Ergonomic Assessment of Composite Ballistic Products

A. Bogdan, A. Marszałek, A. Łuczak,

Department of Ergonomics,
Central Institute for Labour Protection – National Research Institute

G. Bartkowiak , K. Majchrzycka, G. Owczarek

Department of Personal Protective Equipment,
Central Institute for Labour Protection – National Research Institute

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND

Key Project No. POIG 01.03.01-10-005/08 entitled: „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

INTRODUCTION

Helmets and vests with the respective refills and ballistic shields are typical protective equipment used by police and army. In order to improve the quality and functionality of these products numerous works of esearch and development are carried out, that aim is to obtain products with the highest level of protection. Simultaneously it is necessary to conduct research in the field of structural adjustment to the requirements of users and the specificities of their work, i.e.: physical effort, workers exposure time, thermal environment and the application of other required equipment.

The aim of the paper is to present a methodology of comprehensive evaluation helmets, ballistic vests and the shields, reflecting the assessment of users' physiological and psychological parameters. Conducting research in accordance with the planned methodology allows for an assessment of physiological stress resulting from long-term work in the clothing that disturb exchanging body heat in the environment, as well as hysiological disturbances resulting from the proper reception of external stimuli, irritation and mental stress during work with ballistic equipment.

GENERAL PRINCIPLES

All tests will be conducted with participation of 12 volunteers - policemen (future users of respondents) aged 20 - 40 years. Volunteers will be selected in accordance with similar physical capacity and similar body shapes.

PHYSIOLOGICAL STUDIES

Physiological studies can deliver knowledge about a physiological load of users' body during physical effort in a set of personal protective equipment under thermal environment impact.

Physiological responses of human body were an aim of many studies with protective clothing, including impermeable one and protected against chemical hazards (Bishop et al. 1995, Levine i in. 2001, White & Hodous 1987). Such researches indicated that thermal load of the user's body could be significant even during work in moderate thermal environment. Thermal load is increasing in a higher environmental temperature and with higher physical work intensity (Holmer et al. 1992, Ilmarinen et al. 2004). Physical activity in ballistic vests makes heat exchange difficult in the area of the trunk. The limitation is even more in the case of full garment applying by intervention forces workers, because of multilayer construction of the clothing, which disturbs heat exchange in large extend.

The weight of ballistic vests currently produced, depending on a construction type, is equal one to several kilogram but together with other equipment (weapons) even 8-10 kg for different kind of military service. Users of the ballistic vest wear also: inflammable uniform for exercises, light vest, heavy vest, gloves, balaclava and helmet. Full garment achieves mass of 20-30 kg but with other equipment - even 40 kg. Users of ballistic vests wear full equipment both in every season and during a day and at night. In the physiological point of view main factors influencing comfort of he vest's users are:

- weight of full garment and
- heat process exchange between environment and skin surface, disturbed in a great extend.

On one side, personal protective equipment ought to ensure enough protection but on the other side – to fulfill ergonomic requirements. Unfortunately, it often makes physiological and psychological stress larger, physical performance lower and higher discomfort. This situation occurs when multilayer and impermeable clothing is applied, especially in a hot environment condition (Mihal 1981, Ilmarinen et al. 2004, Holmer et al. 1992, Marszałek et al. 2004).

In the case of ballistic vest using, especially high challenge for body heat equilibrium will be applying of the full garment mentioned above, in condition of high air temperature, when heat accumulation in human body and increased sweat production for heat removing to the environment are expected.

In physiological studies connected with the influence of vest on user's body there will be analyzed changes of heat stress indices including internal and skin temperatures, heart rate, sweating intensity and also air humidity between the clothing layers (Bartels 2007).

Physiological studies will be carried out in a climatic chamber of CIOP-PIB, at air temperatures of –20 °C and +35 °C, according to PN-V-87000:1999 Standard. There will be monitored rectal temperature and local skin temperature at four places, according to PN-EN ISO 9886:2005 Standard, heart rate, temperature and humidity between clothing layers at two places (chest and shoulder) and body mass. Also subjective ratings of thermal sensations (PN-EN ISO 10551:2002 Standard), skin wetness (Nielsen i in. 1990) and perceived exertion (Borg G. 1982) will be collected.

