EEVC/CEVE

European Experimental Vehicles Committee

Report of a working group on biomechanics

Presented to the Sixth ESV Conference Washington October 1976

EUROPEAN EXPERIMENTAL VEHICLES COMMITTEE

-:-:-:-:-

REPORT OF A WORKING GROUP ON BIOMECHANICS

-:-:-:-:-

Presented to the Sixth ESV Conference

Washington, October 1976

CONTENTS

1. TERMS OF REFERENCE OF THE GROUP

In June 1974, the European Experimental Vehicle Committee (EEVC) took the initiative in sending in a report entitled "the future for car safety", whose aim was to put forth common views as to vehicles to be produced in the early 1980's. The EEVC especially recommends judging new kinds of vehicles, in a limited number of impact tests, on the seriousness of injuries received by occupants - or people outside the vehicle involved in the accident.

In order to do this, having criteria of human tolerance levels, and their transposition in measurements applicable to dummies, is indispensable. The EEVC has gathered the data already established, or still subject to caution, in the annex written by the ad'hoc working group (known as group 3). This report puts forward (with good reason) the difficulty in being very accurate, because of the problem complexity and insufficient knowledge in certain areas. Nevertheless, acceptable human tolerance levels must be determined, at least temporarily, to carry the EEVC's recommendations into effect.

This is why the ad'hoc group has been asked to propose a set of criteria applicable to controlled collision tests retained by the EEVC in order to judge secondary vehicle safety and the equivalent measurements applicable to dummies.
The group should state also how equivalent loads on one dummy should be deduced from loads measured on another dummy.
It should propose, if possible, what dummy should be produced for test purpose in the 1980's. If there is not a sufficient consensus, the group should present elements for a dossier, so that representatives of qualified administrations can decide on a common viewpoint on this subject. The ad'hoc group will begin by studying the situation in which front-seat occupants, wearing seat-belts, are simulated by dummies, the vehicle undergoing impact tests as defined by the EEVC. The group will possibly study the case of

unrestrained front-seat occupants in low-speed accidents. The EEVC working group 3's review of current research in biomechanics will be completed, if necessary, expecially in the field of accidents involving children occupants and pedestrians. Recommendations will be made if possible as to research needs in this field. The group might consult experts from national or private scientific organizations and from different branches of the car industry.

2. WORKING APPROACH

2.1. PROTECTION OF RESTRAINED CAR OCCUPANTS

The basic information was drawn out from the data of accident statistics. For every main body location, the frequency of injuries as well as their severity were taken into account. For both frontal and side impact configurations, it was then possible to classify injuries as "very important", "important" and "not important".

For each injury, the following aspects have been studied : type of loading, relevant parameter, possible measurement on dummies, tolerance level when known.
Then, when possible, a requirement level was recommended.
In some cases, the group proposed easily adoptable design recommendations and needs for research were pointed out. To establish recommended requirement levels, it was necessary to investigate the possibility of measuring the parameters relevant to the tolerance levels on standard dummies and the validity of such measurements. Current dummies were reviewed and their main failures discussed. Tolerance levels were examined from the point of view of possibility of measuring them on these dummies. Sometimes, the group judged measurements possible ; at other times, the group had to point out the need for improvements in the design of future dummies. In these cases, recommendations could not be established at present.

2.2. PROTECTION OF NON RESTRAINED CAR OCCUPANTS

While waiting for the evaluation of the first effects of the recent compulsory use of seat belts in some countries, the group could not reach a full agreement on the need to protect unrestrained occupants. Nevertheless, the problem was examined and the need of protection for non restrained occupants was considered.

2.3. REVIEW OF THE PEDESTRIAN PROBLEM

The group had essentially to estimate the importance of the pedestrian injury problem. Using accident statistics, the injuries were assessed by their frequency according to the age (adults and children) and for two ranks of severity (AIS $\geq$ 3 and AIS $<$ 3).
In addition data from experimental studies, researches in progress and result of studies on vehicle technology were reviewed.

3. CONCLUSIONS OF THE GROUP REGARDING INJURY CRITERIA AND RECOMMENDED REQUIREMENT LEVELS

The text is, for the main points, the result of an agreement between the different national delegations.

