# TESTING OF SPORTING PROTECTIVE EQUIPMENT: A TOOL IN APPLIED RESEARCH

Merih Malmqvist
National Testing Institute
Box 857
S-501 15 Borås
Sweden

## ABSTRACT

Whether it is done for quality control or for homologation, testing often reveals qualities that are not intended to be detected or measured by the test methods used. This gives the test engineer unique insight as to the quality, relevance and ambiguity of the test method and the protective quality of the product. This information which, as far as the instantaneous test result is concerned, might be considered irrelevant, can and should be used by research personnel for deriving more relevant and perspicuous test methods and for developing products with better protective qualities. This paper discusses various aspects of testing as a tool in applied research with two case studies, namely testing of boxing gloves and testing of sporting helmets.

## INTRODUCTION

Testing can be made for a number of different purposes, like investigation of the causes of accidents, quality control of products for manufacturers, comparative quality control for consumer organisations and testing for homologation. In the latter case there is always a test method that is either accepted by the authorities in question at a local level or a national or international standard test method. In the other cases there might or might not exist an applicable standard method and more often than not the final method used is the result of discussions between the testing engineer and the authority or manufacturer requiring the test. In the case of personal protective wear the tests are often full scale tests and comprise the product as a whole.

Whatever the background might be the testing engineer always has a unique possibility to detect discrepancies in the test method, and flaws in the protective qualities of the product. We have in many cases seen that the assimilated experience of the testing engineer can result in observations that might at first sight seem purely intuitive but prove to be verifiable. These observations may even seem irrelevant at the time of the test but should be noted for future research.

Within the scope of this paper I would like to emphasize the importance of testing and the role of the test engineer as a major factor providing feedback for research personnel and design engineers. To accomplish this I am going to discuss two cases namely testing of recreational helmets and testing of boxing gloves. While doing so I do not by any means claim to have made unique discoveries in these fields. I do however claim that we must take advantage of the test engineers experiences, and increase our awareness of the importance of testing for the development of products with better protective qualities. The points to be discussed in the paragraphs to follow are, in the case of helmets, results of over five years work at the National Swedish Testing Institute. In the case of boxing gloves the discussions in this paper are based on tests made for the Swedish Boxing Association at the National Testing Institute and we have the permission of the Swedish Boxing Association to publish them.

## CASE 1: TESTING OF SPORTING PROTECTIVE HELMETS

The sporting protective helmets regularly tested at our institute are ice-hockey, riding, skiing and bicyclists helmets. With minor variations they are all tested according to the guidelines for riding and skiing helmets issued by the National Swedish Board of Consumer Policies, in 1977 [1] and are classified as recreational helmets. During the last year special guidelines for bicycle helmets have been developed under the coordination of the same National Board and based on the SP-RAPP 1984:31 [2]. These guidelines have, however, not been put to use yet.

### GSI vs. resultant peak accelerations [2].

Since 1978, when testing according to the Guidelines of the National Swedish Board for Consumer Policies test results have been recorded and stored. The protection criterion utilized in the Guidelines is the Gadd Severity Index (GSI) but the peak acceleration was kept for reference. this material now consists of the results of 34 complete tests, each including 20 drop tests (falling headform). Every helmet type was dropped in a guided free fall from five different drop heights between 0.5 and 2.0 meters to impact four different sites (front, back, side and top) against a flat, rigid surface. A triaxial accelerometer was mounted approximately at the center of gravity of the dummy head and the resultant acceleration and GSI were calculated instantaneously using an analogue computer. For further descriptions of the test method see [3].

The peak acceleration and the GSI value of a helmet drop test can each be regarded as monotonous functions of the drop height and it is natural to assume that their graphs will pass through the origin. For each set of five data points obtained under the same circumstances, i.e. the same helmet type and the same impact direction, linear regression has been used to calculate the parameters $c_1$, $c_2$, $c_3$ and $c_4$ of the assumed laws:

$$a_p = c_1 h^{c_2} \qquad (1)$$

$$GSI = c_3 h^{c_4} \qquad (2)$$

where $a_p$ is the peak acceleration and h is the drop height. The correlation coefficients obtained in these calculations are normally high, the mean values being $r = 0.944$ and $r = 0.974$ respectively. The fact that the correlation coefficient r is higher in the case of the GSI law than in the $a_p$ law is quite natural, since peak measurements are more easily corrupted by noise than an averaged measure like the GSI, even when careful filtering has been performed. In the present study low pass filtering conforming to the channel frequency class CFC 1000 Hz of ISO 6487 has been employed throughout.

