Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 2 (2010) 2587–2592

Procedia Engineering

www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

Development of an instrumented anthropomorphic dummy for the study of impacts and falls in skiing

Nicola Petrone[a,*], Luca Tamburlin[a], Fausto Panizzolo[a] and Bruno Atzori[a]

[a]*Department of Mechanical Engineering, University of Padova, Via Venezia 1, 35131 Padova, Italy*

Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

Abstract

The development of anthropomorphic dummies to be used during impact and fall tests in skiing is presented. The dummies allow introducing in the impacts the realistic conditions of skiing equipment against the safety barriers; on the other side, the dummies can wear protective devices whose performance can be evaluated during full scale simulations. The concept, design, construction and calibration of the dummies during the INTERREG SkiProTech project are presented to explain the possibilities of applications of such devices in research.

Keywords: Skiing; impact; safety barriers; anthropomorphic dummy

1. Introduction

Skiing is such a popular sport discipline that safety in the slopes is becoming an important issue for disseminating the sport among beginners and ensuring a safe skiing to amateurs and athletes. Most common causes of injuries are personal falls during slalom and collisions with other skiers or snowboarders: collisions with fixed obstacles are rare, but can lead to severe injuries and are important during competitions where high speeds are sustained on icy slopes.

The present work was developed within the INTERREG project SkiProTech, in order to develop an instrumented anthropomorphic dummy suitable for simulated impacts against barriers or obstacles under controlled conditions. Several methods were explored to evaluate a repeatable test method for measuring the full scale behavior of mattresses and nets with solid cylindrical dummies with a tower pendulum [1] or with a snow toboggan [2].

Despite the success in giving comparative deceleration values between impacts on foam and air mattresses, the major limitation was the use of a solid wooden dummy as impactor. In this work, an anthropomorphic dummy was designed, constructed and calibrated for testing against type A nets and foam mattresses.

---

* Corresponding author. Tel.: +39-049-8276761; fax: +39-049-8276785.
E-mail address: nicola.petrone@unipd.it

doi:10.1016/j.proeng.2010.04.036

2. Concept, Design and Construction

Aim of the SkiProTech project is the development of anthropomorphic dummies that could be successfully used to collect experimental data during simulated impacts (against obstacles), collisions (between skiers) or falls (such as boot-induced drawer or phantom foot falls): these are recognized as relevant topics in improving skiing safety levels.

It is very difficult to retrieve data for the validation of numerical simulations of, on one side, impacts of human subjects on safety barriers and of, on the other side, joints injuries during falls: for this reason, the development of physical dummies with a sufficient degree of biofidelity to be used during simulated impacts and falls under controlled conditions was seen as a contribution to the development of higher safety levels in skiing.

Initial requirements of such dummies were stated as: (i) presence of a realistic head & neck assembly enabling to wear helmets and neck protectors, (ii) presence of realistic flexible feet enabling to wear boots and skis, (iii) presence of adjustable flexible joints to keep a skiing posture during impacts, (iv) presence of localized load cells to obtain dynamic load valued during impacts and falls.

An incremental approach to the development of the dummy was adopted: starting from former experiences with simple solid dummies [1,2] and adding incrementally limbs and sensors to gain experience while increasing the degree of complexity was seen as the most appropriate approach in a research where not only the instrumentation is complex but also management of logistic and ambient conditions during full scale field simulations are very complex.

Car crash dummies, even if successfully used in similar studies for helmet development in snowboard [3], were considered at this stage not suitable for skiing impact simulations due to difficulty in keeping a skiing posture and the difficulty in adding customized sensing systems or posture control devices. The sequence followed in the development of dummies is summarized in Table 1.

The first prototype dummy (namely “S0”) was a simple wooden cylinder of 75 kg, suspended along its axis, with four lateral cosmetic appendices simulating the limbs [1]: it was instrumented with a tri-axial accelerometer at the center of mass. During the tests, the dummy was connected with cables to a data logger (IMC Cronos) to collect the acceleration values.