The group recognized the fact that knowledge of biomechanics of impact is as yet scarce, particularly with regard to the distribution of injury tolerance levels amongst the car occupant population. This depends on many factors including age, sex and size. Most of the group, however, believe that recommended levels put forward are the best available at the present time. In accidents where they are not exceeded, it is expected that many of the adult car occupants involved would escape serious injury. Thus a very significant advance in car safety should be achieved by designing to these protection levels.

However, the Italian delegation did not fully agree and made the following reserves. The Italian delegation joins in the statement that the most advanced tolerance levels indicated represent a synthesis of the present time knowledges. It considers nevertheless optimistic the belief that such levels might signify, if applied to vehicle design, a significant advance in car safety. On the contrary, Italy believes a design trend based on tolerance levels not suficiently corroborated by the experimental research and therefore susceptible of being corrected, or even based on parameters which might be varied in the future will eventually result in a certain cost burden without a compensation in terms of improved and certain passenger protection levels.

3.1. NON SYMMETRICAL FRONTAL IMPACT *

Although the group agreed on general principles for occupant protection, it was sometimes difficult to reach full agreement on numerical values of certain relevant parameters. Therefore, in some cases, alternative values

* The tolerance levels for non symmetrical frontal impact would also apply to symmetrical frontal impact.

are indicated.

In order to prevent injuries caused by high localized pressures, the group recommended that protrusions with an area of less than the small impactors which have been used in experimental works (i.e. 1 in^2 or approximately 6.5 cm^2) should not be placed nor created where they could be contacted by restrained occupants.

3.1.1. Injuries to the head

This type of injury was considered by the group as "very important".

* Brain injury

The parameter to be measured is linear acceleration as a function of time.

If there is a head contact, a value of HIC 1000 or 80 g for more than 3 ms should be considered as a tolerance level until further data become available and both values combined whichever is exceeded first is recommended as the requirement level for the resultant acceleration.

The group felt that, if there is no head contact, with present safety belt restraint, accident data indicate there is no need for a requirement level, in particular, a HIC value above 1000 should not be considered as dangerous.

* Skull fracture

Although the relevant parameter which is not yet measurable is contact force or contact pressure, the group felt that, if the preceding requirement (3.1.) is fulfilled, the recommended requirement level for brain injury might possibly prevent skull fractures.

* Face fracture

As force measurements are not yet possible with present dummies, the group was unable to recommend any requirement level to guard against face fracture in an in-vehicle test.

In case of head contact, the usefulness of a subsidiary test with a head form was discussed but some members of the group were of the opinion that such a subsidiary test should not be recommended now because further research is needed in this area.

* Facial laceration

The group felt unable to recommend any method for the assessment for the facial laceration.

3.1.2. Injuries to the neck

The group felt that injury to the neck by direct impact is very rare and did not consider that a requirement level is needed.

The other types of injuries were considered by the group as important.

The group felt unable to recommend any requirement limit for flexion of the neck and felt that a survey of the accident statistics and experimental research are needed to determine whether flexion is a more important cause of injury than extension.

For extension of the neck in frontal impact, the group did not think a requirement is needed at present.

3.1.3. Injuries to the clavicle

This type of injury was considered by the group as "not important".

3.1.4. Injuries to the thorax

The group felt that injuries to the thorax were "very important".

The group felt that the parameter which should be measured in tests of this kind is chest deflection. This would be measured as displacement of the sternum relative to the spine. The tolerance level suggested in this type of loading would be 45 mm of deflection and this value could be used as a requirement level provided the dummy has the same force-deflection characteristics as man. If not, the level of 45 mm will have to be transformed into corresponding levels for other types of dummy.

If it is not possible to measure chest deflection in the near future, then, as an interim measure, acceleration levels exceeded for at least 3 ms could be used. The recommended levels will have to be different for dummies with different load-deflection characteristics.

Different acceleration values, either as components or as resultants were proposed by the different delegations as indicated in Annex 1.

The steering wheel impact could be measured as force using a load cell and force distribution but the group could not agree an any recommended level here.

The group felt that protection against thoracic fracture at a given severity of impact would, at least with present belt systems of restraint, protect against most cases of intra-thoracic injuries. Therefore, for this last kind of injury, the group did not propose any requirement limit.

3.1.5. Injuries to the spine

The group was unable to recommend any particular requirement level. It would like to advise car manufacturers and the authorities that this type of injury could probably be avoided to a great extent by securing loads in the rear of the vehicle, using seat belts for rear seat passengers and also by strengthening the back-rest of the front seats.