If unweighted averages are computed for the parameters the results will be

$$\begin{aligned} c_1 &= 140 \\ c_2 &= 1.0 \\ c_3 &= 610 \\ c_4 &= 2.0 \end{aligned} \tag{3}$$

Weighting the parameter values does not change the resulting averages substantially. Inserting the parameters $c_1$, $c_2$, $c_3$ and $c_4$ into the eqs (1) and (2) shows that the dependence upon the drop height seems to take the form

$$a_p = 140\ h \tag{4}$$

$$GSI = 610\ h^2 \tag{5}$$

Now, let every group of five experiments - same helmet and impact direction - be noted as a pass or a fail depending on whether the GSI value computed from the regression laws at a drop height of 1.5 m falls below or above the performance criteria level GSI = 1500. The cases where the GSI value falls between 1400 and 1600 are judged to be border cases. Plotting the pairs of parameter values, $c_1$ and $c_2$ for the peak acceleration regression law again, while distinguishing between passes, fails, and border cases results in Figure 1. An interesting question is whether it is possible to make the same pass/fail decision with the help of another performance criterion, e.g. peak acceleration. If it is, then of course the performance criteria level in question would be of interest. To help settle that question five curves have been drawn in figure 1, each line illustrating one choice of performance criteria level in terms of peak acceleration. It is quite obvious from the figure that a choice of performance criteria level around $a_p = 250$ g, would result in the same decision making as that of the performance criteria level GSI = 1500.

It is interesting to try to study how the two discussed criteria are connected, and analysis is possible if the situation is simplified. The GSI is defined as

$$GSI = \int_{t_0}^{t_1} a(t)^{2.5} dt \qquad (6)$$

The integration can be carried out under the assumption of simple acceleration curve forms, for instance sinusoidal, rectangular, and triangular. If it is furthermore assumed that the impact occurs without any rebound, so that the velocity change during the impact can be calculated from the drop height, the following simple expressions result

$$GSI = 0.258\ a_p^{\ 1.5}\ h^{\ 0.5} \text{ triangular pulse shape} \qquad (7)$$

$$GSI = 0.325\ a_p^{\ 1.5}\ h^{\ 0.5} \text{ sinusoidal pulse shape} \qquad (8)$$

$$GSI = 0.451\ a_p^{\ 1.5}\ h^{\ 0.5} \text{ rectangular pulse shape} \qquad (9)$$

If, on the other hand, the rebound is not negligible, which is normally the case for thermoplastic helmet shells, the drop height h in the above formula should be replaced by h (1+q), where q is the rebound coefficient. A constant rebound coefficient would consequently appear as if the constant factor on the right hand sides of eqs. (7) - (9) had been increased.

In Figure 2 an attempt has been made to check the validity of the above analysis by producing a graph in which eqs. (7) - (9) would appear as straight lines with slopes equal to the constant factors. In this case the complete material comprising 680 triplets of drop height, peak acceleration, and GSI values has been used. The curves corresponding to the previously given formula are also plotted in the diagram. Obviously, the bulk of the material does not contradict the simple analysis performed. The law of the same form as above which best fits the data can easily be calculated to be

$$GSI = 0.339\ a_p^{\ 1.5}\ h^{\ 0.5} \qquad (10)$$

Now, the performance criteria level of the Guidelines of the Swedish Board of Consumer Policies was GSI = 1500 at a drop height of 1.5 m. If these figures are put into eq. (10), we will obtain the corresponding performance criteria level if the performance criterion is chosen to be peak acceleration. The result is $a_p$ = 235 g.

