaluation of their performance while wearing the ballistic vest was developed based on Standard No. BS 7971-1:2002 [14] and modified so that it was possible to perform them in the climatic test chamber. Experience gained during other project research was also taken into account [15–17].

After donning and adjusting the vest, the subject answered questions about its fit and the ability to adjust the vest, and then, after removing the vest, the process of donning and removing it was evaluated in accordance with Standard No. BS 7971-2:2002 [14].

During the test of the ballistic test model, the subject was wearing the basic clothing specified earlier. The activities performed during the test consisted of 13 activities with increasing strain: (a) movements of the arms in a standing position; (b) reaching behind his back; (c) reaching towards the front of the body; (d) head movements; (e) a forward slope; (f) sitting and standing up from the floor; (g) putting on and getting up; (h) marching on a flat and inclined surface; (i) lifting and carrying a weight of 10 kg; (j) simulation of getting in and out of the van; (k) making a shot in a standing, kneeling and lying position; (l) walking with a weight pulled on the ground (20 kg); (m) walking with a weight on the back (20 kg).

The test was carried out until all of the tasks were completed or could be discontinued if the following physiological limits were reached: internal body temperature of 38.5 °C or heart rate (HR) > 85% of the maximum value specified individually for each subject. If, after completing the exercise, the subject's HR was higher than 120 bpm, the subject had to rest in a standing position for approximately 5 min until the HR was below this value.

After completing the exercises and leaving the climatic test chamber, the subject evaluated the physical discomfort from using the vest, in accordance with Standard No. BS 7971-1:2002 [14].

The test order (type of the vest and conditioning temperature) was random.

2.7. *Indicators calculated*

Based on the test results, the weighted average skin temperature was calculated as per Standard No. ISO 9886:2004 [13]. The amount of sweat produced was calculated from the difference in body weight of the subject prior to and immediately after the test, after removing clothing and wiping the skin with a towel. The amount of sweat accumulated in the garment and in the examined vest was also calculated by determining the difference in their weight before and after the test. The physiological cost of the exercise was calculated from the difference in HR at rest and at the end of exercise. Heat storage (S) during exercise in both types of ballistic vests was also determined in accordance with the following equations [18]:

$$\mathrm{S1} = (3.55 \times m/A_{\mathrm{Du}}) \times (0.8\,\Delta T_{\mathrm{ab}} + 0.2\,\Delta \bar{T}_{\mathrm{sk}}) \times T_{\mathrm{eks}}^{-1}, \quad (1)$$

$$\mathrm{S2} = (3.55 \times m/A_{\mathrm{Du}}) \times (0.9\,\Delta T_{\mathrm{ab}} + 0.1\,\Delta \bar{T}_{\mathrm{sk}}) \times T_{\mathrm{eks}}^{-1}, \quad (2)$$

where m = initial body weight of the subject; A_{Du} = body surface calculated from the DuBois formula; T_{ab} = internal body temperature measured in the gastrointestinal tract; $\bar{T}_{\mathrm{sk}}$ = weighted average skin temperature; T_{eks} = duration of test. Equation (1) was applied under pre-conditioning conditions with air temperatures of −40 and +20 °C, and Equation (2) was applied for conditioning at a temperature of +50 °C.

2.8. Pre-conditioning of the ballistic vest tested

Before the test involving the police officers started, the ballistic vests to be tested were conditioned for 5 h at an air temperature of −40, +20 or +50 °C, in accordance with Standard No. PN-V-87000:2011 [11] (clause 4.5). Translated, this clause reads as follows:

> Ergonomic properties should be preserved dry at an air temperature ranging from –40 °C to +50 °C. The ergonomic properties of the vest shall be understood as: the ability to don and fit to your torso quickly with no assistance; not interrupting the activities to be performed by the user; accessible and easy-accessible pockets and fasteners.

Both types of vest, i.e., individual (I) and averaged (A), were conditioned under the aforementioned conditions.

2.9. Pilot tests for vest conditioning

Before the test of ballistic vests involving police officers started, the temperature of the inner surface of the vest at air temperatures of −40 and +50 °C was measured in order to determine whether they would cause irritations to the user's skin or not. In accordance with Standard No. ISO 9886:2004 [13], the local temperature of the skin surface should not fall below 15 °C or exceed 43 °C. In both cases, the surface temperature of the conditioned vests after conditioning was well within the specified limits.