3.1.6. Injuries to the abdomen

The group considered injuries to the abdomen as "very important".

For injuries caused by loading from the lap portion of the restraint system, the group proposed that the requirement be that the lap part of the seat belt shall be below the iliac crests in the normal sitting position and be shown not to have slid up off the iliac crests during the loading phase of the impact. Means to do this for current dummies need to be developed.

Injuries to the upper abdomen might be caused by loading from the shoulder strap of the restraint system. The group felt that this type of loading could be avoided if the specifications for thorax protection were respected and would like to propose that the position of the anchorage points of the seat belts be carefully studied.

3.1.7. Injuries to the knee-femur and hip

The group agreed that injuries to this part of the body were "very important".

A fracture to the femur may be caused by bending component of loads and posterior dislocation of the hip joint by compressive component of loads in the femur.

It is possible to measure compressive force at present, but the tolerance levels quoted in the literature vary considerably probably owing to the exact loading direction. However, the majority of the group agreed that the requirement level of 4 kN for each femur should be used as long as it is not quite clear that the loadings will take place in a straight anterior-posterior direction. The German delegation however proposed a value of 7.6 kN.

The group did not recommend any requirement level for bending load.

3.1.8. Injuries to the lower leg and foot

The group considered these injuries as "not important".

However, the group would recommend requirement that no trapping of the feet occurs.

3.2. LATERAL IMPACT

The group discussed the test situation and the problem of side-impacts very carefully and has found that very little is known about these accident situations.

The group agreed that for most injuries, measuring force on a standard dummy would appear to be the best method of assessment if it is practical. This is not possible at present. There was no agreement concerning the validity of other methods such as the use of a special side-impact dummy, the measurement of vehicle intrusion, or the measurement of dummy accelerations.

As a solution, most of the group hoped that it would be possible to develop a practical universal dummy for front and side impacts, but some members thought that a more practical solution might be the use of two types of special dummies.

As for frontal impact, the group recommends that protrusions with an area of less than the small impactors which have been used in experimental works (i.e. 1 in^2 or approximately 6.5 cm^2) should neither be placed nor created where they could be contacted by restrained occupants.

3.2.1. Injuries to the head

* Brain injury

The group considered this type of injury as "very important".

The parameter of interest would be linear acceleration as a function of time.

The HIC value is not scientifically founded for side impacts but until further research has been carried out in this area, the group would propose, as a requirement, if head contact occurs, both a level of HIC not more than 1000 and a resultant acceleration of 80 g for not more than 3 ms.

* Skull fracture

Appart from the general design recommendation concerning small protrusions, the group could not propose any other requirement until force measurements are possible.

* Face fracture

This type of injury was considered as "not important" in side impacts.

3.2.2. Injuries to the neck

The group found injuries to the neck to be "important".

Because of the lack of valid tolerance levels available in the literature, the group at present does not recommend any requirement level.

3.2.3. Injuries to the clavicle

The group felt that injuries to the clavicle were "not important".

3.2.4. Injuries to the thorax

The group felt that injuries to the thorax were "very important". The group could not agree on any specific tolerance level to be used here and could not recommend any requirement level.

Concerning the injuries of intra-thoracic organs, the group felt that if some requirements to prevent thoracic fracture could be recommended and were respected, there was very unlikely to be an intra-thoracic injury problem but that the accident situation should be monitored.

3.2.5. Injuries to the hip and pelvis

The group felt that injuries to these organs are "important". The group was not able to reach an agreement on requirement levels for force, acceleration or intrusion.

3.2.6. Injuries to the abdomen

The group considered injuries to the abdomen as "very important".

The group felt that the recommendations for hip and pelvis injuries should also take care of injuries to intra-abdominal organs as long as the recommendation to monitor the position of the lap portion of the restraint system is carried out.

3.2.7. Injuries to the femur

The group considered injuries to the femur as "important". However, the group could not agree on any requirement level.

3.3. GENERAL REMARKS

These conclusions show that in many cases it was not possible to recommand any requirement level and it appears that there is a great need of research. Indeed, research is wanted in the following fields :

- investigation on human tolerance in order to have a better understanding of the relevant parameters and criteria and of the tolerable levels of these criteria (particularly with respect to head injury tolerance and side impact tolerances) ;

- research to determine methods of measuring such as force and its distribution, thorax deflection, belt strap displacements, etc. and improvements of dummies to make these measurings more meaningful.