During the study subjects will fulfil some exercises recommended by BS 7971-1:2002 Standard if there is possible to do them in the climatic chamber.

Described above studies will allow to compare influence of the set of ballistic protectors (three kinds of vests with two different refills, helmet and shield) on users in two thermal environments – cold and hot.

PSYCHOLOGICAL TESTS

Three psychological tests will be used while ergonomic assessing of vests and ballistic shields: complex reaction time, TUS and Grandjean Scale. These tests are esigned for evaluating human traits and skills, which are necessary to perform difficult and dangerous profession. Its make possible to assess both objective and subjective parameters of human performance (e.g. reflex, attention, mood, feeling of fatigue). Psychological tests will be conducted during two sessions of measurement: before start and after the end of each experiment. The session of psychological testing will last about 10 minutes. The sequence of tests will always be the same: (1) Grandjean Scale, (2) TUS, (3) complex reaction time.

Grandjean Scale is a subjective method for describing current mood and mental load. It is used as a subjective measure of fatigue resulting various types of work and occupations, such as Air Traffic Controllers (Costa 1993), as an indicator of changes in human performance and in the level of arousal caused by drugs(Weber et al. 1975), and as an indicator of mental load arising from mental activity (Baschera 1979). Polish adaptation of the Grandjean Scale indicated, that its validity is satisfactory (Luczak 1994).

TUS (Ciechanowicz i in 2006) is a test for assessment an attention and perceptiveness. The concept of attention refers to the selective aspect of perceptiveness, which is manifesting itself in the notice and concentrate on some elements of the environment and the relative ignoring the other ones (Reber 1985). This ability may be manifested as the possibility to focus the mind simultaneously on a specific problem or on several problems for a long time. Attention is placed on 2nd position among 10 other capabilities important for safe and well work performance (Luczak 1999).

Complex reaction time test is a measure of reflexes. The response time is defined as "the time interval separating the stimulation perceived by subject and its conscious response." The assessment of the reaction time is practiced in job selection for occupations, requiring superb reflexes, attention and for operators' work (Sillamy 1989). Reflex is placed on 2nd position among 15 other sensomotor features important for safe and well work performance (Luczak 1999).

THERMAL INSULATION TESTS

Thermal insulation of used protective equipment influence on amount of heat transferred to the environment and thereby on thermal stress of users (Holmer 2009).

All the experiments on a thermal manikin will take place in a climatic chamber. Thermal insulation of the vests and helmets will be determined on he thermal standing, stationary manikin type TM 3.2/R110, named 'Diana' (Konarska et. al. 2008). The measurements will be taken in accordance with EN ISO 15831 standard. Each measurement will be repeated three times at the assumptions that the climatic chamber had the following environment parameters: air temperature 10 ± 0.1°C, air velocity 0.4 ± 0.05m/s, relative humidity 45 ± 1%. All the measurements were taken with 1-second intervals and subsequently a 1-minute average value was calculated and recorded. The results were constantly displayed to help to evaluate the steady state. The tests will be conducted in three stages: measurement of thermal insulation of air layer, measurement of insulation of clothing ensemble used with vest and helmet, measurement of thermal insulation of complete protective ensemble. Resultant insulation of vest and helmet will be calculated on basis of difference in measured insulation values.

OPERATIONAL LABORATORY TESTS

Operational research methodology takes into account a subjective assessment of people taking part in them, psychophysical tests as well as on objective evaluation of researchers. During operating tests users will wear vests and helmets and then carry out a sequence of activities that simulate the use of ballistic products in the predictable conditions of use. A similar set of exercises will be related to ballistic shields, designed for handheld by the participants. Before performing tests users will answer survey questions on their own experiences with the use of ballistic products. After completing a series of exercises, users will be asked to study the subjective assessment of equipment and appropriate comments. Before and after performance users will be performed the psychological testing without the devices and product ballistic missiles, designed to assess the size of mental stress resulting from the use of ballistic products.