Yet another way of finding corresponding tolerance levels is the following. The functional dependence upon the drop height suggested in eqs. (4) and (5), is seen to fit the analytically proposed forms, eqs. (7) - (9). Using the eqs. (4) and (5) one would obtain

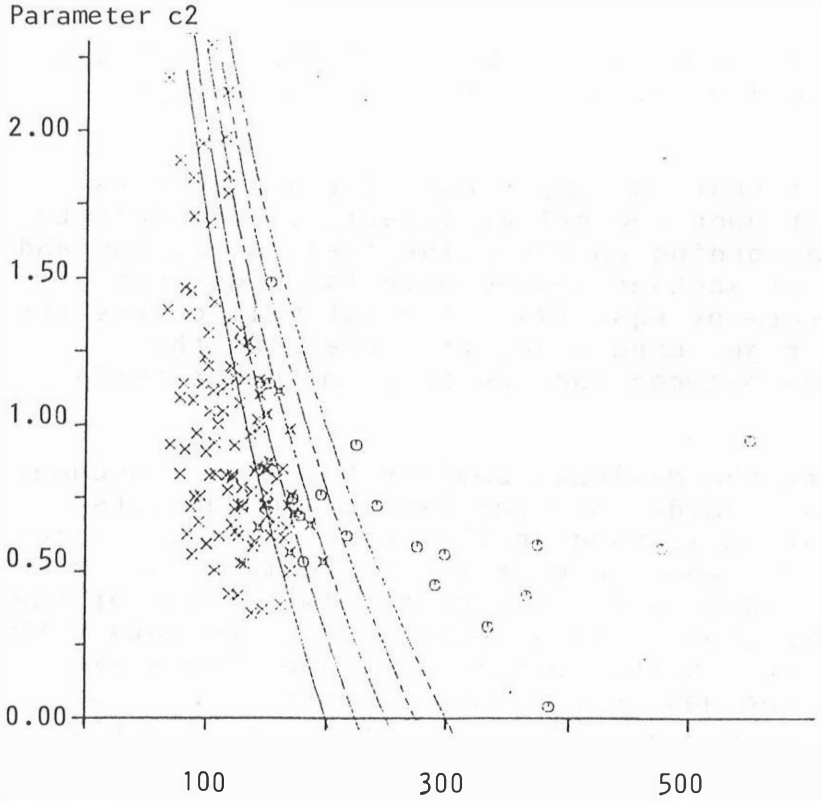

Figure 1. The parameters of the regression law for peak acceleration as a function of drop height. Experiments which constitute passes, fails, or border cases according to a GSI performance criterion are marked differently. Included in the graph are also curves illustrating the decision rules resulting if peak acceleration is used as a performance criterion.

