COMPARISON OF SINGLE- AND MULTILAYER MATERIALS USED AS DAMPENING ELEMENTS IN KNEE-PROTECTORS

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The purpose of this study was to identify characteristics of protectors and materials used to assemble protectors, which can be used to create a ranking and proof that a protector has the effects wanted. Single layer neoprene of increasing material strength (n=7) was compared to prototype multilayer materials (n=18) and different commercially available knee protectors (n=18). The test object was attached to a realistic knee dummy, and a fall to the floor was recorded, both kinematically and kinetically. Maximum acceleration and pressure on a single sensor was calculated at the time of the impact, as well as the height of the first rebounce after impact. For single layer materials, results showed a linear correlation of material strength and all three measured parameters. While max. acceleration and pressure both decreased with growing material strength, bounce height increased. This behaviour cannot be observed in multilayer systems. For our test materials as well as fully assembled protectors, pressure values were almost identical, while bounce height varied in a wide range. Different protectors showed great difference in their effectiveness to reduce maximum acceleration.

KEY WORDS: knee, protection, falling, kinematic, pressure

INTRODUCTION: The frequency of falling in sport poses a high risk, for amateurs (Nugent 1974), as well as for professional athletes. Typical techniques e.g. in Volleyball or Handball make it very likely for the athletes to make ground contact with their knees Long recovery times due to joint injuries, and therefore financial loss are often a consequence. Especially knee injuries are known to possibly lead to permanent disability (Kujala et al. 1995) Protectors are sometimes, but not always used. Materials and configuration of these protectors are not standardized in any way, thereby possibly putting the health of the athlete at risk.

This study evaluates different materials and commercially available protectors concerning their dampening properties, to show up the importance of high quality products, not only in elite sports, but also in sport for the masses.

METHODS: Data Collection: A realistic dummy of the knee was molded by applying a polyurethane cast to a human knee in 90° flexed position. Then the cast was cut open to remove it, and reinforced with additional cast layers. The mass of the dummy was 2kg. This dummy was mounted onto a steel construct at the ankle area, allowing rotation around the horizontal axis. (See Figure 1) In the topmost position the height of the reference marker OL1 (boxed marker in Fig. 2) is 63.5cm.

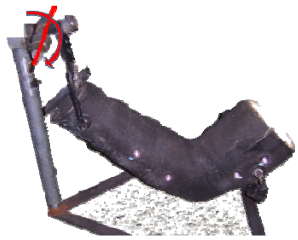

Figure 1: Knee Dummy and Marker Position

8 reflecting markers were attached for the kinematic measurement, 4 at the upper leg part, and 4 at the lower leg part of the dummy. Measurement took place using a 5 camera system at 1000Hz (Motion Analysis). At the same time, data of a 4 by 4 cm pressure measurement sensor array (16 sensors, calibrated to a maximum of 200N/cm² each) (Pliance, Novel), positioned at the area of impact on the dummy, was collected. The two systems were set to be triggered simultaneously, to ensure synchronous data.

3 virtual markers were calculated, one at the assumed position of the kneecap, and one at the longitudinal axis of the lower leg and the upper leg. These were used for visualization purposes only (Segment axes in Fig.2).

The reference for all the following Data is the marker OL1 (see Figure 2,boxed) – due to its position it moves most and is least likely to be disturbed by noise. Rebound height was calculated in reference to the height of the resting position of the knee

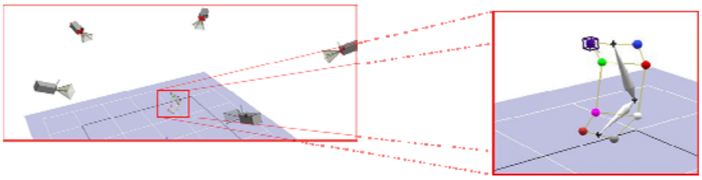

Figure 2: Camera and Marker Setup

The kinematic data were used to calculate maximum acceleration at the moment of impact. Additionally, the height of rebounce was calculated..

From the kinetic data, maximum pressure onto a single sensor was derived.

Our samples are divided in 3 groups as shown in Table 1.

Table 1: Test Objects

Item	n
1. Single Layer Neoprene of 1.5,2,3,4,5,7 and 14 mm strength.	7
2. Prototype multilayer materials of varying composition and strength	18
3. Commercially available knee protectors	18

The samples were attached to the dummy, then the pressure sensors where set to zero, to remove bias from preload due to fixation. Each sample was measured 5 times in a row, without changing position.

Data Analysis: Kinematic and kinetic data were imported to Matlab 2008b (The Mathworks), smoothed (10thorder lowpass butterworth filter, 30Hz cutoff frequency), the time of impact calculated using self written code and the results saved to Excel 2007.

RESULTS: Single layer neoprene is the first group of tested materials.

