SHIN GUARD IMPACT PROTECTION

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ABSTRACT

Test methods simulating soccer kicks and field hockey ball strikes were evaluated to assess commercial shin guard performance for injury prevention. Literature on injury criteria, tolerance levels and on loading conditions relevant for lower leg injuries in soccer and field hockey has been reviewed.

High speed films of a field hockey player were made to estimate hockey stick and ball impact velocities. A number of impact tests were evaluated with respect to reproducibility, discrimination between shin guards and load conditions.

The results of the various test procedures will be discussed. It was concluded that a stiff impactor with rigidly supported shin guards provides the best results. An evaluation of nine different shin guards, commercially available in the Netherlands, indicated that all nine shin guards show a significant reduction of lower leg impact load. Some shin guards performed better than others for reducing the severity of leg impacts.

INTRODUCTION

The sports injury problem in the Netherlands is well documented due to the availability of a permanent injury surveillance system called PORS [1]. Injury data have been compiled from representative samples of hospital casualty departments. Additional enquiries are made for accident cases and injuries. The resulting database maintained by PORS can be used to identify high risk activities and dangerous consumer products.

The PORS data show that 25% of the participants in sports activities receive medical treatment for an injury every year. About 1/3 of all medically treated sports injuries are sustained in soccer. Other sports in the Netherlands that have high injury incidence rates are hockey, ice skating, volleyball and physical education. According to Huppes and de Graaf [2] about 55% of all injuries in soccer concern leg injuries. Ankle and knee injuries were most prevalent with 60% and 24% respectively of the total number of leg injuries. The portion of injuries attributed to lower leg injuries was 16%. For hockey, similar figures were recorded by PORS. The most important lower leg injuries in soccer and hockey were contusions, abrasions, cuts and fractures.

In soccer, 30% of the medically treated lower leg injuries appear to be fractures while in hockey this percentage is 7%. On the other hand, cuts contribute to 45% of lower leg injuries in hockey while this value is 9% in soccer [2]. Most of the lower leg fractures in soccer appear to be caused by kicking by the opponent. The cuts in hockey are mostly caused by the hockey ball or hockey stick.

The use of adequate protective equipment is one way of reducing the number and severity of sport injuries. Lower leg protection in soccer and hockey can be obtained by using shin guards. Most common shin guards cover the anterior side of the shin and consequently the injury reduction potential of shin guards will mainly be related to tibia injuries and injuries of the skin region directly protected by the shin guard. The effect of shin guards for reducing knee, ankle and fibula injuries is expected to be small.

A knowledge of lower leg injury mechanisms, tolerance levels and loading conditions is necessary to rate the injury reduction potential of the shin guards. Available literature in this field appears to be related mainly to automotive safety research. Biomechanical knowledge on skin injuries of the lower leg (i.e. contusions, abrasions and cuts) appears to be rather limited. Careless [3,4] concludes that shear stress is an important parameter to indicate skin injuries. Therefore we will concentrate on fractures of the tibia for which several sources of tolerance data appear to be available. Implicitly it will be assumed here that if protection against fractures can be obtained that also skin injuries will be reduced.

The major objective of this study is to develop a test method for the evaluation of the injury reduction potential of shin guards. A number of commercial available shin guards have been evaluated with this test method.

LOWER LEG FRACTURES

Fractures of the tibia are caused by a high tensile stress resulting from an extreme bending or twisting moment or a combination of both. Since shin guards only interfere with loads resulting in a bending moment, the twisting moment will not be considered further. Although it should be noted that the bending moment fracture strength decreases significantly if a twisting moment is acting also [5,6].

Fracture tolerance data have been studied using human lower leg specimen in dynamic impact tests. Asang [5] applied a transverse force at the middle of the tibia to determine the fracture strength. Other authors used the bending moment as an injury criterion. The findings of the four authors are summarized in Table 1. Column two gives the range of impactor velocities used in the experiments. The bending moment and impactor peak force presented in column four and five were calculated if they were not reported in the original reference (It was assumed that the length of the tibia or lower leg between the supported ends is 300 mm). The last column indicates whether an isolated tibia or a complete lower leg including fibula and soft tissues was used for the test specimen.

Table 1. Tibia and lower leg fracture tolerance levels.

Author	Impactor Velocity (m/s)	Number of Specimens	Bending Moment (Nm)	Impactor Peak Force (N)	Specimen
Asang [5]	0 - 4	3	195 - 300	2600 - 4000	Tibia
Nyquist [7]	0 - 4	20	274 - 453	4300 - 7150	Tibia
Kramer [8]	4 - 8	232	90 - 585	1200 - 7800	L.Leg
Stalnaker [9]	8 - 13	19	560 - 1670	7517 - 22241	L.Leg

The results of Kramer [8] and Stalnaker [9] are most relevant for this study because of the higher impactor velocities used in these experiments. The higher impactor forces found by Stalnaker can be partially explained by the location of the applied load. The point of application was positioned at one quarter of the lower leg length near the top of the tibia. Differences in age and dimensions also contributed to the observed variation. Kramer obtained forty three specimens out of two hundred thirty two with fractured lower legs. Forty two out of forty three observed fractures occurred with subjects over sixty years old.