The design of a first Anthropomorphic Test Dummy was then approached: design requirement of the first prototype, named A1 was to match a 50th percentile male anthropometry, in analogy with experiences in the car crash testing with Hybrid III dummies. The dummy was developed by adding to a wooden CNC machined trunk two legs with fixed hips (30° flexed) and adjustable knees, two feet enabling to wear ski-boots and skis and a Hybrid II neck assembly (Figure 1).

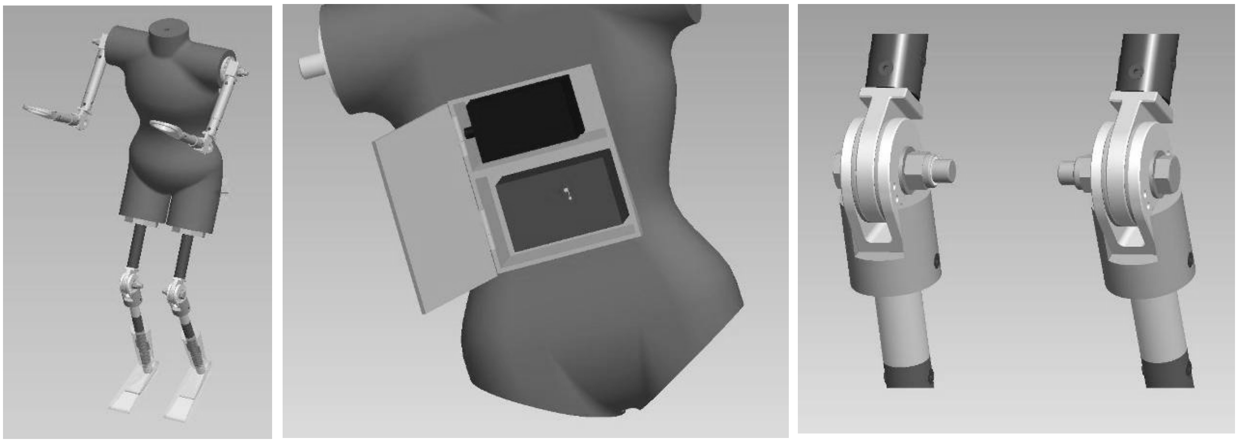

Fig.1. (a) Model of the dummy A1; (b) Housing of the data acquisition system and battery; (c) Model of knees with 1 DOF.

Table .1. Description of dummies to be developed during the project.

Dummy	Mass [kg]	Height [cm]	Head	Neck	Hips	Knees	Ankles	Sensors
S0	70	110	-	-	-	-	-	Tri-axis accelerometer at the COM Cable data transmission
A1	85	175	ANSI	Hybrid II	Fixed	1DOF	2DOF	2 Tri-axis accelerometers at Head and Chest Cable data transmission
A2	85	175	Hybrid III	Hybrid III	Fixed	1DOF	2DOF	2 Tri-axis accelerometers at Head and Chest 6 component load cell at thighs Onboard data acquisition system
A3	85	175	Hybrid III	Hybrid III	3 DOF	1DOF	2DOF	2 Tri-axis accelerometers at Head and Chest 6 component load cell at thighs Onboard data acquisition system

The knees of dummy A1 were designed with a single degree of rotation in flexion/extension: the knee can be friction locked after tightening a bolt by a calibrated wrench, in order to obtain a preset torque for slipping. In this way, the knee can ensure the dummy to stand at a predefined posture under static or straight skiing loads, but to be free of flexing under dynamic overloads. A1 feet were developed in analogy with standard silicon feet used by boot manufacturers to test the boot flexibility and durability, therefore ensuring a realistic action of the buckles during the closure of the boot and maintaining the two degrees of freedom at the ankle joint. The construction of Dummy A1 was completed by the assembly of a 5.5 kg dummy head used in the impact tests of helmets as in ANSI 89.1 (Figure 2). At this stage, arms were neglected as segments of lower influence on the global inertial properties and their mass was added to the trunk at shoulder level. This was also decided in order to simplify the handling of the dummy during impact testing in a vertical and horizontal attitude.

