T H E   N A T U R A L   C R A S H - H E L M E T

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Summary

Injuries may be classified in various ways. The origin of over-loading from the mechanical point of view must be considered if the prevention of injury is to be attempted. There are 4 main causes of injury; the most common and dangerous resulting from shock loads in the brain, specifically in the cases of moped- and motor cycle riders.
The principal object of the investigation was comparison of the shock-absorbing qualities of present day helmets to those of natural materials e.g. the coco-nut rind .

A historical and biomechanical view of head injuries

The basic principles of injury remain almost unchanged throughout history. Weapons were designed to injure mainly by penetration. Fig. 1 illustrates an ancient Roman boxer.

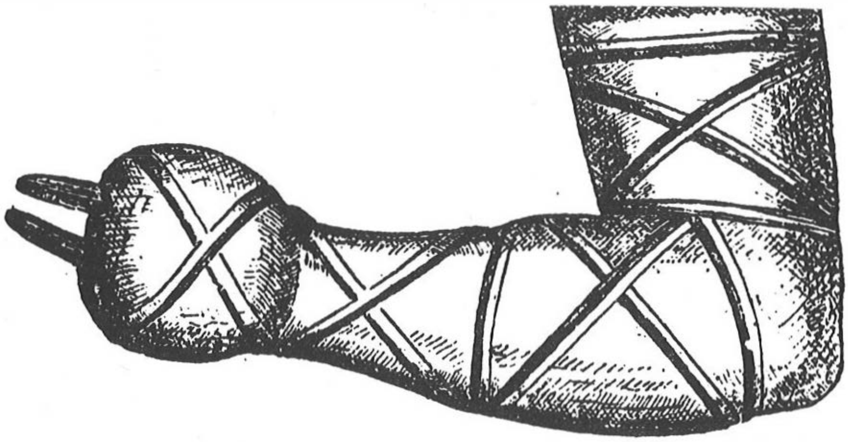


fig.1

Friedrich Unterharnscheidt in his book about boxing :
"Review of historical and medical aspects"

This shows the fist covered by a glove which bears sharp prongs.
All weapons are identical in this respect. Javelins, spears, axs, knives as well as recent fire arms-pistols, rifles etc., are based on the same principle, that is to hurt the enemy by means of penetration.
The means of protection against these weapons were accordingly designed. Sword attacks were counteracted by shields and hairtraces. Also the modern army helmet is designed to prevent only one type of injury; namely the pe-

tration injury . Towards the end of the 19th century it was discovered, that serious brain injury could occur without actual penetration as in boxing. Sword fighting was regarded as uncivilized form of sport and the more "human" boxing overtook it in popularity. This led to a new form of injury, caused by shock or short-time deceleration .
These injuries were not as bloody and externally obvious as those caused by sword fighting, but they were equally dangerous.

This deceleration injury is the most common and dangerous form of injury for the riders of mopeds and motor cycles .

Types of injury

The prevention of traffic injuries is a mechanical problem. Based on this statement it seems to be logical to recognize and classify the injuries to their mechanical origins
Accordingly injuries may be subdivided into :

a. penetration injuries
b. deceleration injuries
c. compression injuries
d. abrasion injuries

For a well designed safety device an individual approach is needed for each type of injury. By other words ; it is not possible to increase the protection against deceleration using parameters of the penetration injuries etc.

a. Penetration injury

A penetration injury is caused by the penetration of the body by an object from outside. This injury inevitably occurs at the site of the penetration.

The penetration injury may be prevented by decreasing the surface pressure .

This may be brought about by decreasing the load and/or increasing the contact surface.

b. Deceleration injury

This type of injury occurs, when parts of the body are decelerated. Unlike the penetration injury, this injury does not occur where the deceleration was introduced, but mostly in other parts of the body.E.g. deceleration of the skull gives rise to brain injuries, chest deceleration may cause rupture of the aorta etc.

The decelerating injury may be prevented by decreasing the input-deceleration and by localising the deceleration in an anatomical feasible manner .

c. Compression injury

The compression injury is the result of an overloading . The fracturing of a thorax by the steering column is an example caused by inertia forces, but this type of injury may also occur without speed or inertial forces. "Run-over" accidents may cause identical injuries.
Compression injuries may occur at the site where the load was introduced, but these injuries are mainly found in other parts of the body e.g. when the load is introduced at the sternum, the rib fractures may be located at the sides of the thorax,namely at the site of the maximum bending moment .