LOADING CONDITIONS

The opponent's foot, the hockey stick and hockey ball are all potential impactors of the lower leg in soccer or hockey. The motions involved in executing a soccer kick were studied by Robertson [10]. He found that the foot hits the ball with a maximum velocity of 8 m/s. No information on the effective mass and injury producing impact velocities could be found in literature.

The mass of the hockey ball and stick are prescribed in the rules of hockey [11]. The weight of the hockey ball should be between 0.156 kg and 0.163 kg. The weight of the stick has to be between 0.340 and 0.794 kg. The stiffness of the ball and stick have been measured in a static compression test resulting in values of 0.75 kN/mm and 1 kN/mm respectively.

The velocity of a hockey ball and stick were measured in our laboratory by using high speed films. An amateur hockey player was asked to hit the ball as hard as possible. A high speed camera running at 3000 frames per second was positioned perpendicular to the plane of motion. The test showed a velocity of the hockey stick of 126 km/h (35 m/s) just before impact and 96 km/h (27 m/s) for the hockey ball just after impact.

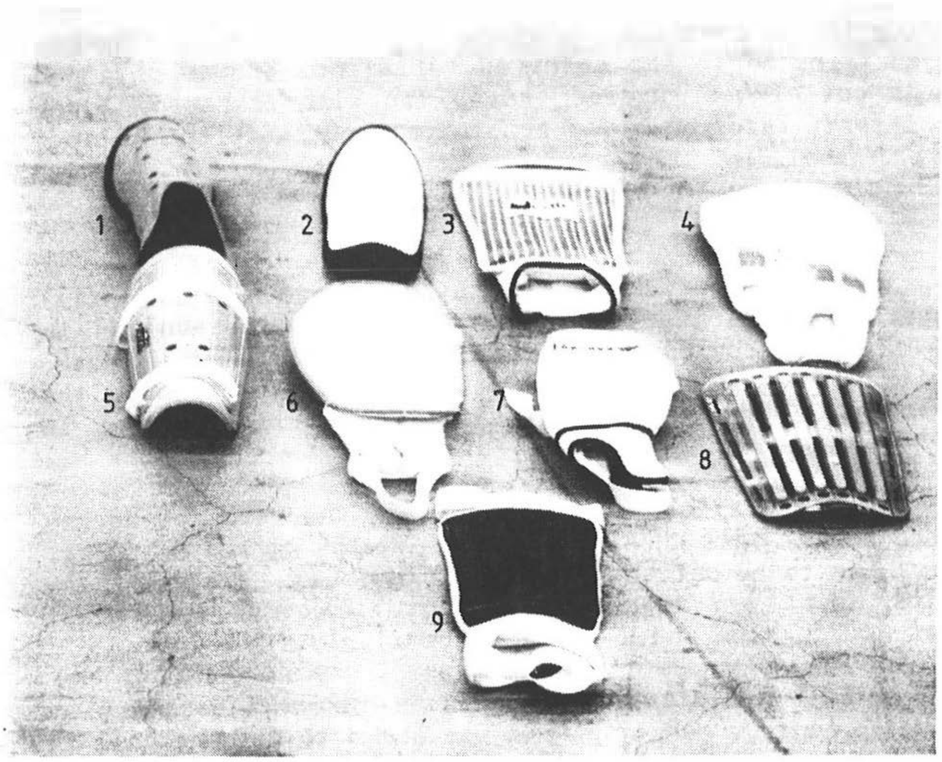
SHIN GUARDS

The materials evaluated in this study are commercially available shin guards. All guards consist of a soft inner layer and a hard outer shell. One of the guards (Uhlsport) has an extra feature, an aircushion between the hard outer layer and the soft inner layer. The guards can be divided into three types based on the construction and shape. Type 1 has a curved hard shell with a smooth surface. Type 2 has a curved hard shell with a profiled surface. The third type has a non-continuous outer shell consisting of long small strips held in pockets on the guard. The test shin guards are shown in Figure 1.

The weight and dimensions of the guards were measured and they are presented in Table 2. The attachment of the guards to the leg relied on one of three methods. Some have to be worn inside a stocking, others have one or two elastic bands with velcro fasteners and a third type does have an elastic stocking around the ankle in combination with a velcro fastener around the calf. Information on the method of attachment is included in Table 2.

The stiffness of the various shin guards were measured with an Instron universal test machine. The shin guards were supported by a rigid cylinder (diameter 100 mm) and compressed by a steel ball (diameter 88 mm). The tests were conducted with a compression speed of 100 mm/min. Compressive force and displacement of the compressing body were measured.

The compression was stopped if the distance between steel ball and top of the wooden cylinder was 1.5 mm. This event was used as a reference to compare the measurements of the different guards.



1. Avento V
2. Avento S
3. Uhlsport
4. Masita
5. Jofa
6. Puma
7. Rucanor
8. Novelastic
9. Kranzle

Figure 1. Shin guards used in the tests.