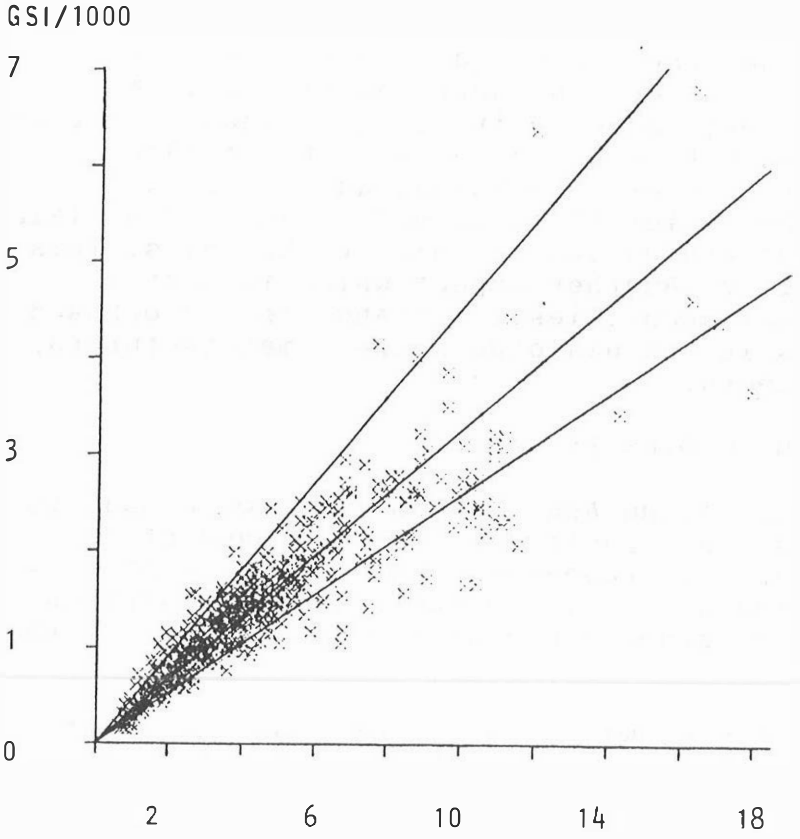

Figure 2.GSI vs. $a_p^{1.5} \cdot h^{0.5}$

The theoretical results for three different simplified pulse shapes under the assumption of negligible rebound have also been included.

$$GSI = 0.368\, a_p^{\,1.5}\, h^{\,0.5} \qquad (11)$$

Solving for the peak acceleration, $a_p$, with the severity index value GSI = 1500 and the dropheight $h$ = 1.5 m this time gives $a_p$ = 225 g.

It should be pointed out that the experimental results of this discussion are dependent upon the helmet material, i.e. helmets submitted for testing according to the guidelines for riding and skiing helmets. Choice of another helmet material might not change the functional form of eqs. (7) - (9) but will change the constant factor on the right hand side, thus changing the suggested correspondence between the two performance criteria levels.

As a result of this work the National Swedish Board for Consumer Policies has issued draft Guidelines for bicyclists' helmets where the peak acceleration is used as the performance criterion instead of GSI. The same change is expected to be made in the guidelines for skiing, riding and ice-hockey helmets. One of the questions that arises is whether this would lead to helmets with better protective quality. In this particular case, the answer is likely to be no, as the new performance criteria limit is derived directly from the old and the correlation between the two limit values is very high. The change that is established in this case is more a simplification of the method than an increase or decrease of the severity of the requirements. It is therefore not believed that the manufacturer will suffer increased costs due to this change. The next question that naturally arises is why the performance criteria is changed if it is not expected to result in better performance of the product. Experience shows that the closer to physical quantities a performance criterion is the easier it is to understand and explain the physical phenomena governing the outcome of the tests. This is a very desirable quality. Another aspect which is just as desirable is that physical quantities are "tangible" as opposed to calculated quantities in the dialogue between manufacturers, designers and test engineers.

## CASE II TESTING OF BOXING GLOVES [4]

On request of the Swedish Boxing Association tests were made to compare the shock absorption capacity of boxing gloves of 6 different types. A litterature research revealed i.a. that comparative studies of boxing gloves as to their shock absorption capacity have been made on several occasions and have led to the following conclusions.

- The impact velocity achieved with a glove of 6 oz was about 2.7 times greater than that achieved with a 16 oz glove [5], [6].

- The importance of a protective helmet increased with increased hardness of the glove (i.e. with decreasing number of ounces) [5].

- On the average, higher accelerations were registered from the last blow of a series of 3 to 4 consecutive blows, which meant a deterioration of the shock absorption capacity of the material [5].

As the main purpose of the test was to obtain comparative data, the shock absorbing qualities of the tissues of the face have not been taken into account.

Moreover a realistic set-up including all aspects of a real fight like sweat, heat etc was abandoned in favour of a controllable set-up with acceptable repeatability.

The boxing glove to be impact tested was placed on a steel plate of 60x100 mm, mounted on a rigid anvil. The impact was made by means of a 4.85 kg mass of aluminium with a curvature of ø 165 mm on the contact surface. A guided free fall from a height of 630 mm was used to give an impact energy of 30J and an impact velocity of 3.5 m/s (12.6 km/h) which corresponds to a blow of normal hardness.

The acceleration of the mass was measured by means of an accelerometer. Each glove was impacted 10-20 times at the same point, to see how the shock absorbing capacity of the material changed as a function of the number of impacts. The tests were made at room temperature and without preconditioning. The gloves that were tested were stuffed with horse-hair, synthetic wadding, and foamed-plastic wadding. Foamed-plastic laminate, known by our test engineer to have good shock absorbing capacity was also impact tested in order to provide a comparison with the commercially available boxing gloves. Figures 3-5 shows the accelerations for the gloves after the stated number of impacts the same direction at the same point.