The compression injury may be prevented by decreasing the load and localising the load in an anatomically feasible manner .

Fig.2 shows an example of a typical compression load. The wearer was run-over by the rear wheel of a truck but was only slightly injured .

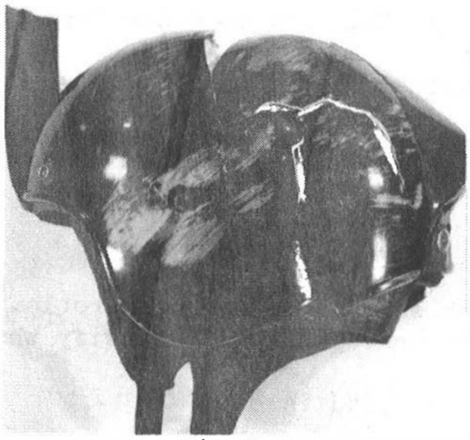


fig.2
example of a loading by compression

d. Abrasion injury

Abrasion injuries occur when part of the body slides over a rough and sharp surface. This type of injury is not frequently found in car accidents when the occupant was belted . Most commonly it occurs when the road user slides over the pavement or other abrasive surface. Like penetration injuries, abrasion injuries are always situated at the site of introduction of the load .

The abrasion injury may be prevented by decreasing the load, by decreasing the degree of abrasion or by placing protective material between the body and the abraded material for instance a crash-helmet .

Fig. 3 shows an example of the effectiviness of helmets against abrasion . The user involved was seriously hurt but not as result of an abrasion injury.

fig.3
example of abrasion of a used crash-helmet

Brain injuries for the riders of 2 wheeled vehicles

Head injuries are the most common injuries found in all accident analyses of riders of 2 wheeled wehicles .
There was a significant decrease in the number of fatal accidents on introduction of the crash-helmet .
It is interesting to consider the effect of the helmet in the light of the various causes of injuries as mentioned above .
The **resistance** to penetration (a) is almost 100% in the area covered by the shell of the helmet.The use of helmets significantly increases the resistance to deceleration injury, but the effectiviness depends on the energy-absorbing properties of the specific helmet.Anyhow, when the user of a crash-helmet has serious brain-injury it is of the fact, that the helmet was not able to give a sufficient amount of protection against the deceleration injury.

Resistance to compression injury (c) also increases with the use of crash-helmets as shown on fig.2 . However it is very difficult to make the helmet rigid enough to withstand very high compression loads .

The area covered by the helmet has almost optimal resistance against abrasion-injuries (d) .

Considering the present days results with crash-helmets it seems, that mainly the shock-absorbing properties indicate the quality of the helmet as safety-device .

The coco-nut

Crash-helmets have a very high mass; sometimes more than 1,5 kg .Obviously, the lighter the design the higher the acceptance to the user .
It also seems desirable from the biomechanical point of view, that the mass is reduced as much as possible . Accordingly researchers in different countries are trying to design helmets made of integral foam ; i.e. helmets without an external shell .
One of the idea's in searching for new shock-absorbing materials with a high impact capability was to study natural material .
This material should have the same fuction as a crash-helmet ; to protect some valuable material during a high-deceleration impact .
The best example found was the coco-nut. The coherence of the coco-nut and the impact conditions are basically identical to that of a crash-helmet protected head which is involved in an accident .
The nuts drop from a height of $\pm$ 20 m and survives .
There was also another reason to investigate the coco-nut, because it differs on one point from the helmet, namely the coco-nut has no external shell.
On fig. 4 a simplfied comparison is given between a coco-nut and a helmeted head.
When a normal helmet is tested without shell, bottoming easily occurs .
The shell gives sufficient resistance against penetration injuries and spread the forces over a greater surface .
The coco-nut does not need an external shell, because the fibrin material incorporates the shock-absorbing properties .

The purpose of the investigation was to compare the shock absorbing qualities of the coco-nut with those of the crash-helmet .

