PERFORMANCE OF CROWD MANAGEMENT SHIN GUARDS SUBJECTED TO BALL AND BASEBALL BAT IMPACTS

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Two impact apparatuses simulating projectile and baton blows were used to evaluate the blunt impact attenuation performance of shin guards used in Crowd Management Interventions (CMI). These guards are strapped to the lower leg similarly to the baseball and hockey counterparts. Transmitted forces were measured through the use of piezoelectric force transducers and an accelerometer. Force attenuation factors as high as 81% were obtained when compared to impacts generated directly on a human shin surrogate. The results of an injury analysis based on bone fracture thresholds confirm the importance of wearing protective equipment in CMI. Large deviations were observed when comparing the results from the two threat simulators, baseball bat impacts yielding higher transmitted force than ball impacts for the same energy level. This indicates that the impact energy alone is not sufficient to fully describe the impact profile. When testing protective equipment, it is important to select impact generators that appropriately replicate the type of threats that the equipment must protect against.

KEY WORDS: Force attenuation, blunt impactor, pitching machine, injury analysis.

INTRODUCTION: In the last several years, a core of international "Demonstration Organizers" were present at major events in North America and Europe, studying, documenting and learning about the weaknesses in the way that the authorities handle protests and demonstrations. During these events, it was observed that police equipment in modern Crowd Management Interventions (CMI) was not always adequate with law enforcement personnel being injured. Therefore, it is important that research be carried out on the blunt impact performance of CMI personal protective equipment (PPE). The present study focuses on the lower leg, a part of the body often prone to impacts, as it is not always protected by shields. Most threats that security officers have to face in the event of a CMI can be classified into two categories: launched projectiles, and hand held blunt weapons. To simulate these two categories of threats, two experimental apparatuses, the Blunt Impactor (BI) and the Pitching Machine (PM) were used. The BI, depicted in Fig. 1a, uses a pneumatic system to power a baton or baseball bat. It has been designed especially for testing PPE against simulated baton, crow bar, or baseball bat blows. The PM, shown in Fig. 1b, consists of a standard projectile launcher, i.e. a baseball pitching machine. A similar study investigated the impact performance of soccer shin guards using a pendulum impactor (Bir et al., 1995). However, a pendulum impactor is not appropriate for generating the high level of impact energies typical of CMI. This level of energy could only be achieved by increasing the mass of the gravity-driven pendulum, yielding a non-realistic impact profile. As compared to pendulum impactors and drop towers, the BI and PM allow for more realistic simulations of blows typically encountered in CMI and in sports environments.

METHODS: Nine pairs of V-Top shin guards (by Med-Eng Systems Inc. Ottawa, Canada), were tested at room temperature (25°C) against baseball bat blows generated by the BI and ball impacts generated by the PM, at various impact energies. The V-Top shin guards are a component of the V-Top modular ensemble for blunt impact protection shown in Fig. 2. The shin guards were secured to a maple wood surrogate attached to a force platform, which permits the measurement of the peak-transmitted force through the protective equipment and surrogate. A cylindrical surrogate (36 cm long, 9 cm diameter) simulating a human shin was used (Fig. 3). Upon release of the air reservoir pressure from the BI, the baseball bat was swung and set to hit the equipment to be tested in a horizontal position. Different impact energies were generated by varying the air reservoir pressure. With the PM, a rubber baseball weighing 140 grams, representative of the weight of an official baseball, was launched at various velocities, recorded through the use of a radar system. The peak transmitted force was measured through the use of three force transducers and an accelerometer fixed to the force platform. For the BI, the impact energy was determined from the measured angular velocity of the bat, using the effective mass of the bat.

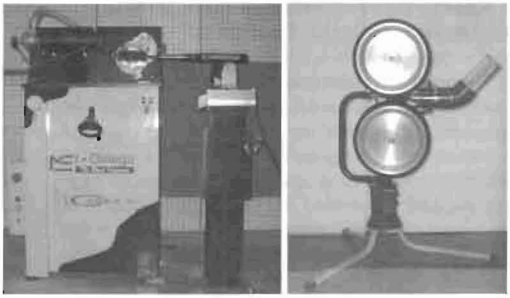

Figure 1. (a) The *Blunt Impactor* and (b) The *Pitching Machine* apparatuses.