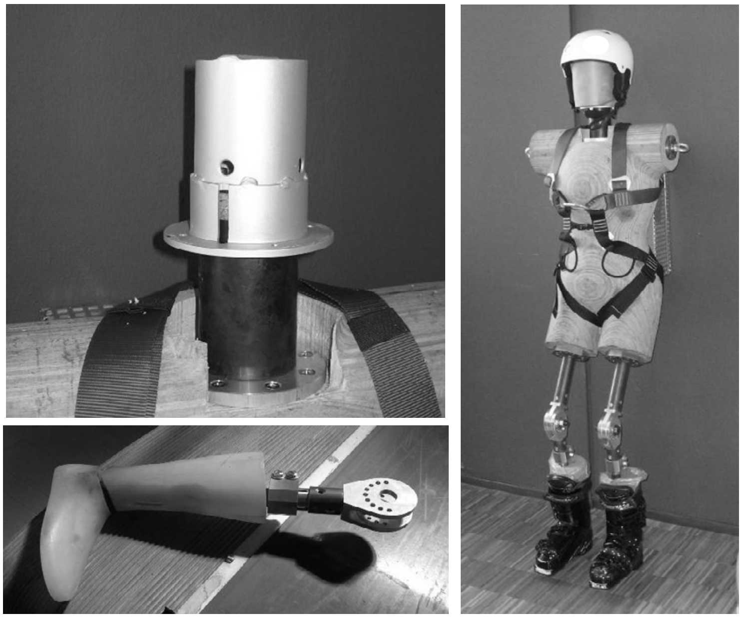

Fig.2. Construction of Dummy A1. (a) Neck assembled to the trunk with support for the tri-axial accelerometer at head COM. (b) Foot-shank assembly with 2 DOF ankles. (c) Full assembly of dummy A1 equipped with ski-boots.

A second version of the dummy, named A2, was designed after the first field tests performed on A1: some components of dummy A1 were changed to improve the dummy biofidelity to collect additional structural data during testing.

Head and neck of A1 were replaced in A2 with a Hybrid III neck-head assembly (78051-90 and 78051-61X, First Technology) as shown in Figure 3.a. Moreover the steel thighs of the dummy were machined in order to obtain a 6 channels sensing devices calibrated for measuring loads at the knee (Figure 3.b).

A further development of dummy A2 will bring to dummy A3: it will involve release of the flexion degree of freedom at the hip joint in order to enable the simulation of falls in the sagittal plane (like those known as boot-induced drawer), and in a further analysis the release of hip internal/external rotation to enable the simulation of phantom foot falls and injuries. At that stage, an appropriate solution for the simulation of loads coming from the muscle stiffness and contraction will need to be implemented.

3. Instrumentation and Calibration

Acceleration values at the head and at the chest of dummy A1 were measured by two triaxial piezoelectric accelerometers PCB 353B17 with a full scale of 500g, -3 dB range of 30 kHz. Data collection on that dummy was based on a IMC Cronos data acquisition system connected by cables, controlled by a Laptop, at a sampling rate of 50 kHz per channel. Impact tests against barriers were performed with or without skis, using a tower pendulum (maximum speed 67 km/h) and were filmed by a High Speed Camera Motionblitz [4].

Accelerations at the head and at the chest of dummy A2 were measured by two triaxial piezoelectric accelerometers (SAPE-HLS-3010, Somat) with a full scale of 500g, -3 dB range of 10 kHz. Biometrics angle sensors were applied to ankles, knees and head to record the joint motion during impacts; an MTi IMU sensor was applied to the trunk in order to obtain the absolute instantaneous orientation of the trunk during the impact. By the measure of the limbs relative orientation to the trunk, the limbs absolute orientation could be evaluated after adding the absolute trunk orientation.

On dummy A2, a customized 6 component load cell enabling to measure three forces and moments at the knee was developed, based on a sensing area machined on the thigh. The thigh load cell presented six strain gauge full bridges (3/350DY43, 3/350XY33 and 1-XY43-3/350, HBM) applied to the cylindrical sensing area (Fig. 3.b) to record load time histories during the impacts. Two channels were directly calibrated as Axial load and Torque along the thigh axis, the other four were calibrated as bending moments at proximal and distal sections in a lateral and sagittal plane.