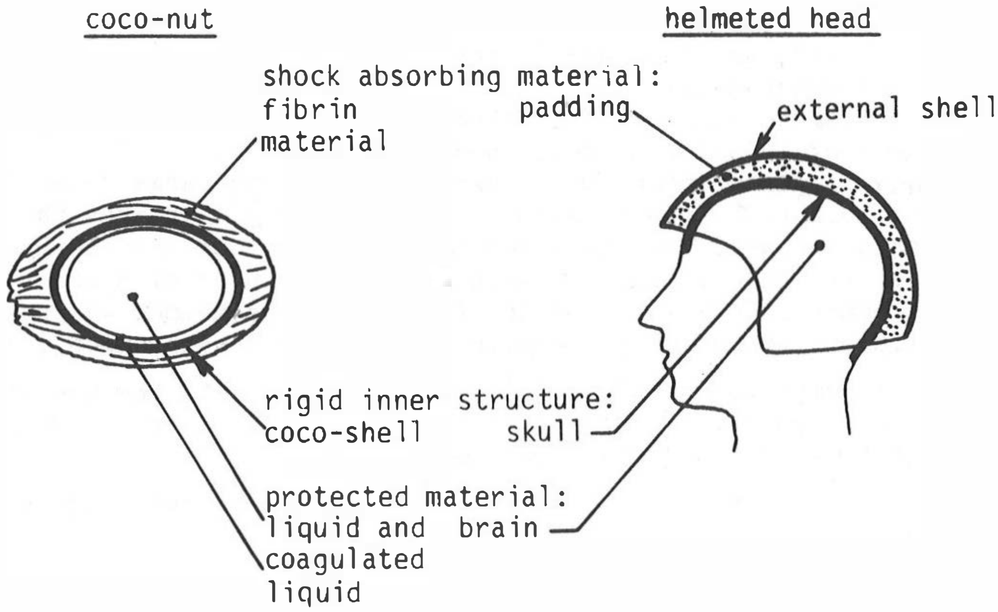


fig. 4
comparison helmeted head with a coco-nut

Test procedure

Sampling of coco-nuts

The coco-nuts used for the tests came from Ghana Africa .
These are a small type of coco-nuts and samples varied in length from 100 - 150 mm . It was thougth that the percentage of water in the rind could affect the shock-absorbing properties, but the amount of water lost between the gathering of the nuts and the tests was unknown. Because of this one group was tested under dry conditions and one under moist conditions .
The first group was stored in a room with standardised conditions for one week . Throughout this time the nuts were drier than fresh nuts .
The second group was stored under water for one week and this group had a higher moisture content than fresh nuts .
It was assumed that a fresh nut should yield results no worse than a drier, or moister, than a normal nut.

Way of testing

So that the results could be compared with those of crash helmets, the tests for the shock-absorbion were carried out on a normal test machine which was designed to measure the helmets according to the dutch standard .
This standard is also used with slight modifications in most european countries.

Fig. 5 shows a general outline of the test machine .