Table 2. Shin Guard Characteristics.

Brand	Type	Weigth (grams)	Length (mm)	Width (mm)	Layer Thickness Outer (mm)	Layer Thickness Inner (mm)	Attach-ment
Jofa	1	62	250	170	2.2	5.3	VV
Avento V	1	75	270	180	2.0	5.5	VV
Novelastic	2	76	220	150	4.5	3.5	VV
Avento S	2	45	225	155	1.5	3.3	S
Kranzle	3	80	210	130	3.0*	NA	SV
Masita	3	86	250	150	1.2*	NA	SV
Rucanor	3	68	200	130	3.0*	NA	SV
Puma	3	82	185	150	4.5*	NA	SV
Uhlsport	3	147	265	145	4.7*	NA	SV

Type: 1 = smooth curved outer shell, 2 = profiled curved outer shell, 3 = small strips in pockets; * thickness of strips.
Attachment: V = Velcro, S = sock, SV = ankle sock with velcro
NA : not applicable

Results are shown in Figure 2. There are three types with a significantly different force penetration characteristic: Novelastic, Kranzl and Rucanor. The Novelastic, marked with an x, is the only guard without a solid outer shell. The hard outer shell of the Novelastic is made of square tubes. During the first part of the deformation there is a bulging of the tube until the sides crack, followed by compression of the solid material.

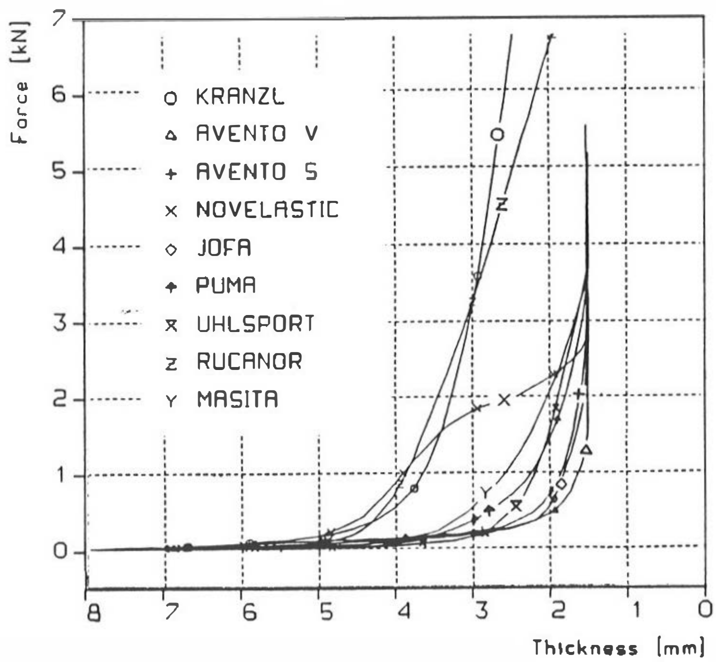


Figure 2. Quasi static compression of shin guards

DYNAMIC TEST SET UP

The injury criterion that will be used to evaluate the shin guard performance is the impact force applied to the lower leg. Several test methods have been evaluated for this purpose. It was necessary that the test method be relatively easy to use and that the reproducibility of the test method be satisfactory. Furthermore, the test should represent a realistic loading condition. The effect of different striking objects and different impacted bodies (representing the lower leg) has been studied.

Two possibilities were evaluated for the impacted body which serves as the support for the shin guards:
1) a free hanging lower leg of a crash test dummy
2) a rigid wooden cylinder with a diameter of 100 mm and a length of 300 mm (rigidly supported).

For the striking objects (i.e. impactor), three options were studied: a hockey ball, a foot prosthesis provided with a soccer shoe, and a wooden spherical impactor (mass 6.8 kg).

Although the crash test dummy lower leg appeared to offer a better anatomical fit for the shin guard compared to the rigid wooden cylinder, use of a dummy leg appeared to be unpractical due to the relatively thick skin layer of the lower leg. Due to this layer, it was not possible to discriminate the effect of the various shin guards. For the same reason it appeared not to be feasible to apply a foot prosthesis provided with a soccer shoe as an impactor. The stiffness of the foot prosthesis is too small to notice any significant differences on the shin guard performance.

As a result, two potential test methods remained: a small mass hockey ball impactor or a more heavy spherical impactor. The last impactor is considered to be representative of a kicking foot. In both test methods the wooden cylinder was used to support the shin guards. Figures 3 and 4 illustrate both test methods. Table 3 summarizes the most important test conditions.

Table 3. Dynamic test conditions for shin guard impacts.

Apparatus	Impact Velocity	Impactor	Guard Support
Spring loaded impactor	1.25 m/s	Wooden ball 164 mm diam. 6.8 kg mass	Wooden cylinder 100 mm diam.
Pendulum	2.5 - 3.6 m/s	Hockey ball 70 mm diam. 0.159 kg mass	Wooden cylinder 100 mm diam.