At increasing material strength, maximum acceleration at the time of ground impact decreases from 102g(+/- sd 21.7) at 1.5mm, to 57.9g(+/- sd 2.3) at 14mm, as shown in Figure 3 (whiskers indicate standard deviation). The maximum pressure per sensor is also decreasing linearly from 76.25N/cm²(+/- sd 10.7) to 41.88N/cm²(+/- sd 1.72). One can easily see the high correlation between these two values. (Correlation of 87.5%)

At the same time, the height of rebounce after impact increases, from 71.4mm (+/- sd 4.7) to 172.9mm (+/- sd 3.6)

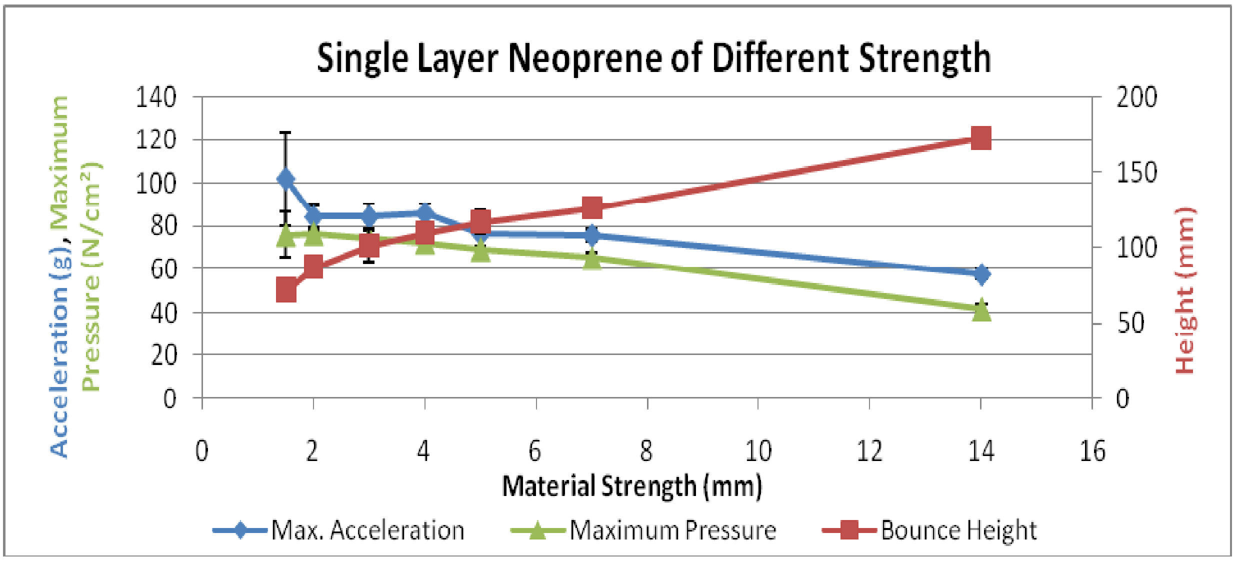

Figure 3: Max. Acceleration, Pressure and Bounce Height of single layer neoprene of increasing strength.

The characteristics of the tested multilayer materials are shown in Figure 4. Though max. acceleration differs greatly, max. pressure stays within a small value range. Bounce height doesn't show the inverse proportional behavior.