2.10. Statistical analysis of the study results

In the first stage, the statistical analysis of the measurement data consisted of the calculation of basic statistics such as the mean, standard deviation and minimum and maximum values, and then checking the normality of the distribution of all data using the Shapiro–Wilk test. In the analysed measurement data test, the Shapiro–Wilk test showed a lack of normal distribution, so a Wilcoxon non-parametric signed-rank test was carried out. The statistical analysis of the measurement data was performed using Statistica version 9.1. If the differences are statistically insignificant, the smallest p value is given.

3. Test results

3.1. Duration of test

The average duration for each variant of the vest used and pre-conditioning is presented in Table 1. A single test lasted approximately 25 min. Each test was continued until all exercises were completed. There was no need to discontinue the test because the assumed physiological limits were reached. Slightly longer duration was observed in the tests where the vests had been conditioned at neutral ambient temperature. This could have been due to the fact that more tests of this variant, for technical reasons, were carried out first, when the subjects did not yet know the nature of the test and performed it a little longer. However, in all variants of vest conditioning there were no statistically significant differences between A and I vests, $p > 0.07$.

Table 1. Duration of test when using the averaged and individual vests, pre-conditioned at temperatures of −40, +20 and +50 °C.

	Duration of test (min)		
Vest	−40 °C	+20 °C	+50 °C
Averaged	25.1 ± 9.0	28.7 ± 8.7	27.3 ± 9.1
Individual	24.4 ± 7.2	26.4 ± 7.0	26.3 ± 7.4

3.2. Heat storage

Results on the level of heat storage attained at the end of the exercise are presented in Table 2. The level of heat storage was most balanced in the A vest after all types of pre-conditioning. This parameter was more varied in the I vest, reaching about 40 W/m^2 after pre-conditioning at extreme ambient temperatures and about 60 W/m^2 after pre-conditioning at neutral ambient temperature. The differences between both vest variants were not statistically significant, $p > 0.12$.

Table 2. Level of heat storage when using the averaged and individual vests, pre-conditioned at temperatures of −40, +20 and +50 °C.

	Level of heat storage (W/m^2)		
Vest	−40 °C	+20 °C	+50 °C
Averaged	52.2 ± 9.8	53.8 ± 11.5	44.7 ± 12.2
Individual	39.6 ± 10.3	59.6 ± 11.4	43.2 ± 8.5

3.3. Loss of body weight

During the test, a low level of perspiration was observed, which resulted in weight loss. The results are presented in Table 3. In the case of the I vest, the body weight loss level was similar after pre-conditioning them at temperatures

Table 3. Loss of body weight when using the averaged and individual vests, pre-conditioned at temperatures of −40, +20 and +50 °C.

	Loss of body weight (kg)		
Vest	−40 °C	+20 °C	+50 °C
Averaged	0.11 ± 0.08	0.17 ± 0.10	0.19 ± 0.10
Individual	0.17 ± 0.06	0.17 ± 0.07	0.21 ± 0.05

of −40 and +20 °C, and slightly higher in the case of vests pre-conditioned at the highest temperature of +50 °C. In the case of the A vest, the body weight loss level increased with the increase in the vest pre-conditioning temperature. No statistically relevant differences were found between both vest variants, $p > 0.35$.

3.4. *Sweat in clothing*

Due to the low level of perspiration during the exercises performed, sweat accumulation in each part of the garment was not considered; however, its presence in all garments combined was examined. The results are presented in Table 4. The amount of sweat accumulated in the clothing depended on the vest pre-conditioning temperature – the higher the temperature, the greater the amount of accumulated sweat, for each vest variant. Only with air conditioning at the highest temperature was slightly more sweat accumulated in users of the I vest compared to the A vest. However, differences between the A vest and the I vest were not statistically significant, $p > 0.35$.