Two methods were studied to obtain the appropriate hockey ball speed: a drop test and a ballistic pendulum. In the drop test, the maximum drop height possible in our laboratory was 9.13 m, resulting in an impact velocity of 13.4 m/s. In this test the maximum contact time between ball and guard appeared to be less than 1 ms, causing vibrations of the instrumented guard support (resonance frequency ~ 1000 Hz). The drop test was not used further. In the hockey ball pendulum test (Figure 4) the maximum impact velocity that could be obtained was 3.6 m/s which is below the actual hockey ball velocities (i.e. 27 m/s). Peak impact load due to this low velocity is below fracture producing loads (see test results). In this test it was possible (in contrary to the drop test) to attach an accelerometer to the hockey ball, allowing a direct determination of the impact load. The hockey ball in this pendulum test is supported by two pieces of nylon line (length 1 m).

The tests with the heavy spherical impactor were conducted with a spring loaded guided impactor. The impactor was instrumented with an accelerometer. Although impact velocities up to 6.7 m/s can be obtained with this impactor. It was decided to not test with a velocity larger than 1.25 m/s. Otherwise the support body or impactor would be damaged. The order of magnitude of the resulting impact force for this velocity (see test results) is within the range of injury producing forces. Note that this impact velocity is below the actual maximum kicking velocities observed in soccer. Both the hockey ball pendulum and spring loaded impactor tests appeared to be reproducible. As an illustration Figure 5 shows the force-time histories for a 3.6 m/s hockey ball pendulum test with a shin guard. Maximum, minimum and average are shown from four tests with the same guard type.

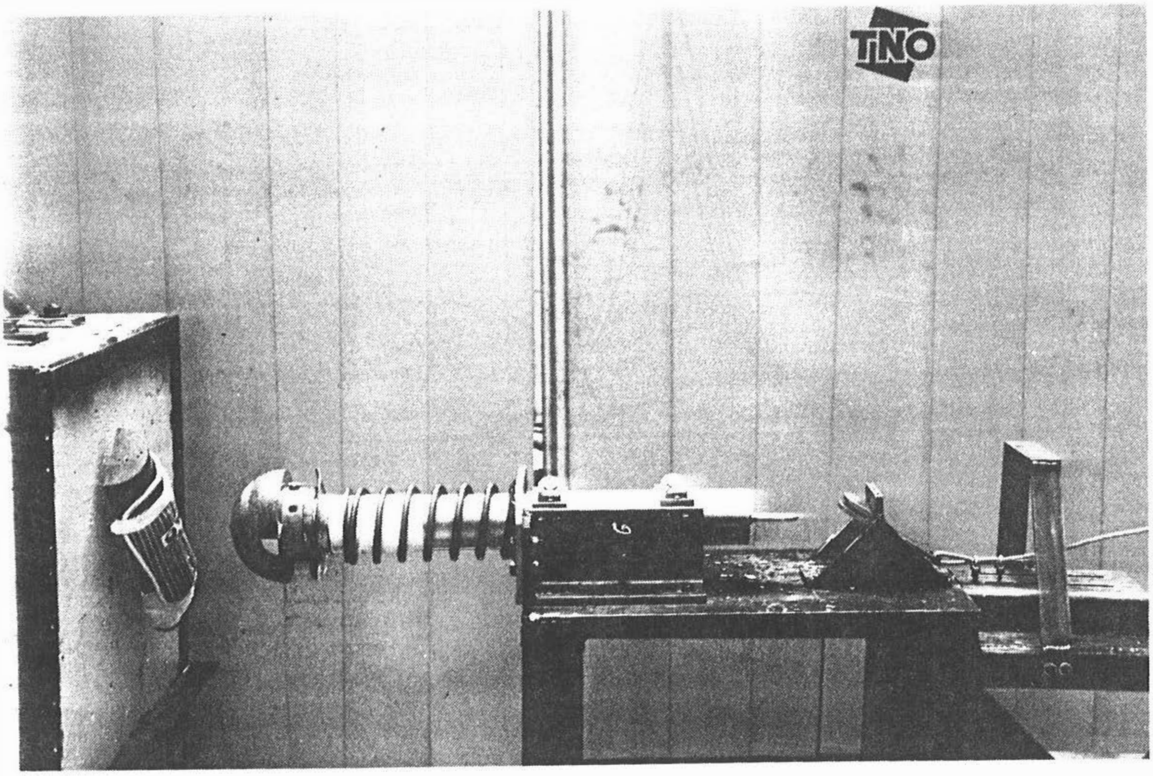


Figure 3. The spring loaded impactor test set up.