Operational tests will be performed at the air temperature ranging from 16°C to 32°C and relative humidity from 30% to 80% with sound effects (a noise simulation during the action) in order to evaluate the ability of communication and the effects of light enabling the premises and nooks in terms of safety.

Operational tests in the laboratory will include a set of skill exercises in the following sequence: walk in an upright position - 100 meters with a speed of 6 km/h for 10 minutes, going in an inclined position 1.3 m - 140 m for 5 minutes, walking on a horizontal plane in an upright position - 125m at any time, walking in an upright position - at speed of 3 km/h for 5min, 1min walk, or run on the treadmill at a speed of 8 km/h on the distance 133 m, 2 min walk, or run on the treadmill at speed of 2.4 m/h on the distance 80 m and 20% slope; 4 min walking on the horizontal treadmill at a speed of 4.0 km/h - a total distance of 267 m, crawling in the tunnel of 70 cm height by 5 minutes - a total distance of 70 m, entering and exit the ladder, and once the transition in both directions by the square hole of dimension 460 mm side, at a height of 20 m; filling the basket scraps of rubber 20 times by 10 minutes, moving successively to 10 m distance and laying in a pile of 20 sand bags, each weighing 12 kg.

After the test users will subjectively evaluate equipment by completing a questionnaire assessing their helmets and viewfinders. During tests the compatibility of their helmets used with another of their equipment (vests, shields) will be assessed.

OPERATIONAL FIELD TESTS

The aim of field tests is to evaluate the design of new prototype devices in the ballistic conditions similar to the actual use, and verify the test methodology developed laboratory supplies, during which the devices are assessed subjectively in the field of ballistic ergonomics and safety.

Before and after field tests the psychological tests will be carried out without the products and with products of ballistic missiles.

The exercises will consist of: crawling by about 30 m under the barbed wire, beat the underground tunnel, cross the brick walls and go through dark labyrinth, where you can only navigate "blindly"; slide down the rope into a pit filled with water, where at the height of 0.5 m from the pane is hidden entrance to the underground tunnel, after crossing about 40 meters go into the basement, check all the rooms and corners to make sure that they are safe.

During field and laboratory tests the energy expenditure will be analyzed. The excessive work load of human organism may cause a peripheral tirering, including the musculoskeletal system and general fatigue, and functional changes in central nervous system. These changes can lead to discomfort, exhaustion of energy resources, and a metabolic, cognitive dysfunction, including eye-hand coordination and a reduction in mental capacity (Indulski 1999, Kozlowski et. al. 1999), which may lead to additional risks in the work environment.

SUMMARY

The proposed method will allow a full ergonomic assessment of typical personal equipment used by the police and the military.

The method will be verified on the basis of discussions with potential products users, as well as on the basis of preliminary tests, developed by the project, models of ballistic protection.

ACKNOWLEDGEMENT

Publication prepared on the basis of the results obtained within the framework of the first phase of the project POIG.01.03.01-10-005/08 "Nowoczesne balistyczne ochrony osobiste oraz zabezpieczenia środków transportu i obiektów stałych wykonane na bazie kompozytów włóknistych" (acronym KOMPOZYTOWE)