3.5. *Changes in vest weight*

The short duration of the test resulted in a low level of moisture accumulating in the vests. The results are presented in Table 5. After pre-conditioning at the lowest temperature, the gain in vest weight was hardly detectable, as the accuracy of the applied weight was 0.005 kg. Only slightly higher weight gain was observed after pre-conditioning at neutral temperatures. After pre-conditioning at the highest temperature, variations in the weight of the tested vests were at the level of approximately 10 g, and therefore also small, but slightly higher in the I vest. Differences between the A vest and the I vest were not statistically significant, $p > 0.53$.

Table 4. Amount of sweat accumulated in the clothing when using the averaged and individual vests, pre-conditioned at temperatures of −40, +20 and +50 °C.

	Accumulated sweat (kg)		
Vest	−40 °C	+20 °C	+50 °C
Averaged	0.009 ± 0.007	0.019 ± 0.008	0.020 ± 0.009
Individual	0.006 ± 0.005	0.019 ± 0.007	0.028 ± 0.011

Table 5. Changes in vest weight when using the averaged and individual vests, pre-conditioned at temperatures of −40, +20 and +50 °C.

	Change in vest weight (kg)		
Vest	−40 °C	+20 °C	+50 °C
Averaged	0.000 ± 0.001	0.004 ± 0.001	0.007 ± 0.003
Individual	0.002 ± 0.001	0.004 ± 0.002	0.008 ± 0.003

3.6. *Temperature and humidity of vests tested*

The results of temperature and relative humidity tests on the inner surface of the front part of the vests tested are shown in Figures 3–8.

Figures 3–5 show that, on the inner surface of the front part of the vest, the greatest increase in temperature was

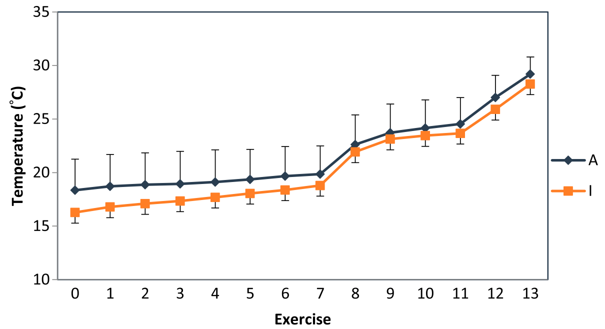

Figure 3. Course of temperature (T) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at −40 °C.
Note: Values are $T \pm SD$, error bars denote SD, $p > 0.25$.

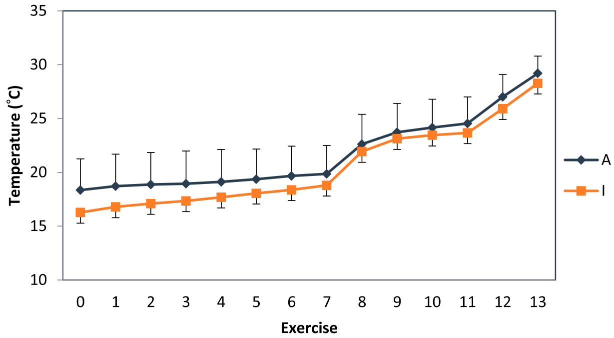

Figure 4. Course of temperature (T) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at +20 °C.
Note: Values are $T \pm SD$, error bars denote SD, $p > 0.17$.

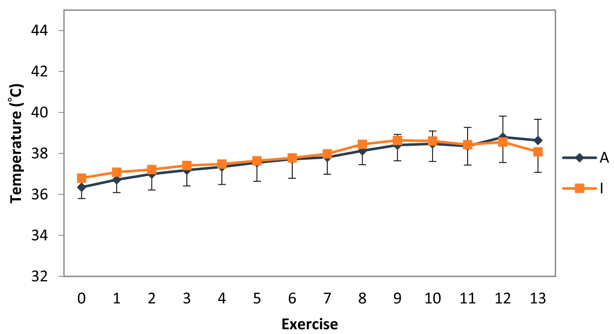

Figure 5. Course of temperature (T) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at +50 °C.
Note: Values are $T \pm SD$, error bars denote SD, $p > 0.25$.

recorded during the test with the vest pre-conditioned at the low temperature. In this case, during the test, the temperature on the surface examined increased by 11–12 °C, while after pre-conditioning the vest at a neutral temperature, the temperature increased by 6–7 °C and in the case of vests pre-conditioned at the highest temperature, the increase in the temperature was only 2 °C. At the same time, the least variation of this parameter was noticed among the vests pre-conditioned at the highest ambient temperature. However, differences between the A vest and the I vest were not statistically significant.