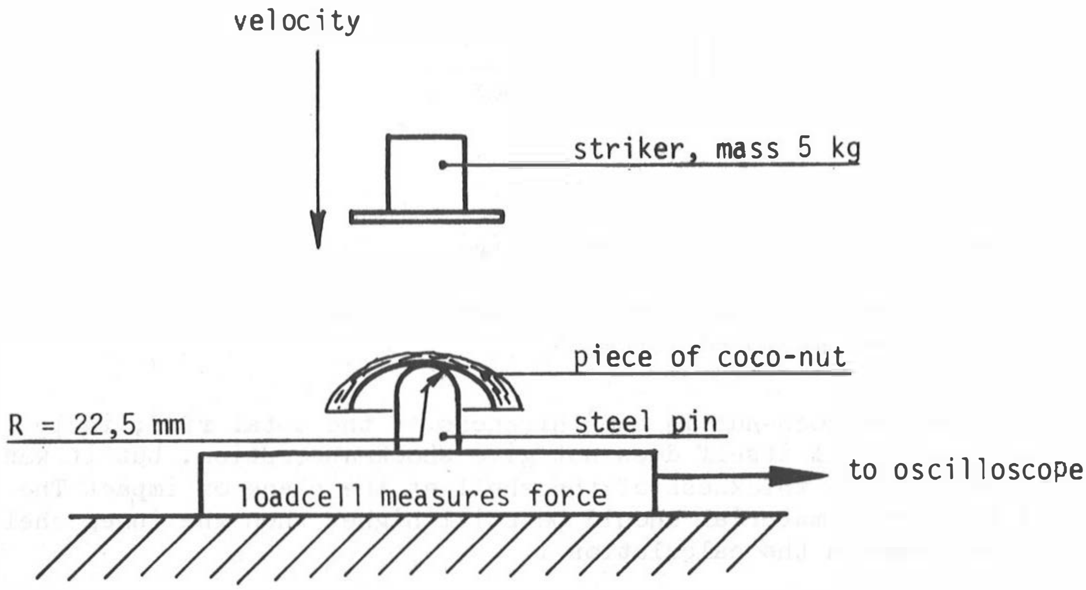


fig.5
test machine for crash-helmets used to test coco-nuts

As written in the ISO specifications the transmitted force shall not be higher than 20.000 N. The dutch specification is a little more severe. Two tests shall be carried out on the same place; the first from 2,5 m and the second from 1,5 m . The transmitted force shall not be higher than 15.000 N for each of both tests .
The helmet involved is supported by a wooden headform .
This headform was naturally too big for the coco-nut, so a special headform was made to support the nut at the inner side .
In order to find comparison with existing safety devices , the results were compared to a group of helmets of superior quality .

The calculation of the output

In order to judge the shock-absorbing properties, the output percentage has been determined by means of the following formula :

$$\eta = \frac{\text{the theoritical lowest possible force}}{\text{the maximum transmitted force}} \qquad (1)$$

This criterium is based on the falling-test system whereby a certain mass falls from a certain level .
The subject itself has been supported and the force is measured as the function of the time duration .
The theoretical lowest possible force is reached, when the falling weight uses the complete thickness of the subject under a constant force .

The total amount of energy just before the impact is m.g.h.;
so it follows :

$$\eta = \frac{m \cdot g \cdot h}{d \cdot F_{max}} \qquad (2)$$

η = effectiviness (%)
g = acceleration of the gravity (g)
h = falling distance (m)
d = thickness of the subject before the test (m)
F_{max} = maximum measured force (N)

The d of the coco-nut is the thickness of the total rind; incl. inner shell. The inner shell itself does not give shock-absorption, but it was difficult to measure the thickness of the shell at the place of impact The efficiency of the fibrin material should be still higher when the inner shell should be excluded in the calculation .

Other materials

A couple of different foams were investigated. Some of them gave reasonable results. Within the scope of this study those results will not be reported with one exception. A particular foam has been invented which has a specific orientation of its structure . This foam can only be loaded in one direction and until now it can be made only in sheets and not in forms .
The basic material is Polyphenyleen oxyde; abbreviated to PPO .

Result of the investigations

In table 1 the results of the different tests are compiled .
The spread in test results can be explained by the big variations in dimensions of the samples and because of the different locations of the coco-nuts on which the tests were carried out.
The great differences in effectiviness are also the result of the bottoming effect. In some cases the test was to severe and in that case bottoming took place and the maximum measured value was taken to calculate the efficiency.
Finally in some cases fracturing of the rind made the measurement valueless .

Test Nr .	Test - subject	Conditi-oning	Thickness (mm)	Falling-distance (m)	Maximum trans-mitted force (kN)	Efficiency (%)	Botto-ming
1	coco-nut	dry	23	1,50	4,5	71	no
2	idem	dry	38	1,50	3,0	65	no
3	idem	dry	20	1,50	25,0	15	yes
4	idem	dry	18	1,50	13,0	31	yes
5	idem	dry	23	1,25	3,6	74	no
6	idem	dry	13	1,25	8,0	59	no
7	idem	dry	18	1,25	4,3	79	no
8	idem	dry	17	1,25	--	fracture	yes
9	idem	dry	17	1,25	--	fracture	yes
10	coco-nut	wet	18	1,25	10,0	fracture	yes
11	idem	wet	18	1,15	4,5	70	no
12	idem	wet	33	1,15	2,7	63	no
13	idem	wet	23	1,25	3,0	89	no
14	idem	wet	34	1,25	10,0	fracture	yes
15	helmet 1	dry	30	2,50	6,0	69	no
16	helmet 2	dry	40	2,50	9,7	38	no
17	helmet 3	dry	26	2,50	7,5	53	no
18	PPO	dry	46	1,50	3,5	40	no
19	PPO	dry	46	1,50	3,5	40	no

table 1
the test results of the shock absorption measurements

Because of the very small samples of the coco-nut material in some cases fractures and/or bottoming occured .