All acceleration, orientation and strain signals were collected by a 24 channels system (eDAQ lite, Somat) programmed to collect acceleration, angle and strain signals at 50 kHz per channel (Figure 3.c).

After the development of the instrumented thigh, a set of calibration tests were performed (Figure 4.). The instrumented thigh was restrained onto a solid wooden block as it was in the dummy thigh, and calibrated loads were applied at the knee center in the six nominal loading directions: three forces (axial, antero-posterior, medio-lateral) and three moments (torque, bending in a sagittal plane, bending in a lateral plane) were applied with increasing/decreasing load ramps to obtain the calibration matrix of the six channels load cell at the thigh.

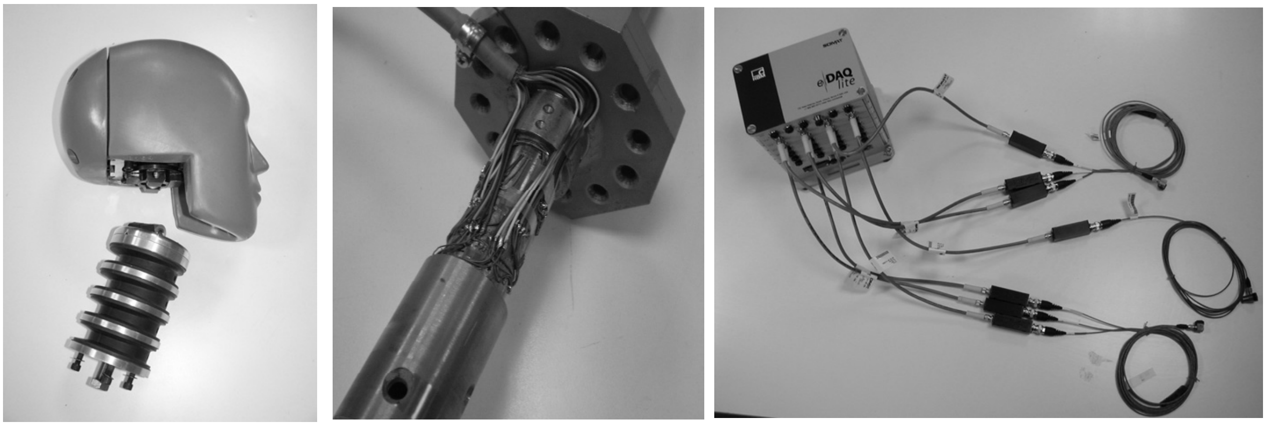

Fig.3. Components of Dummy A2. (a) Hybrid II head and neck; (b) Instrumented thigh for 6 load component acquisition; (c) eDAQ lite data logger with tri-axial accelerometers.

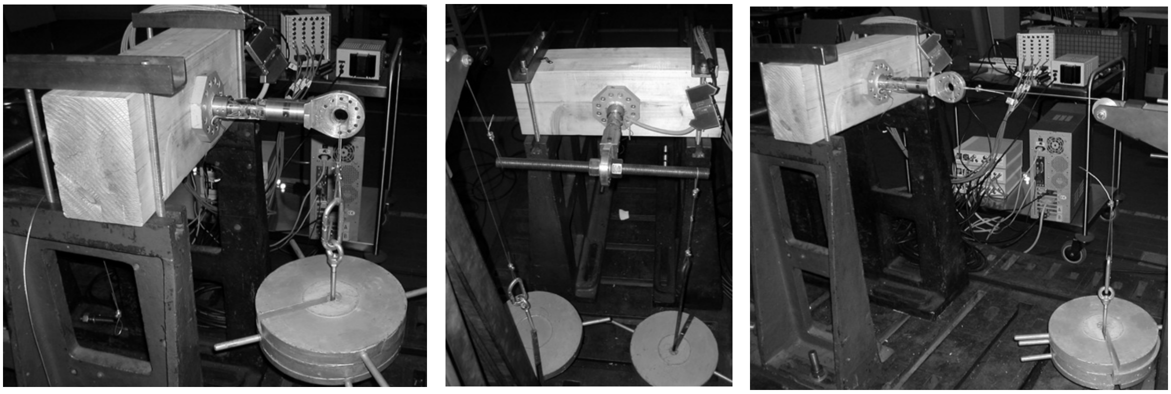

Fig.4.Calibration of instrumented thigh for Dummy A2. (a) Bending moment calibration in the sagittal plane. (b) Torque calibration. (c) Tensile axial load calibration.