Figure 2. The V-Top ensemble, used for crowd management interventions with detail of shin guard.

The effective mass was measured by supporting the bat at its handle, and by resting the impact location ("sweet spot", located 72 cm from the knob) on a scale. The choice of using the effective mass instead of the total mass of the bat in the calculation of energy is based on the fact that the bat is not thrown but hand-held through the impact. For the PM, the impact energy was taken as the kinetic energy of the ball just prior to impact, using the velocity measurement from the radar. In this study, impact energies ranging from 10 J up to 90 J were generated with both impact simulators. Control tests without protective equipment were first carried out, in which the surrogate was directly subjected to the two types of impacts (from the BI and PM). The results from these tests were used as a reference condition. The force attenuation factor f_{att} was calculated for a few representative cases. This factor is defined as:

$$f_{att} = \left(1 - \frac{F_{protected}}{F_{unprotected}}\right) \cdot 100\,(\%)$$

where $F_{protected}$ is the transmitted force when protective equipment is fitted to the surrogate, and $F_{unprotected}$ is the force measured when the impact occurs directly on the surrogate.

RESULTS AND DISCUSSION: The relationship between the energy and the transmitted force was approximated with a linear regression function. A strong correlation (R>93%) was found between the impact energy ranging from 10 and 90 Joules and the corresponding force yielded by the impacts in both the protected and unprotected scenarios. This linear relationship was validated only within the above energy range. Force attenuation factors were interpolated from the curve fits for two levels of energy, 30 and 60 Joules. An energy of 30 J corresponds to the highest energy level adopted by the British Standards Institution for protective clothing in use in violent situations and in training (BS 7971-4). The transmitted forces and the attenuation factors are presented in Figure 4. It can be seen from this diagram that for the same impact energy, the BI yielded transmitted forces approximately twice as high as the PM did. It was also found that the force attenuation factor decreased with increasing impact energy. The highest force attenuation factor (81%) was found for the BI at 10 J (not shown on the histogram), and the lowest factor (22%) was found for the BI at 60 J. For the PM, a weaker dependence of the force attenuation factor on the impact energy was observed. In the study of Bir *et al.* (1995) on the performance of soccer shin guards, the measured attenuation factors ranged from 40 % to 77 %. These factors were obtained with much less severe impacts. The impactor used by Bir *et al.* (1995) produced impact forces of 2.3 kN on the unprotected surrogate (energy not specified), as compared to about 8.5 kN for 10 J impacts and 15 kN for 60 J impacts on the shin surrogate in the present study. As the attenuation factor vs. impact energy relationship was found to be a decreasing function, it would be expected that impacts corresponding to energies lower than those reported here would yield higher attenuation factors. Therefore, at the impact level used by Bir *et al.* (1995), attenuation factors in excess of 81% would be expected with the Med-Eng shin guards. The force attenuation factor is a convenient tool to compare the impact performance of protective equipment, as it is relatively independent of the surrogate used. However, it does not provide information on the probability of injury. Although injuries can occur prior to bone fracture (e.g. contusions), the force required to break bones is often used for injury thresholds, as it is more readily measurable. Most studies defining the fracture threshold are related to the automobile industry, and their results vary greatly due to different experimental protocols and the age and gender of the tested specimens. For instance, in a study on 209 fresh cadaver legs (> 60 years old), Kramer *et al.* (1973) found the average tibia bone fracture threshold to be 4.3 kN with the largest peaks observed being as high as 8.3 kN. In a more recent study, Porta (1996) found tibia fracture thresholds varying from 4.3 kN up to 8.93 kN. These tibia fracture threshold values, illustrated in Figure 4 as horizontal dotted lines, were directly compared with the peak-transmitted forces measured in the present study, to correlate the impact energy with the injury potential. It was found that much higher impact energies could be tolerated with the PM, as compared to the BI, and that the shin guards provided a significant reduction in injury potential, as compared to the unprotected case. For instance, when considering the higher energy threshold, the energy required to cause a fracture is 151 J in the protected case, as compared to half this energy for the unprotected case. Although injuries cannot always be avoided even when wearing protection, the above results stress the importance of protective equipment during crowd management interventions to minimize the risk of injury. In fact, impact energies in excess of 30 J are very likely to occur, since they correspond to the typical energies of projectiles thrown by assailants (e.g. 140 g ball thrown at 75 km/h). The actual protection offered by the V-Top shin guard may be underestimated, when comparing with the published injury thresholds. The studies from which they are derived are carried out on cadaveric specimen (often embalmed) from aged donors, and the test surrogate used in the present tests does not take into account the presence of soft tissues, which are known to attenuate transmitted forces (Robinovitch *et al.*, 1995). Moreover, the tested specimens were constrained in the present study, as opposed to the actual riot conditions during which a security officer is free to move when hit by a projectile or baton blow. In such a case, a significant fraction of the impact energy may be absorbed by the inertia of the equipment and the leg.