In table 2 the average values are given of coco-nut samples, which did not show phenomena of fracturing or bottoming . In the same table the average values are given of the helmets and PPO samples.

Test subjects	Average efficiency (%)
coco-nut dry	66
coco-nut wet	74
helmets	53
PPO	40

table 2
average values

In table 3 the particulars are compiled of the best and worst results with the coco-nut and the best results with helmets and PPO .
The polaroid pictures of these tests are given on page 10.

Test Nr .	Test - subject	Conditi-oning	Thickness (mm)	Falling-distance (m)	Maximum trans-mitted force (kN)	Efficiency (%)	Botto-ming
13	coco-nut	wet	23	1,25	3,0	89	no
3	coco-nut	dry	20	1,50	25,0	15	yes
15	helmet	dry	30	2,50	6,0	69	no
18	PPO	dry	46	1,50	3,5	40	no

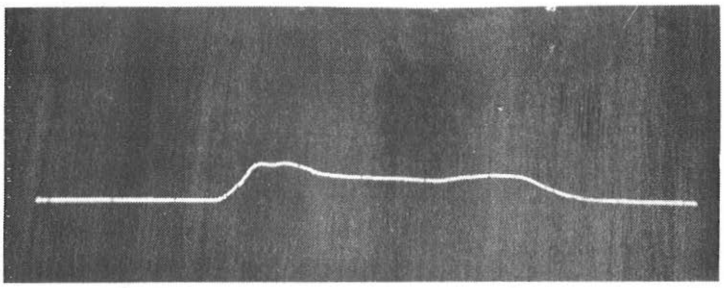
table 3
comparison coco-nuts with helmet and PPO material

Conclusion

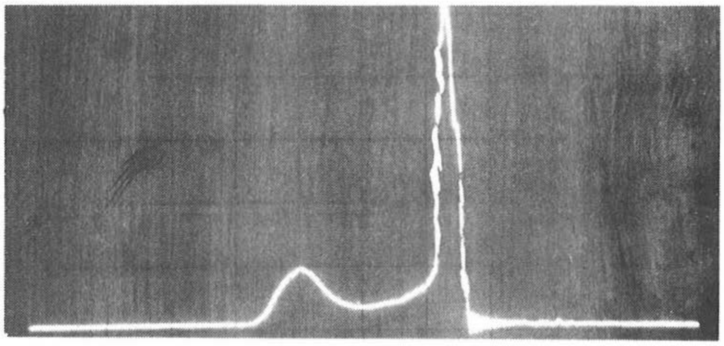
The investigation shows the following interested information :

- the shock-absorbing property of the coco-nut rind is better, than those of the best known helmet
- the degree of moisture of the coco-nut rind is not as important for the shock-absorption quality
- it shall be taken into account, that the results with the coco-nut and the PPO were reached without external shell
- it is desirable to investigate the possibility of making helmets without external shell in order to reduce the total mass
- in this respect the material of the coco-nut should be investigated further; e.g. microscopally

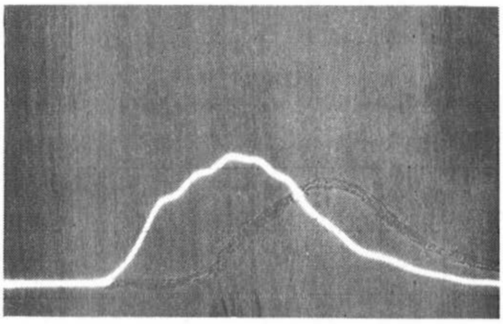
best result with wet coco-nut



worst result with dry coco-nut



best result with a dry crash-helmet



best result with PPO foam