4. Field Testing Results

Dummy A1 was adopted during field tests on type A nets and foam mattresses [4] for comparison with the behavior of solid dummy D0.

The field tests were able to highlight most of the issues correlated with the use of such dummies. First of all, the launching method chosen for the dummies was a tower pendulum, whose height of 18 m allowed to reach maximum speed of 66 km/h. This method [1] was preferred to a sledge solution, a toboggan [2] or a cable [3] solution for its simplicity of installation in an open field as a skiing area.

Lifting and guiding the dummy against the barrier was obtained by means of a climbing harnesses applied to the trunk. In the instant of impact, a release system controlled by a cable was developed to ensure that the dummy could impact unrestrained against the barriers: the use of signal cables for the collection of data did not allowed the complete release of the dummy. This will be achieved with A2 and A3 dummies.

Examples of the application of the dummy in the field tests are reported in Figure 5. The frame of maximum penetration depth captured by a high speed camera during the impact of dummy A1 with skis on a type A net is reported in Figure 5.c: in Figure 5.d, the same instant is reported for an impact on foam mattresses.

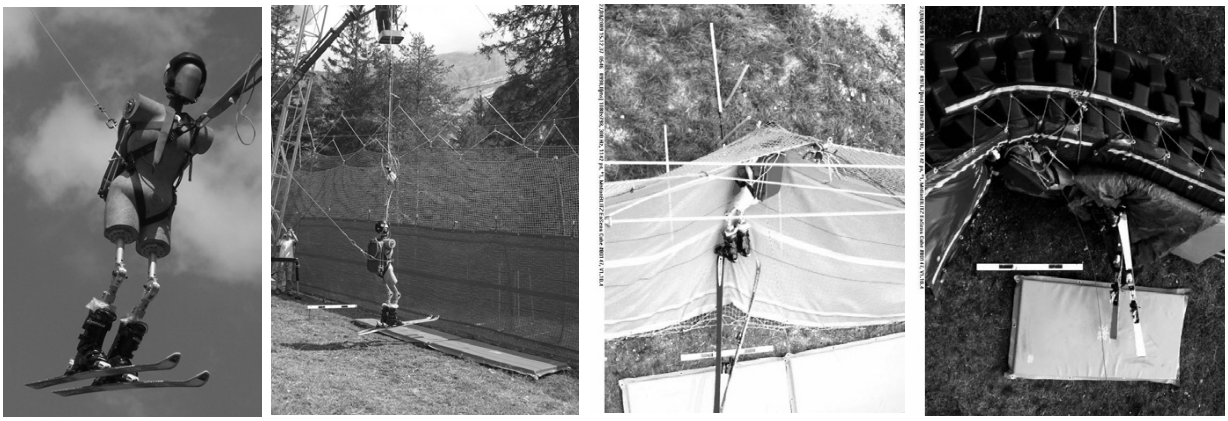

Fig. 5 .Field testing with Dummy A1. (a) The dummy A1 during the lifting before impact. (b) The arrangement for testing type A nets. (c) Maximum penetration instant for dummy A1 against type A net. (d) Maximum penetration instant for dummy A1 against foam mattress.

Quantitative values of deceleration recorded during impacts with dummy A1 were reported in [4]. Figure 6 reports a sample of deceleration values recorded at the dummy chest during the impact of Figure 5.c: the spikes present on the four channels before the peak deceleration correspond to the ski binding release before the full diving of the dummy into the net.