The relative humidity measurements on the inside of the vests tested at their front and back are shown in Figures 6–8. The results of relative humidity measurements presented in Figures 6–8 show that the value of this parameter in all test types increased from the 7th exercise, e.g., due to more dynamic effort. After completion of the tests, the relative humidity reached a value of approximately 90%. Relative humidity of vests pre-conditioned at a high air temperature was higher by 11–12% from the 7th exercise for the I vest, compared to the A vest when it was reached from the 9–11th exercise. Differences between the A vest and the I vest were not statistically significant.

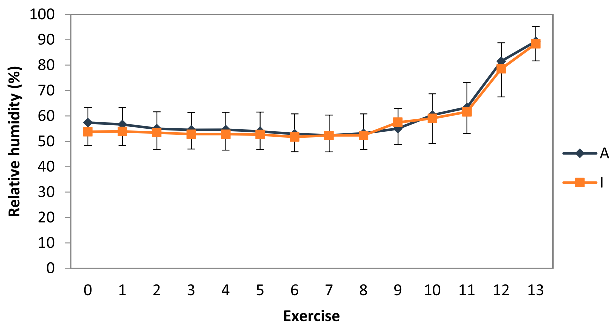

Figure 6. Course of relative humidity (RH) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at −40 °C.
Note: Values are $RH \pm SD$, error bars denote SD, $p > 0.25$.

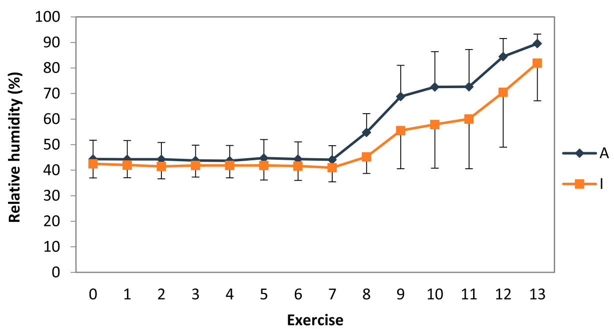

Figure 7. Course of relative humidity (RH) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at +20 °C.
Note: Values are $RH \pm SD$, error bars denote SD, $p > 0.07$.

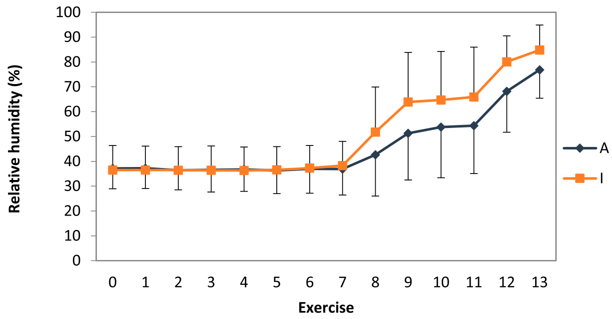

Figure 8. Course of relative humidity (RH) changes on the inner surface of the front part of the vest during the test in the averaged (A) and individual (I) vests, pre-conditioned at +50 °C.
Note: Values are $RH \pm SD$, error bars denote SD, $p > 0.22$.

3.7. Subjective evaluation of the vests tested

Several types of subjective evaluation were conducted with regard to the developed vests. Donning and removing the vest was one of them. Evaluation results are presented in Figure 9. Ratings show that the subjects had little trouble donning and removing the vests. Higher, and therefore slightly worse, ratings were given for performing those activities in vests pre-conditioned at a high air temperature. Large variations in responses were observed, as evidenced by relatively high SD values. Differences between the A vest and the I vest were not statistically significant.

Another subjective evaluation concerned the possibility of adjusting the vests. Results are presented in Figure 10. The mean rating of the possibility to adjust the vests indicates that the subjects had no trouble adjusting the vests when donning them. A slight inconvenience stemmed from the fact that the vests were too tight or too loose for some movements. Differences between the A vest and the I vest, however, were not statistically significant.