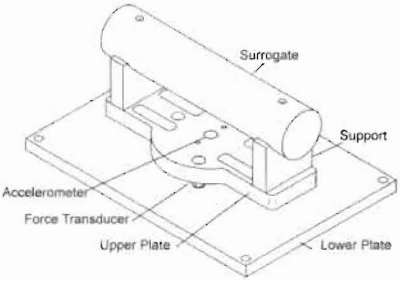

Figure 3. (a) The cylindrical surrogate simulating the tibia, attached to the force platform.

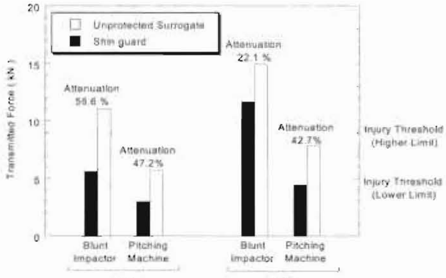

Figure 4. Peak-transmitted forces for nominal impact energies of 30 and 60 *J* generated on the surrogate unprotected, and protected with the shin guard, for the BI and PM. The attenuation factors are shown in %.

The injury analysis from the present paper is also conservative due to the fact that the protective equipment is designed to distribute the transmitted force over a broader surface area, as compared to the unprotected case. An increased surface area results in lower peak transmitted forces felt near the impact site. As the current apparatus only records the total cumulative force transmission, the force distribution effect is not taken into account in the results presented here. Moreover, it may not be appropriate, strictly speaking, to compare the transmitted forces obtained in the protected cases, with the bone fracture thresholds from the literature, as the latter have been derived from direct impacts acting on small contact surface areas. Force distribution of the transmitted force through the shin guard can be assessed using pressure mats inserted on the contact area between the surrogate and the shin guard.

CONCLUSION: This work showed that impacts of the same energy yielded different transmitted forces depending on whether a ball or baseball bat was used to generate the impacts. In the present case, the smaller force transmissions observed with the pitching machine could be due to the deformation of the ball upon impact, as compared to the more "rigid" impacts generated with the BI. It can therefore be concluded that the energy levels and impactors used in product testing and certification of protective equipment should be validated against realistic threats to ensure that experimental results lead to a safe assessment of the protection offered. This implies that the design of a protective component such as shin guards should be tailored to a specific activity, as the impact dynamics associated with baseball, soccer, hockey, crowd management, and other, may significantly differ. The blunt impact apparatus presented in this work can find applications in the testing of protective equipment for various sports, such as hockey, baseball and cricket. For instance, hockey sticks and cricket batons could be used instead of the baseball bat with the BI, if protective equipment from these sports were to be assessed. The BI allows for swing velocities adjustment for a better replication of the parameters of a given sport. The Pitching machine was found to be able to launch projectiles of various masses, ranging from 140 g to 950 g, at various speeds, allowing for the replication of a large spectrum of possible projectile impacts, representative of sports scenarios. Moreover, the injury analysis presented here could also be carried out for different types of impacts representative of various sports environments.

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