Literature

1. *Bartels V. (2007) Improving the physiological function of ballistic protective vest by superabsorbent polymers. Environmental Ergonomics XII, Lubljana, 204-207.*
2. *Baschera, P., Grandjean, E. P. (1979) Effect of repetitive task with different degrees of difficulty on critical fusion frequency (CFF) and subjective state. Ergonomics, 22, 377-385.*
3. *Bishop P., Ray P., Reneau P. (1995) A review of the ergonomics of work in the US military chemical protective clothing. Int. J. Ind. Ergonomics. 15: 271-283*
4. *Borg G. (1982) Psychophysical bases of perceived exertion. Med. Sci. Sports 14(5), 377-381.*
5. *Ciechanowicz, A., Stańczak, J. (2006) Testy uwagi i spostrzegawczości TUS. Warszawa: Pracownia Testów Psychologicznych*
6. *Costa, G. (1993) Evaluation of workload in air traffic controllers. Ergonomics, 36, 1111-1120.*
7. *Holmer I. (2009) Thermal manikin history and applications, International Manikin and Modeling Meeting No5, Strasbourg , FRANCE*
8. *Holmer I., Nilsson H., Rissanen S., Hirata K., Smolander J. (1992) Quantification of heat balance during work in three types of asbestos-protective clothing. Int. Arch. Environ. Health 64: 243-249.*
9. *Ilmarinen R., Lindholm H., Koivistoinen K., Helistén P. (2004) Physiological evaluation of chemical protective suit system (CPSS) in hot conditions. International Journal of Occupational Safety and Ergonomics Vol. 10, No 3: 215-226.*
10. *Indulski A. (1999) Higiena Pracy, Tom I i II, Oficyna Wydawnicza IMP, Łódź*
11. *Konarska M., Soltynski K., Sudol-Szopinska I., Chojnacka A., Comparative evaluation of clothing thermal insulation measured on a thermal manikin and on volunteers, Fibres & Textiles in Eastern Europe April / June 2007, Vol. 15, No. 2 (61), 79 – 85*
12. *Kozłowski S., Nazar K. (1999) Wprowadzenie do fizjologii klinicznej, Wydawnictwo Lekarskie PZWL, wyd. III, Warszawa*
13. *Levine L., Johnson R.F., Teal W.B., Merullo D.J., Cadarette B.C. Staab J.E., Blanchard A.A. Kolka M.A., Sawka M.N. (2001) Heat strain evaluation of chemical protective garments. Aviat. Space Environ. Med. 72: 329-335.*
14. *Łuczak, A. (1994) Wpływ długotrwałego oddziaływania stresu zawodowego na próg krytycznej częstotliwości migotania światła (CFFF) z uwzględnieniem pośredniczącej roli temperamentu jako zmiennej osobniczej. (Niepublikowana praca planowa nr III.020, etap II). Warszawa: Centralny Instytut Ochrony Pracy.*
15. *Łuczak, A. (1999). Dobór do zawodów trudnych i niebezpiecznych. Bezpieczeństwo Pracy, (2), CIOP, Warszawa.*
16. *Marszałek A., Smolander J., Sołtyński K. (2004) Age-related thermal strain in men while wearing radiation protective clothing during short term exercise in the heat. International Journal of occupational Safety and Ergonomics Vol. 10, No. 4: 361-367.*
17. *Mihal J.D. (1981) Effect of heat stress on physiological factors for industrial workers performing routine work and wearing impermeable vapor-barrier clothing. Am. Ind. Hyg. Assoc. J. 42(2): 97-103.*
18. *Nielsen R., Endrusick T.L. (1990) Sensations of temperature and humidity during alternative work/rest and influence of underwear knit structure. Ergonomics 33 (2), 221-234.*
19. *Norma Brytyjska BS 7971-1:2002. odzież i sprzęt ochronny do użytku w sytuacjach przemocy i podczas szkolenia. Część 1: Wymagania ogólne.*
20. *PN-EN ISO 10551:2002. Ergonomia środowiska termicznego – Ocena wpływu środowiska termicznego z zastosowaniem skal osądu subiektywnego.*
21. *PN-EN ISO 15831:2006 Odzież. Właściwości fizjologiczne, Pomiar izolacyjności cieplnej z zastosowaniem manekina termicznego*
22. *PN-EN ISO 9886:2005. Ocena obciążenia termicznego na podstawie pomiarów fizjologicznych.*
23. *PN-V-87000:1999. Osłony balistyczne lekkie – Kamizelki kulo- i odłamkoodporne – Wymagania ogólne i badania.*
24. *Reber, A.S. (1985) The Penguin Dictionary of Psychology. Penguin Books.*
25. *Sillamy, N. (1989) Słownik psychologii. Wydawnictwo „Książnica".*
26. *White M.K., Hodous T.K. (1987) Reduced work tolerance associated with wearing protective clothing and respirators. Am. Ind. Assoc. J. 48: 304-310.*