The subjects also assessed physical discomfort from using the vests during various activities during the test. The results of this assessment are presented in Figure 11. The results obtained show that the use of the ballistic vests

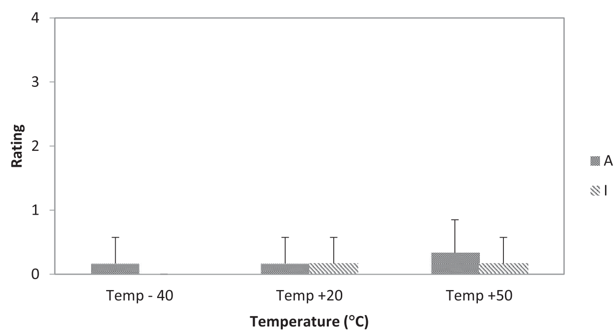

Figure 9. Evaluation of donning and removing the averaged (A) and individual (I) vests, pre-conditioned at −40, +20 and +50 °C.
Note: Rating scale: 0 = *no problem*; 4 = *serious difficulties*. $p > 0.19$.

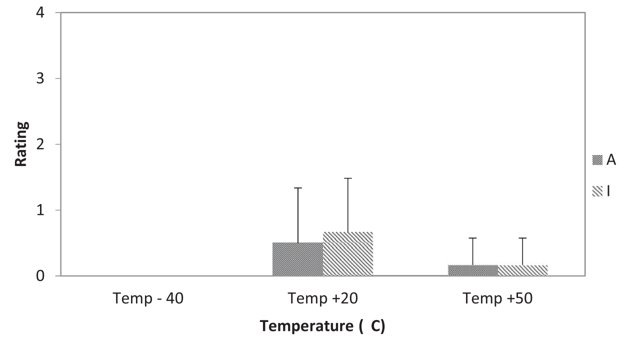

Figure 10. Evaluation of the possibility to adjust the averaged (A) and individual (I) vests, pre-conditioned at −40, +20 and +50 °C.
Note: Rating scale: 0 = *comfortable fit*; 4 = *impossible to adjust*. $p > 0.27$.

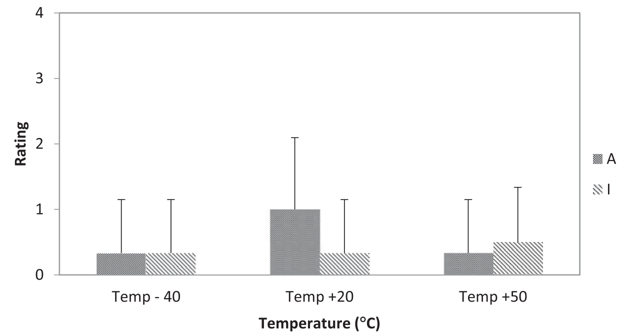

Figure 11. Assessment of physical discomfort when using the averaged (A) and individual (I) vests, pre-conditioned at −40, +20 and +50 °C.
Note: Rating scale: 0 = *no physical discomfort*; 4 = *some physical discomfort and great relief after removing the vest*. $p > 0.22$.

tested was associated with only minor physical discomfort. The high values in the standard deviation were due to the construction of the rating scale, which did not include the rating 1, while the rating 2 represented minor discomfort. Differences between the A vest and the I vest were not statistically significant.

The mean rating of exercise performance when using the developed vests is shown in Figures 12–14. The results presented in Figures 12–14 indicate that the developed ballistic vests do not pose significant problems in doing exercises during the test. The obtained results indicate a slightly higher (worse) score during the dynamic tests performed in the final phase of the study. Large variations in subjects' responses resulted in high values of standard deviations. However, differences between the A vest and the I vest were not statistically significant.