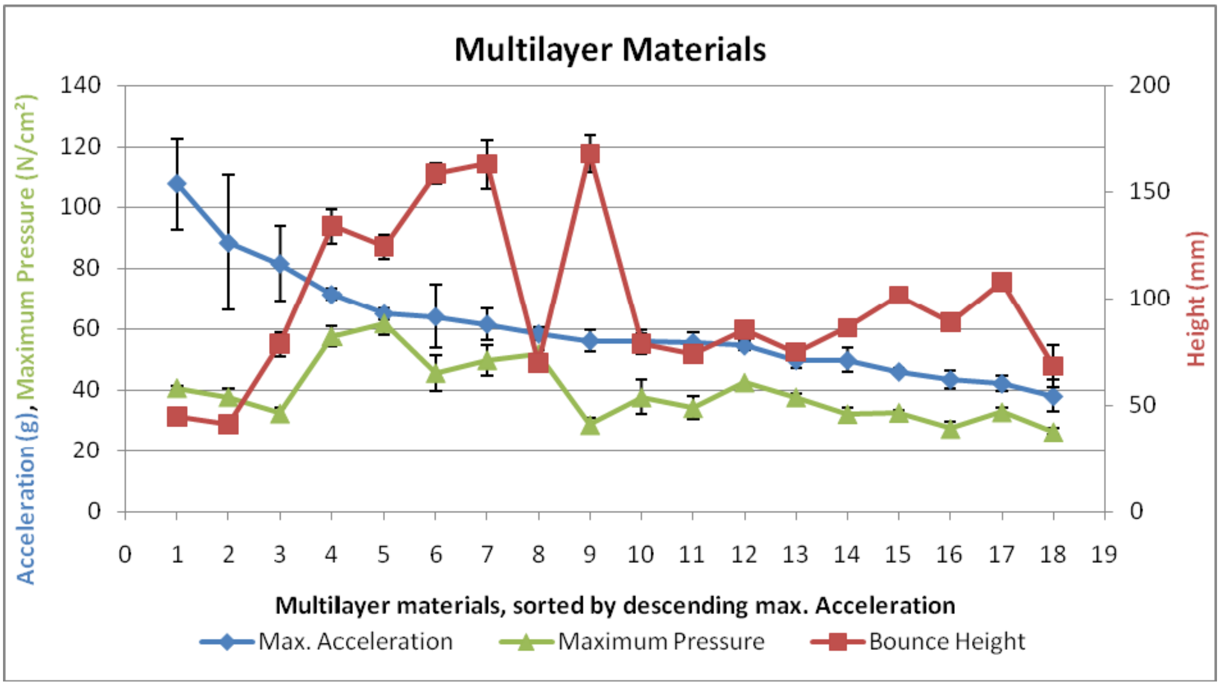

Figure 4: Max. Acceleration, Pressure and Bounce Height in multilayer materials

The same behavior can be seen in figure 5 for the tested knee protectors. Again, no differences in pressure can be seen, while bounce height doesn't behave proportional to the other parameters.

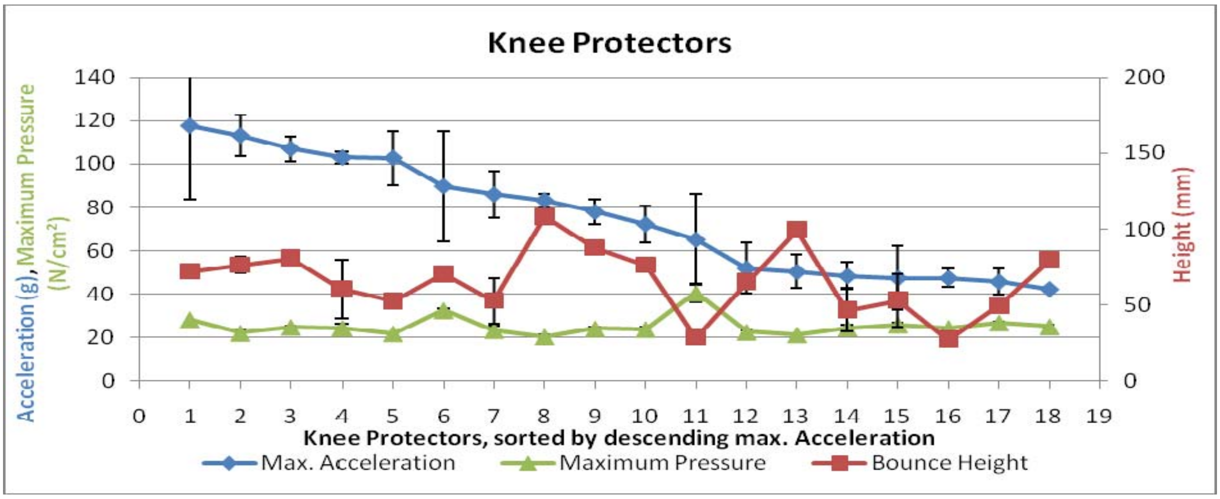

Figure 5: Max. Acceleration, Pressure and Bounce Height in knee protectors

DISCUSSION: We considered the use of a knee dummy essential for our investigation, since the conformation of the knee is quite complex. A simple flat surface could not give us an impression of what really happens at the knee. On the other hand, this uneven surface posed a big problem for our pressure measurement equipment. The Novel sensors are built to work best on flat surfaces, bending them while fixing to a surface leads to inaccurate measurements. Another effect is bridge building, where you get reasonable data on one sensor, but not on the next. Therefore only maximum pressure of a single sensor was evaluated, and no force calculations could be established. The investigation of the single layer neoprene shows the expected result of decreasing acceleration and pressure, and increasing bounce height when the material gets thicker (Figure 3). This proportional behavior between the measured parameters cannot be observed in multilayer materials (Figure 4) and protectors (Figure 5). Both groups show very consistent results in the maximum pressure. The less elastic layers of the materials make the contact area to the ground bigger and distribute the pressure evenly. Bounce height is a sign for the energy that is stored in the material and passed on to it right after the impact. In closed cell materials like neoprene, this effect is more pronounced than in open cell materials, where part of the compression is due to air pressed out of the pores. This can be a reason for the big variations in bounce height.

CONCLUSION: The materials used in building knee protectors highly influence the effect the protector has on maximum acceleration and pressure distribution at the moment of impact. Most protectors show a multilayer setup, and it is shown in our investigation, that the overall behavior of such a complex system is hard to predict.

Commercially available knee protectors show a big difference in effectiveness concerning the maximum acceleration that reaches the knee. Best types reduce it to one third of the least effective ones in our test (42.3g compared to 117.5g). It's therefore essential for the responsible athlete or trainer, to test and choose the right protector for the respective kind of sport.

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