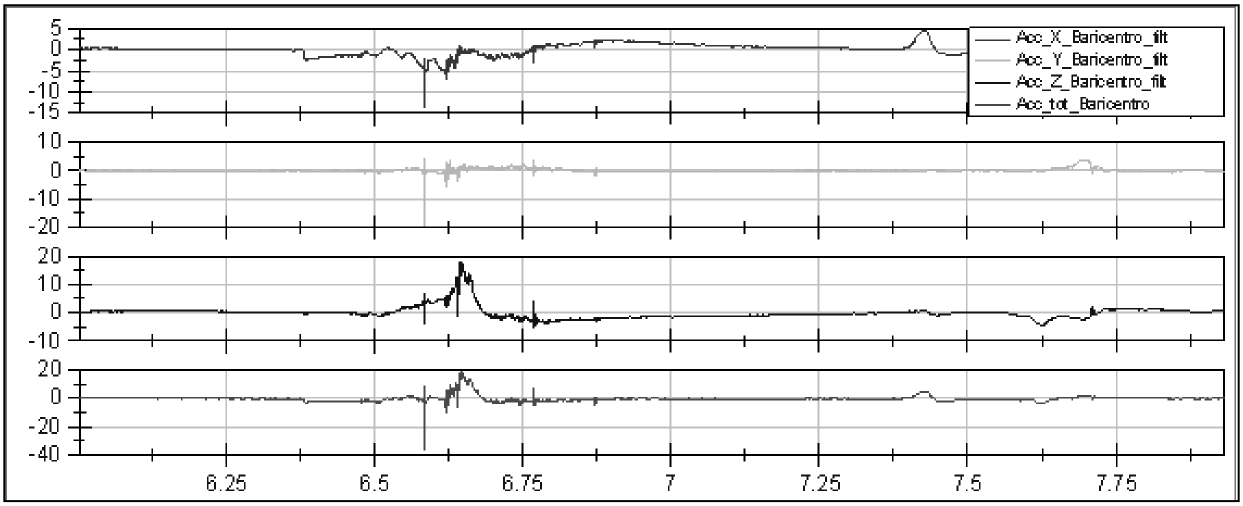

Fig.6. Example of deceleration values at the trunk during the impact against type A net of Fig. 5.c. Top down curves are the deceleration values respectively in the X(lateral right), Y (vertical upwards), Z (backward) and Resultant directions, referred to the trunk axis.

5. Discussion

In terms of comparison between solid and anthropomorphic dummies, despite the disadvantages of a higher complexity during testing and much higher costs, the advantages experienced with anthropomorphic dummies were a more realistic impact on barriers, the presence of skiing equipment or protection devices and the possibility of quantifying safety values such as HIC at the head.

Several failures of skis, boots, helmets, nets and mattresses were recorded, giving interesting information also to equipment manufactures in such extreme events: this method seems to be appropriate for the full scale evaluation of protective devices like Helmets, Neck braces, Knee Braces and Back protectors.

The use of Solid dummies can be seen an advantage only in the development of standard tests for dynamic standard tests on safety barriers.

Acknowledgements

The authors intend to thank the Vidori Sport Equipment – S. Vito (BL-Italy) for supporting the field testing of safety barriers.

References

[1] Petrone N., Pollazzon C., Morandin T., Structural behaviour of ski safety barriers during impacts of an instrumented dummy, Proceedings of 7th ISEA CONFERENCE 2008 Biarritz, June 2-6, 2008.

[2] Petrone N., Ceolin F., Methods for full scale impact testing of ski safety barriers, 18th ISSS Congress 2009 April 26 – May 2 , 2009 Garmish-Partenkircher – Germany.

[3] Richards D., Carhart M., Scher I., Thomas R., Hurlen N., Head kinematics during experimental snowboard falls: implications for snow helmet standards, Skiing Trauma and safety, 17th volume, ASTM STP 1510.

[4] Petrone N., Ceolin F., Morandin T., Full scale impact testing of ski safety barriers using an instrumented anthropomorphic dummy, Proceedings of 8th ISEA CONFERENCE 2010 Wien, 12-16 July, 2010.(in press)