3.8. *Comparison of the vests tested by users*

Having completed each test variation, subjects put on the A vest and the I vest. The subjects evaluated how the vest was donned and removed as well as its adjustment

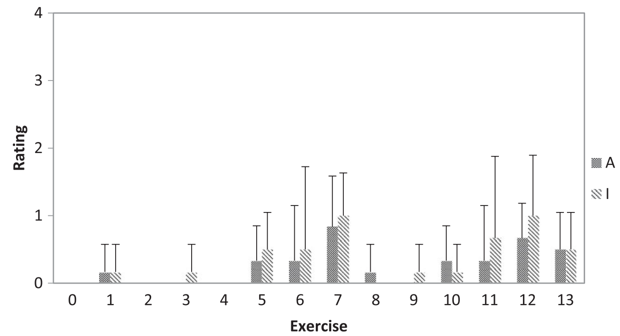

Figure 12. Assessment of the ability to do individual exercises when using the averaged (A) and individual (I) vests, pre-conditioned at −40 °C.
Note: Rating scale: 0 = *no problem*; 4 = *significant difficulties or inability to do the exercise*. $p > 0.26$.

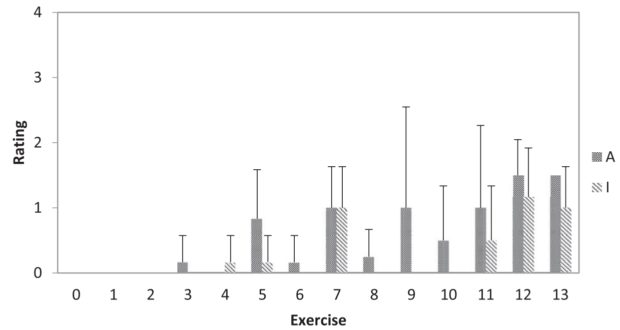

Figure 13. Assessment of the ability to do individual exercises when using the averaged (A) and individual (I) vests, pre-conditioned at +20 °C.
Note: Rating scale: 0 = *no problem*; 4 = *significant difficulties or inability to do the exercise*. $p > 0.37$.

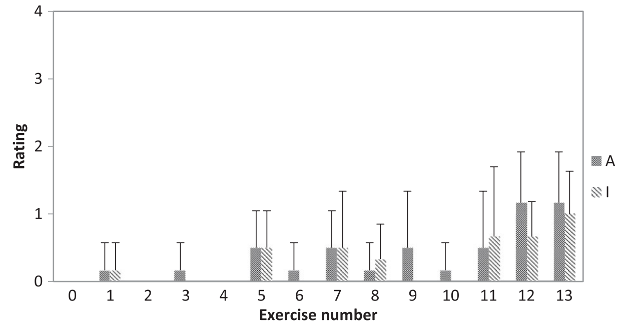

Figure 14. Assessment of the ability to do individual exercises when using the averaged (A) and individual (I) vests, pre-conditioned at +50 °C.
Note: Rating scale: 0 = *no problem*; 4 = *significant difficulties or inability to do the exercise*. $p > 0.41$.

possibilities, and then they had to choose the one they would like to work with and explain their choice. The evaluation results for donning the vest, removing it and its adjustment possibilities are presented in Table 6.

As the test results presented in Table 6 show, the subjects rated donning, removing and the adjustment possibilities of the I vest better; however, they more often (4

Table 6. Comparison of donning the vest and removing it (on/off) and its adjustment possibilities (adj) in relation to the averaged (A) and individual (I) vests after completion of all physiological test variants.

	A vest		I vest		
Subject	On/off	Adj	On/off	Adj	Choice and reason
1	1	0	0	0	A, because it is longer at the front
2	0	0	0	0	Cannot see the difference
3	0	0	0	0	A, because it is longer at the front
4	0	3	0	0	I, because it fits better
5	0	0	0	0	I, because it fits better
6	0	1	0	2	A, because it is longer at the front
Average	0.17	0.67	0	0.33	

out of 6 subjects) chose the A vest as personal protective equipment for work because they preferred it to be longer in the front.

4. Discussion of results

The objective of the physiological tests was to evaluate the thermal strain on police officers who wore two models of ballistic vests designed to be worn under clothing, developed in the framework of the project, after they had been conditioned in high (+50 °C), low (−40 °C) or neutral (+20 °C) ambient temperatures, while performing various occupational activities. Police officers tested the vests developed, based on the results of their body scans. The first vest variant was the A vest adapted to size subgroups determined from the identified group of officers. The second was the I vest that was developed based on the individual body measurements of the officers.

The study did not reveal any significant differences between the physiological responses of officers during the use of the two developed ballistic vest variants.