4. CONCLUSIONS OF THE GROUP REGARDING DUMMIES

At the present time, current dummies are only approximate substitutes for the human being, particularly in their dynamic behaviour. A number of problems occur when using standard dummies to assess injury criteria.

To obtain valid data from tests, a very careful calibration of the dummy in respect of the tolerance data is needed.

Measurements with test dummies are usually associated with a great deal of scatter of the results. A statistical approach would seem to be the best method to reduce the scatter, but if would destroy too many cars for fullscale approval testing. Therefore it might be desirable to use another method, perhaps simulating of the actual car impact deceleration pulse on a dynamic sled or using requirement limits which take into account both the expected value and the expected scatter or requiring the manufacturer to take into account his expected scatter when designing to the requirement limits as he does at present.

No existing dummy allows the measurement of all the parameters the group thinks necessary.

Some parameters are measurable at present and the group recommends the measurements of :

- linear acceleration at the centre of gravity of the head in three axis separately,
- thorax acceleration on the spine in three axis separately, approximately at the centre of gravity of the parts of the dummy above the pelvis (i.e. the head and neck, the upper limbs and the torso),
- femur compressive load.

Other parameters which, the group felt, should be measured were :

- femur bending moment,
- chest deflection,
- lap strap displacement,
- more generally, measurement of forces and of their distribution, especially (but not only) for lateral impacts.

The measurements of some of the preceding parameters imply an improvement of the dummies. Improvement is also needed with respect to their dynamic behaviour for a realistic estimation of some injury potentials ; this is particularly desirable for neck injury assessment.

Is it preferable to use a single dummy for all the crash configurations or to have different dummies for frontal impact and for side impact ? The group could not agree on an answer to this question. The two possibilities involve both advantages and drawbacks.

The group discussed the question of dummy size and recommended the use of the 50th percentile dummy, but pointed out the need to consider the problem of other sizes.

5. REVIEW OF THE UNRESTRAINED CAR OCCUPANT PROBLEM

Even with a compulsory wearing of seat belts in all European countries in a few years time, it can be assumed that unrestrained occupants will still represent a proportion of seriously injured car occupants (refusal to wear the belt and exemptions to the legislation). Thus, protection for unrestrained occupants needs to be considered. Since several European countries are just in the initial phase of introducting compulsory seat belt wearing, it is too early to reach firm conclusions on this point at present.

If they are adopted, protective measures for non restrained occupants may need to be at a lower level of protection and should not lessen the protection afforded for restrained occupants.

6. REVIEW OF THE PEDESTRIAN SAFETY PROBLEM

The present synthesis was developed using data from each national delegation and from the analysis of American, Australian and Japanese reports of studies in this field.

6.1. ACCIDENT STATISTICS

Pedestrian accidents are an important problem of traffic safety and they are especially important in urban areas though, in rural areas, the injury severity is much higher probably because of a higher speed of impact.

The frequency of pedestrian accidents is especially high in children and elderly people, but the severity is greater in adults.

Head injuries are both frequent and severe. Injuries to the lower limbs are also frequent but not so severe. Thorax injuries are less numerous but tend to be more severe than those to the lower limbs.

Injuries result either from the first impact on the vehicle or from the subsequent impact on the ground.

6.2. DATA FROM EXPERIMENTAL STUDIES

From experimental works, it appears that many parameters, such as posture, impact speed, pre-crash and post-crash braking, car shape and struck area, have an influence on pedestrian kinematics. Thus, the results from studies performed in different conditions are not easily comparable.

Mathematical modelling is a new approach which seems to corroborate some experimental data.

6.3. CURRENT AND FUTURE STUDIES

Whereas accident statistics will be developed specially to get a better knowledge of injury mechanisms, experimental studies are needed to determine the effects, of protective measures proposed for the adult pedestrian, on the child.

With a better knowledge of the real accident situation, it will be possible to study measures intended for lessening the severity of the vehicle-pedestrian collision using mathematical modelling techniques .

6.4. RESULTS OF STUDIES ON VEHICLE TECHNOLOGY

These studies deal with both the vehicle shapes and the materials used to reduce the severity of the pedestrian impact on the vehicle and the development of devices intended for avoiding the pedestrian impact with the ground.

From present knowledge, it appears that little protection can be given in high speed impacts.