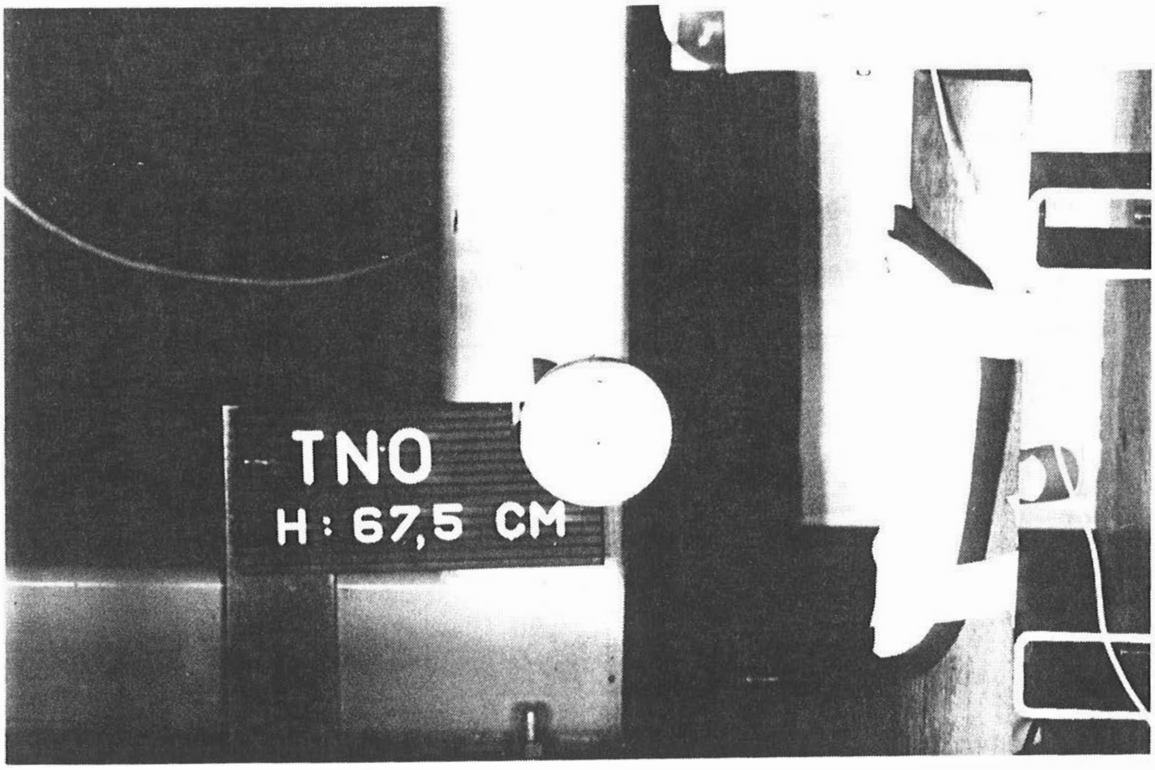


Figure 4. The hockey ball pendulum test set up.

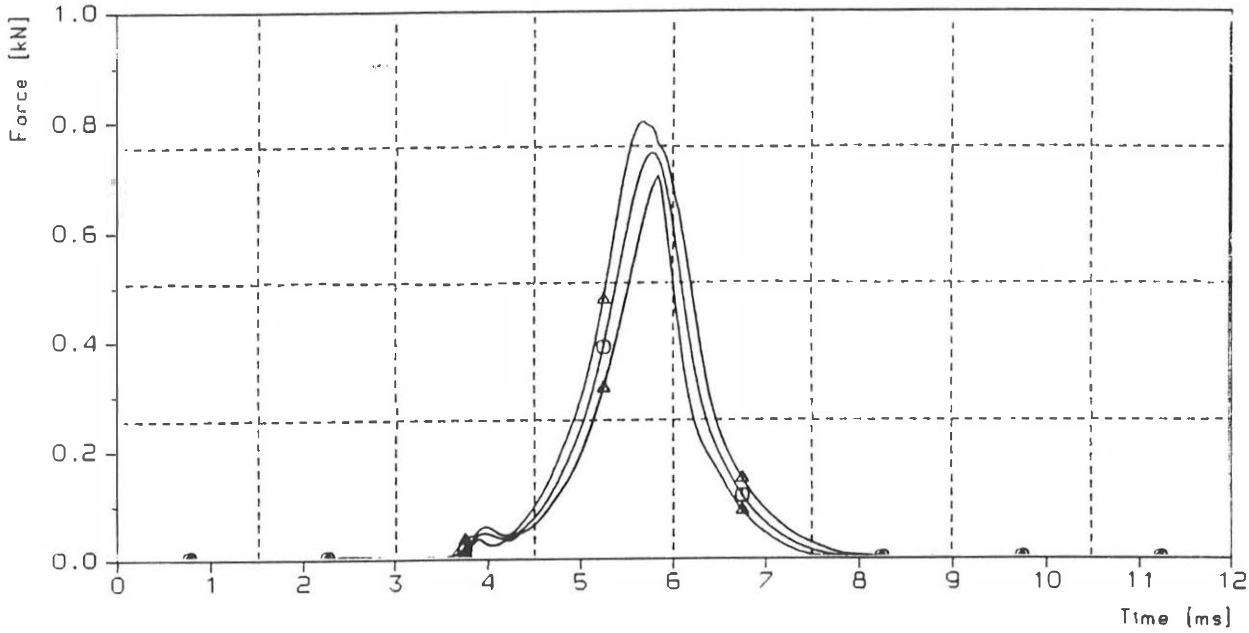


Figure 5 Maximum, minimum and average of force time histories for hockey ball pendulum tests at 3.6 m/s with shin guard (type Masita) mounted.