The tests showed that gloves stuffed with horse-hair or synthetic wadding, have better shock absorbing capacity than gloves stuffed with foamed-plastic wadding. Furthermore, horse-hair and stynthetic wad stuffing do not loose their shock absorbing capacity as easily as foamed-plastic wad which tends to be "punctured" when exposed to repeated impacts at the same point.

The foamed-plastic laminate showed the best result in this particular test. The deformation of the laminate was restored within 25-30 s, leaving the material with its original shock absorbing capacity. This means that the critical parameter for foamed-plastic laminate was the time elapsed between impacts. during the test a period of 15-20 s was allowed to elapse be-

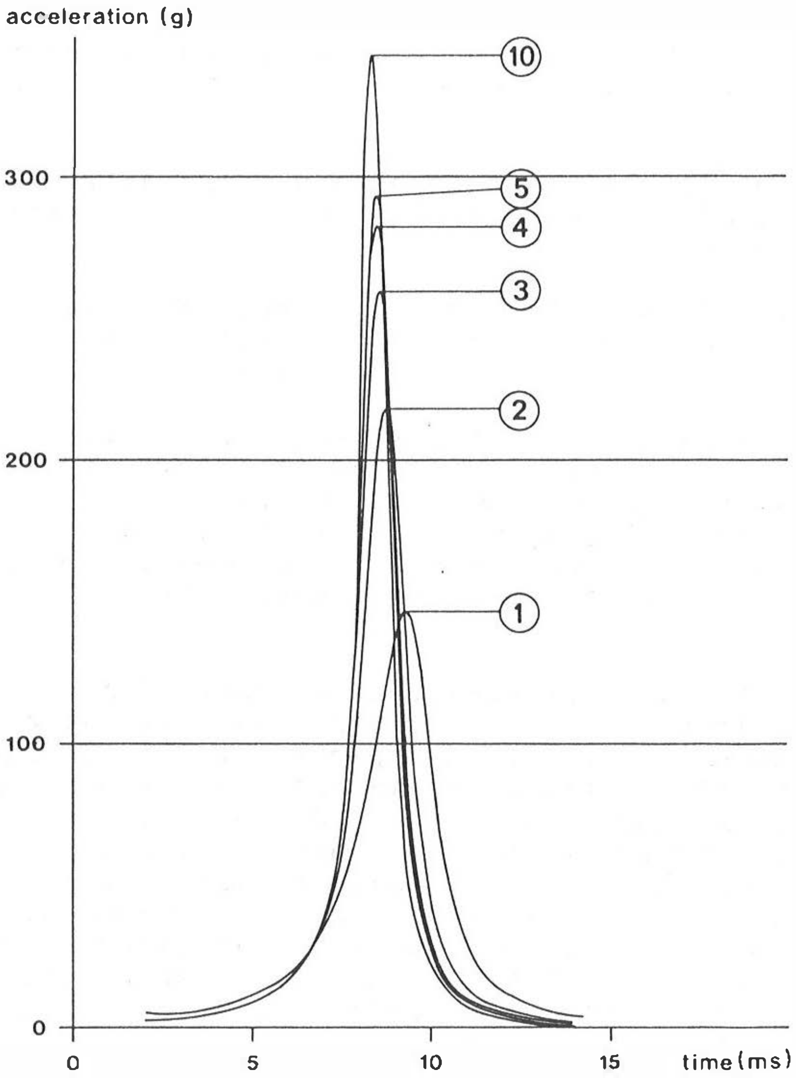

Figure 3. Acceleration vs. time for 10 oz boxing glove with foamed-plastic wad stuffing, after 1, 2, 3, 4, 5 and 10 impacts. Mass = 262 g.