While pre-conditioning the vests at the low ambient temperature, the temperature of their inner surface reached approximately17–18 °C, which influenced the decrease in skin temperature, the largest compared to vest pre-conditioning at positive air temperatures.

The studies show a moderate level of heat storage in all air conditioning variants. In addition, the level of perspiration was low, despite the rather demanding nature of exercises. Despite the high humidity on the inner surface of the vests at the final stage of the test, the perspiration intensity was not high, reaching approximately 0.11 kg in the test with cooled vests to about 0.20 kg in the test with heated vests. This was due to the fact that the test duration was less than 30 min. As a result of this low level of perspiration, there was a small amount of sweat accumulated in the garment, which accounted for 10% of the secreted sweat. Even less sweat accumulated in the vests tested. In test variants with heated vests, they were found to be damp with the same level of sweat found in the garment as during the test with cooled vests, i.e., approximately 0.01 kg.

In the remaining variants, the amount of accumulated moisture was minimal, almost indeterminable.

The presented facts may indicate that the body of a ballistic vest user is able to maintain its thermal balance. A minimum sweat content was also found in the garment and was even lower in the vests tested despite the high humidity on the inner surface of the vest.

After conditioning the vests at neutral temperature, the temperature on their inner surface increased during the test by approximately 6 °C, and only by 2 °C after conditioning them at the highest applied temperature; however, in this test variant the aforementioned parameter reached 36 °C at the beginning of the test. Relative humidity on the inner surface of the vests reached 80–90% at the end of the test; however, its level increased after the 12th (of 13 in total) exercise in the test, after low temperature pre-conditioning, and after the 7th (of 13 in total) exercise during the other two test variants, when subjects started to do more dynamic exercises. After vest conditioning at the highest air temperature, the increased humidity on the vest's inner surface caused a decrease in its temperature on this surface starting from the 7th exercise, which was more balanced on the back surface (approximately 1 °C).

The test results obtained indicate that changes in the physiological parameters of the subjects and the physical parameters of the ballistic vests did not affect the ability to use the vests efficiently.

Subjective assessments regarding donning the vests, removing them and the possibility to adjust them showed that the I vest could have been slightly better fitted and therefore would have better adhered to the body. However, when faced with the option of choosing one of the two types of vests on offer, the subjects, in most cases, chose the A vests as they had a slightly longer front part, so they protect the lower belly area better.

Ratings provided on donning the vests, removing them and their adjustment possibilities, as well as evaluation in terms of physical discomfort during the use of the vests, were limited, and the differences between vests were not statistically significant. These ratings indicate a user-friendly vest structure, with few obstacles to preparing and use them. Usage practice will determine the optimum way to don the vest and fit it in such a way that the vest is of minimal burden to its user as possible.

In this research, vest users had some difficulties in choosing between vest adjustment and the degree of protection they provide. When providing the officers with the opportunity to compare the developed vests one after another, in most cases (4 out of 6 subjects) they indicated that they prefer the vest which was longer at the front, i.e., the A vest. At the same time, subjects found the donning, removing and adjustment of the I vest to be better.

5. Test findings

The vests tested, both the averaged and individual ones, meet the requirements of Standard No. PN-V-87000:2011 [11] (clause 4.5). After 5-h vest conditioning at low (−40 °C) and high (+50 °C) ambient temperatures, the subject was able to put the vest on, adjust it and perform basic occupational activities.

The applied procedure of performing occupational-related activities after pre-conditioning the vests tested did not cause significant physiological stress on the subjects and the differences between the tests with the averaged and individual vests were not significant.

After a short-term, high-intensity exercise, the tested vests absorbed the minimum amount of moisture.

Donning the vest, removing it and adjusting it did not cause major difficulties, in so far as the vest could be adjusted to the right size.

Using the tested vests did not cause significant physical discomfort.

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Note

1. The Secret Study Group is a consortium of five institutions: Institute of Security Technologies MORATEX (the leader), Central Institute for Labour Protection – National Research Institute (CIOP-PIB), Protective Equipment Enterprise MASKPOL (a joint stock company), Military Armed Forces Technical Institute in Zielonka, Poland, and Police Academy in Szczytno, Poland.

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