TEST RESULTS

Figure 6 shows the force-time histories obtained from the spring loaded impactor tests. Results are presented for an unprotected support body as well as protected by seven different guards. Peak force reduction for the different test setups are summarized in table 4. The reduction in measured peak force in the protected condition is given as a percentage of the measured peak force in the unprotected condition.

Table 4. Peak force reduction measured in spring loaded impactor tests and in hockey ball pendulum tests on shin guards mounted on a wooden cylinder.

Shin Guard Brand	Spring loaded Impactor Reduction %	Hockey ball Pendulum Reduction % 2.5 m/s	Hockey ball Pendulum Reduction % 3.6 m/s
Avento S	53	85	81
Novelastic	43	60	59
Jofa	41	77	77
Kranzle	39	76	56
Masita	39	71	44
Rucanor	35	79	71
Puma	28	64	40
Uhlsport	*	79	67
Avento V	*	90	81
No guard	0	0	0

* not available
Spring impactor :wooden ball shaped face, diameter 164 mm, mass 6.8 kg, impact velocity 1.25 m/s.
Hockey ball pendulum, mass 0.159 kg, impact velocity 2.5 and 3.6 m/s.

It can be concluded that use of shin guards results in a significant reduction in peak impact force compared to the unprotected condition. For the best guard (i.e. Avento S) a reduction in peak impact force of more than 50 % can be observed.

Tests with the hockey ball pendulum were conducted at two impact velocities: 2.5 m/s and 3.6 m/s. Results for both test conditions are presented in Figure 7 and 8. Like the spring loaded impactor test, results are shown with and without protection by shin guards. The reduction in peak force for the various shin guards is included in Table 4. Note that the impact force in these tests is much smaller than in the spring loaded impactor test. The relative peak force reduction appears to be larger in the less severe tests. Considerable differences in peak force reduction can be also observed. Except for 3 guards (i.e. Kranzle, Masita and Puma) all guards show a similar relative protection in the 2.5 m/s and 3.6 m/s impact. Remarkable is the very low peak force found for the two Avento guards. The Avento S performed best in the spring loaded impactor test as well. (Avento V was not available for the spring loaded impactor tests).