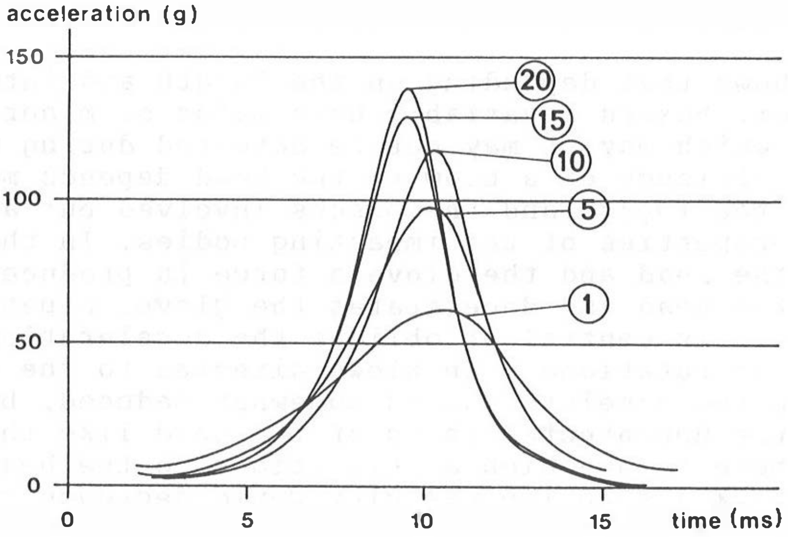

Figure 4. Acceleration vs. time for 8 oz boxing glove with horse-hair stuffing after 1, 5, 10, 15 and 20 impacts. Mass = 253 g

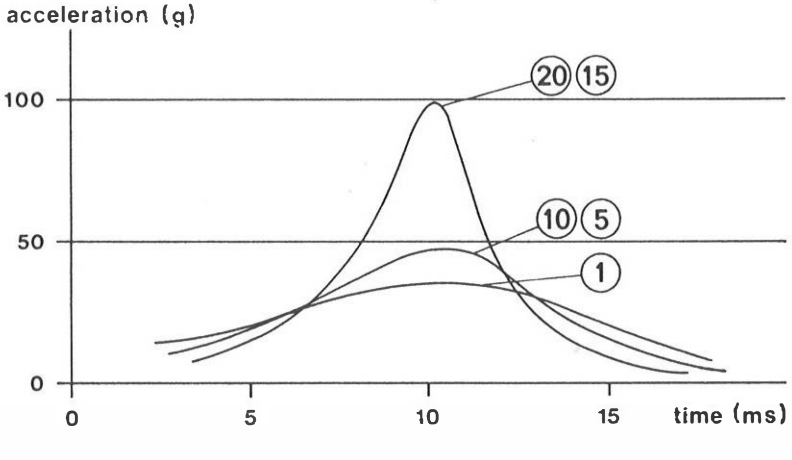

Figure 5. Acceleration vs. time for foamed-plastic laminate, after 1, 5, 10, 15 and 20 impacts. Mass = 123 g.

tween the first 10 impacts giving acceleration values below 50 g. The time period was then decreased to 5 s which caused an increase in the measured acceleration to 100 g. See Figure.
As the number of specimens used in these tests is low, the data obtained cannot be said to have statistical value.

Medical research shows that depending on the length and intensity of their career, boxers invariably have major or minor permanent injuries which may or may not be detected during their active period. The violence of a blow to the head depends mainly on the velocity of the impact and the masses involved but also on the mechanical properties of the impacting bodies. In the collision between the head and the glove a force is produced which accelerates the head and decelerates the glove. Depending on whether the impact is central or oblique the acceleration of the head is linear or rotational. In blows directed to the soft tissues of the face the acceleration is somewhat reduced, but blows directed to the unprotected parts of the head like the chin and the yoke bone induce high accelerations to the head. Gloves with high shock absorption capacity would decrease the damaging effects of the impact to the head and, hopefully, in the long run even change some of the competetive aspects of boxing. We expect that as the awareness of the inherent dangers of boxing increases, the efforts made to decrease them will also be intensified. We also believe that research to improve the shock absorbing capacity of boxing gloves should be integrated with research on shock absorbing fabrics in other fields, like motorcyclists' outfit.

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