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# Thermo-physiological comfort of soft-shell back protectors under controlled environmental conditions

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ABSTRACT

The aim of the study was to investigate thermo-physiological comfort of three back protectors identifying design features affecting heat loss and moisture management. Five volunteers tested the back protectors in a climatic chamber during an intermittent physical activity. Heart rate, average skin temperature, sweat production, microclimate temperature and humidity have been monitored during the test. The sources of heat losses have been identified using infrared thermography and the participants answered a questionnaire to express their subjective sensations associated with their thermo-physiological condition. The results have shown that locally torso skin temperature and microclimate depended on the type of back protector, whose design allowed different extent of perspiration and thermal insulation. Coupling physiological measurements with the questionnaire, it was found that overall comfort was dependent more on skin wetness than skin temperature: the participants preferred the back protector with the highest level of ventilation through the shell and the lowest level of microclimate humidity.



## 1. Introduction

Winter sports are high-energy outdoor activities that involve inherent risks, resulting in numerous falls and collisions with approximately 1.5/1000 traumatic injuries skier/day (Burtscher et al., 2008). The increasing number of skiers and snowboarders makes the development of high performance protective equipment crucial: back protectors have a fundamental role, shielding the spinal cord livers and other underlying organs thus protecting the skier from severe injuries. Historically, protectors had a hard-shell construction consisting of a hard outer shell made of a thermoplastic material combined with an inner soft padding foam. The shock attenuation technology was derived from motorcycling industry and was based on the concept of dissipating impact energy over a wide area (Smith et al., 2005). Recently, the market has seen an increasing number of products based on the soft-shell technology, made of polymeric foams with a pseudo-dilatant nature (Palmer and Green, 2005). Soft-shells are capable of reacting like a hard and rigid material when hit by a high-speed impact and like a soft and viscous material when hit by a low-speed impact. This behaviour enables a high level of protection as well as flexibility and comfort during use (Nicotra et al., 2014). Soft foams allow manufacturers to create perforated structures improving temperature control and ventilation (Nicotra et al., 2014).

Although mechanical properties are important in the development of back protectors, thermal comfort also plays a significant role in the design of such protective devices. Previous studies (Pezzoli et al., 2010, 2012, in press) have demonstrated that garments have a significant effect on sport performance: downhill skiing is particularly demanding because of the intermittent nature, alternating high-intensity phases (skiing) and resting phases (chairlift). These conditions, combined with the insulating and heavy clothing worn during skiing, makes the body sweat and exposes it to large temperature fluctuations. However, body temperature has to be kept as stable as possible and moisture needs to be expelled to avoid condensation and maintain thermal comfort (Huang, 2016). Back protectors are made of thick and bulk materials acting as a barrier against heat and moisture management. One of the reasons why athletes sometimes do not use protective devices is related with thermal discomfort provided by the use of protectors (Wardiningsih et al., 2014). Therefore, it is crucial to design back protectors with improved thermal comfort to convince the largest number of skiers to use this important safety equipment.

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Thermal comfort of clothing has been investigated with simulations in climatic chambers in many works (Wardiningsih et al., 2014; Wang et al., 2012; Renberg et al., 2014; Schindelka et al., 2013; Kofler et al., 2015; Bulut et al., 2013; Deren et al., 2012). In a recent paper (Wardiningsih et al., 2014), the influence of impact protective garments on thermo-physiological comfort has been investigated using a thermal manikin. It was found that the protective garment has a high dry thermal resistance and evaporative resistance. Colonna et al. (2014) have recently measured directly on athletes, in real and simulated conditions, the temperature and moisture management of different ski boot liners. The study has been conducted using small wireless sensors that do not significant affect the athletic performances. The authors have demonstrated that tests in a climatic chamber can simulate real skiing in outdoor conditions.

The aim of this work was to investigate the performances in terms of heat and moisture management of three commercial soft-shell back protectors to identify design parameters affecting thermal comfort during winter sport activities. This goal has been pursued through wear trials of five testers who performed a controlled intermittent physical activity on a treadmill in a controlled environment to simulate the metabolic rate of skiing.


**Fig. 1.** Soft-shell back protectors tested in this work.

## 2. Materials and methods

Back Protector 1 (BP1) fits on the body with adjustable strings and an elastic band around the hip, Back Protector 2 (BP2) has a tight waistcoat with an elastic band around the hip and Back Protector 3 (BP3) is made of an oblong shell covering the lower back and has a double elastic band around the hip (Fig. 1).

The flexible shells have also different shapes: BP1 partially covers the spine from the neck to the waist, while BP2 and BP3 protect the spine up to the sacrum.

Back protectors characteristics are shown in Table 1. The weight of the shock-absorber shell is 60% of the overall weight for BP1, 50% for BP2 and 47% for BP3. Thus, the vest represents a variable and non-negligible portion of the whole back protector mass. BP2 is the lightest due to the low density of the shock absorber material and the high density of holes in its structure.

The tests have been performed inside a climatic room (54 $m^3$volume) where the average air temperature ($T_a$) was 12.83 ± 0.38 °C, the relative humidity (RH) was 65.07± 1.12% and the air-flow in the climatic room was set to 0.2 m $s^{-1}$. Even though back protectors are normally worn under the ski jacket, in this work the back protector was worn as external layer, as shown in Fig. 2: this configuration allowed to assess back protectors performance without the interference of any additional clothing layer attenuating any difference. As the back protector alone did not guarantee protection against cold, a mild temperature of 12 °C was set in the climatic room.

Back protectors were worn by five volunteers (three women and two men) with average age of 33.0 ± 3.8 and average weight of 57.38 ± 2.87 kg. The number of participants is comparable with other literature works investigating thermal comfort of apparel and sports equipment (Splendore et al., 2011; Havenith et al., 2008; Dai, 2011; Öner et al., 2015; Liu et al., 2013; Dai et al., 2008; Hofer et al., 2014). The participants were informed about the type of test and freely decided to participate in the experimentation. The experimental procedure was conform to the Code of Ethics of the World Medical Association (Declaration of Helsinki). Each volunteer wore all three back protectors and did the same physical activity in three different days at the same hour, to avoid the effect of circadian cycles. Apart from the back protector, the volunteers wore the same outfit: long sleeved shirt and underpants of a typical ski outfit. Both shirt and underpants were made of a double layer fabric with the inner layer made of 100% polypropylene and the external layer of 75% polyamide and 25% Elastan.

The physical activity was preceded by a 10-minute acclimatization phase and followed by a 30-minute recovery phase (see Fig. 3), during which the subject was at rest. Acclimatization and recovery are common in this type of trials, independently of the type of activity simulated (Hofer et al., 2014; Kenny et al., 2011). The aim was to make environmental conditions uniform for all subjects before the test starts and to monitor physiological conditions at the end of the test. While doing no physical activity in a mildly cold environment, the body temperature dropped during the

**Table 1**
Characteristics of the back-protectors.

| Protector | Chemical composition | Shock absorber shell mass (g) | Density (g/$cm^3$) | Thickness (mm) | Hardness (Shore A) | Textile lining composition | Overall weight (g) | Vest |
|---|---|---|---|---|---|---|---|---|
| BP1 | PU and PDMS | 459 | 0.38 | 13 | 14 | 100% Polyester | 755 | No |
| BP2 | EVA and nitrile rubber | 345 | 0.15 | 16 | 40 | 80% Polyamide 20% Elastane | 685 | Yes |
| BP3 | EVA and nitrile rubber | 455 | 0.30 | 20 | 25 | 45% Polyester 37.5% Polyamide 7.5% Elastane | 970 | Yes |