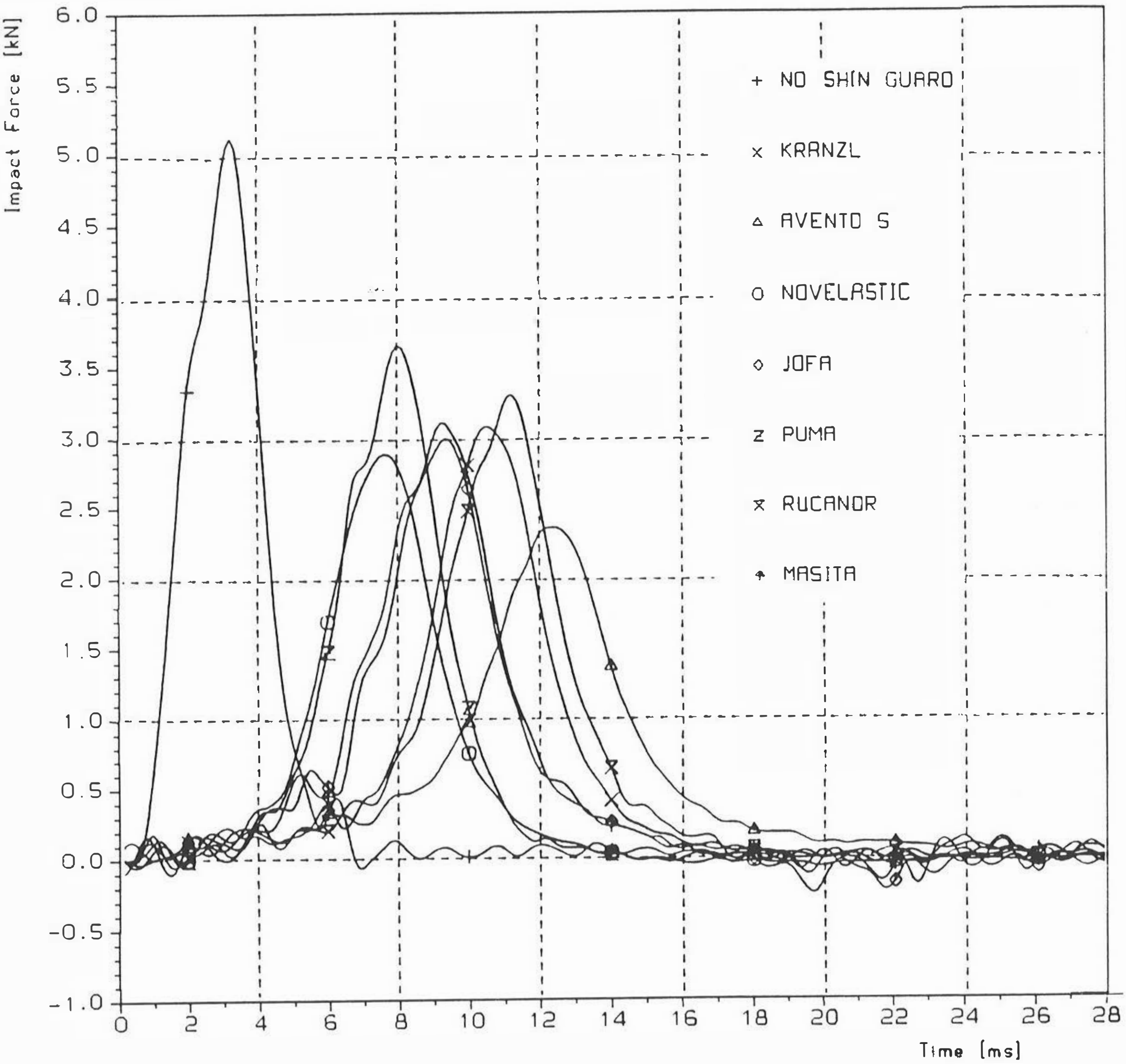


Figure 6. Force time histories for the spring loaded impactor under protected and unprotected test conditions .

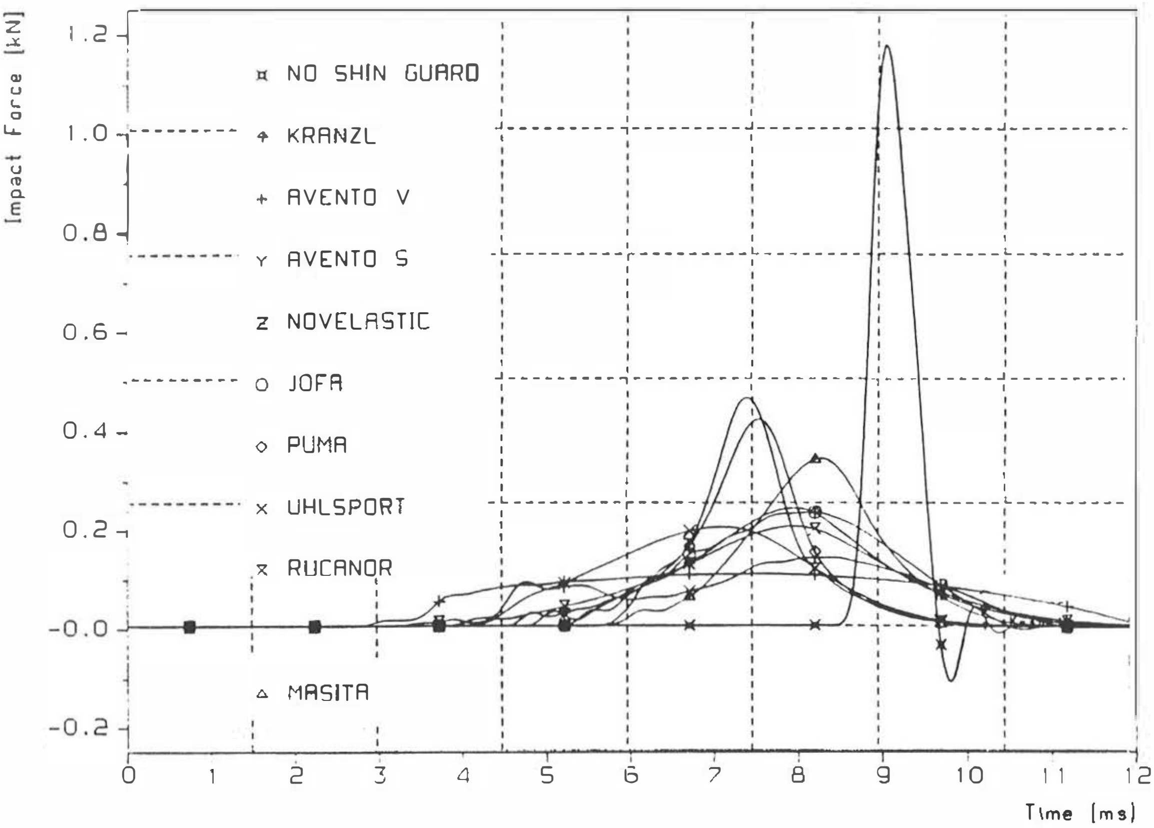


Figure 7. Average of four force-time histories for hockey ball pendulum tests at 2.5 m/s.

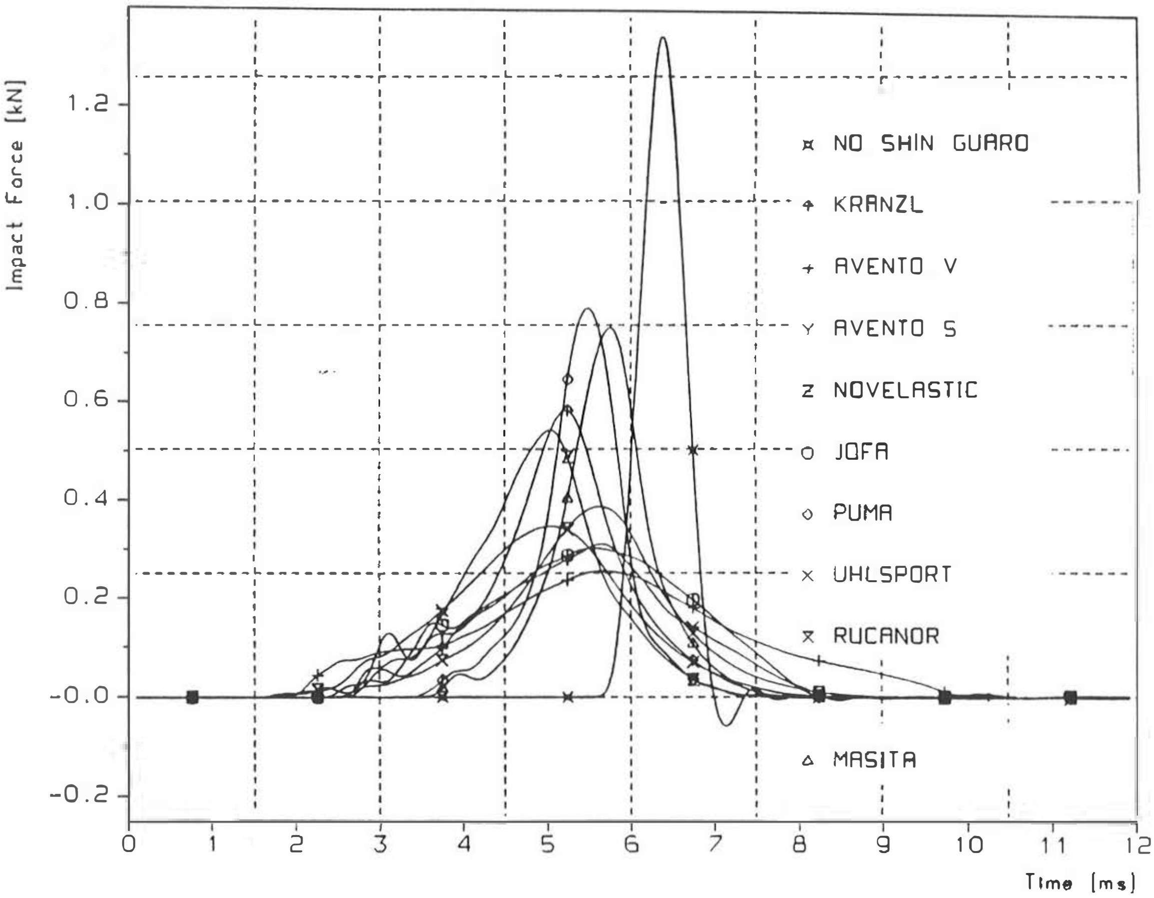


Figure 8. Average of four force-time histories for hockey ball pendulum tests at 23.6 m/s.

DISCUSSION AND CONCLUSIONS

The major objective of the present study was to evaluate various test methods for the rating of injury reduction performance of shin guards. Two test methods showed rather promising results. The first one is a test method with a spring loaded impactor representative of mid-velocity, high mass impacts as they might occur in soccer. The second test-method tried to simulate a hockey ball impact. However the hockey ball velocities which were realized in this test setup were far below the actual velocities observed in hockey. So further research is needed in order to study the effect of shin guards in these type of high velocity impacts. This research should focus on the test method itself as well as on the related injury criteria. The sport accident database used in this study shows that 45 % of the lower leg injuries in hockey are cuts. On the other hand, our literature review indicated that information on injury mechanisms and tolerance levels of soft tissue (i.e. skin) injuries is very limited. Pressure or shear stress loads on the skin appear to be the most important parameters to be used as injury criterion. Pressure distribution is considered to be an important feature of the shin guard to prevent this type of injuries and consequently adequate pressure measurement techniques are required in the future.

The preliminary test results obtained in this study indicate that the present shin guard design indeed offers a certain level of protection. Some of the guards appear to show better results than the others. Based on this it is recommended to perform a field study in which the performance of the "better" shin guards will be evaluated under realistic sport activity conditions during a period of (for instance) a year. Further research in high velocity protection performance which is proposed here might lead to optimized shin guard designs for hockey. In the development of such designs, use of computer simulation methods (e.q. Finite Element Techniques) could play an important role.

Finally, it should be noted that this study only considers the injury prevention performance of shin guards. Other aspects like comfort, cleaning etc. should be taken into account too. Shin guards to be used in such a study should be achieved from players using the guards under sufficient controlled conditions.

ACKNOWLEDGEMENT

The authors wish to thank the Consumer Safety Institute, Amsterdam, The Netherlands for partial funding of this research.

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