ANNEX 1 - INJURY CRITERIA FOR RESTRAINED CAR OCCUPANTS

1. BACKGROUND

1.1. SCOPE

The scope of this document is to give relevant injury criteria for restrained adult car front seat occupants in non-symmetrical frontal and side impact test procedures proposed by E.E.V.C./W.G. 2.

However, the criteria and recommended requirement levels proposed for non-symmetrical frontal impact would also apply to symmetrical frontal impact.

Such injury criteria should preferably be given in terms technically applicable to the design of motor cars. Where such criteria are not generally accepted at present, the authorities, as well as the car manufacturers, should be advised about trends in current research and possible areas where future studies may produce new and better knowledge.

In order to arrive at relevant parameters to be measured and limiting values to be used as requirement levels in approval tests, it has been necessary for the group to take into account the present state of knowledge regarding kinematics of accidents, human impact tolerance and human substitutes used in similar types of tests. The group has recognized the fact that the knowledge in these fields is yet rather scarce and that this is the case for side impacts in particular.

1.2. KINEMATICS OF ACCIDENTS

Most of the research and development work on the kinematics of accidents has so far been related to the symmetrical frontal impact situation, which has been considered to be more easily dealt with in studies of real accidents, as well as in simulation experiments. Although the kinematics of car occupants - unrestrained as well as under the influence of a number of different restraint systems - is fairly well known in symmetrical frontal impacts, this knowledge is not easily transferred to the more complex non symmetrical front or non orthogonal side impact situations. The group has considered however that the kinematics of restrained front seat occupants in the proposed non symmetrical frontal impact will differ very little from that resulting from a symmetrical frontal impact during the main part of the impact sequence.

1.3. HUMAN TOLERANCE

Present knowledge of the tolerance of the human body indicates an age variation where the skeleton and the connective tissues of young adult males have higher breaking strength than those of children, females and elderly people. As children are not taken into account in this document, the tolerance of the muscelo-skeletal system can here be considered as decreasing with age (1). Accident studies indicate a very remarkable decrease in the breaking strength of the female skeleton above 50 years of age. There are, however, also some indications in the literature that the tolerance for some very specific types of injury may well increase as a function of age. As an example of this, the tolerance against rupture of veins bridging the gap between the inside of the cranial vault and the brain can be mentioned (2).

In accidents represented by the test situations prescribed, the population at risk would probably not be the same in different types of cars or in different countries. This means that requirement levels should take into proper account the most vulnerable adult occcupants in cars. These problems are to some extent taken care of if requirement levels are derived from representative samples of accident data from several countries. As only a very limited number of studies have been carried out on the kinematics and tolerance of the human body in side impacts, the knowledge about injury criteria in this situation is very scarce.

1.4. TEST DUMMIES

The standard test dummies, currently used in experimental impacts, have been designed to remain unchanged during a large number of tests. This implies that the structure does not fail in the same manner as it would in a living human body under the same conditions. The kinematics of these dummies are, for this reason, not necessarily the same as those of human beings and this is particularly the case in later phases of complex impact situations. These dummies have also - for obvious reasons - mainly been designed and used in frontal impacts and there is hardly any information about their feasibility for use in side impacts.

1.5. INTERPRETATION OF RESULTS

Measurements of head and chest accelerations as well as of femur loads - for which test dummies have been used - usually are associated with a great deal of scatter of the results. This would make either a statistical approach or some alternative method to reduce the scatter desirable. A statistical approach could imply the use of several cars for full scale approval testing. This would probably not be practical on an economic basis. One possibility would be to require a limit which takes into account both the expected value and the expected scatter or to require the manufacturer to take into account his expected scatter when designing to the requirement limits as he does at present. Another possibility would be to reduce as much as possible the degrees of freedom of the system undergoing approval testing. The current normal procedure, in research and development work as well as in approval tests for restraints, is to simulate the actual car impact deceleration pulse on a trolley or sled where parameters of interest can more easily be recorded. It therefore seems possible as an alternative to limit the number of parameters to be measured in the full scale car impact to what is necessary as a basis for further component testing. The experience from this field indicates however that there would still be a number of problems to overcome in order to obtain repeatable results from this kind of testing. The influence and hence the importance of minor variations in different parameters is yet not fully understood.

The group has recognized these difficulties in the test situations prescribed and reached the conclusion that it would be misleading not to point out very strongly the great uncertainity in many of its recommendations and that the results of further investigations in a few years may lead to a desire to change several requirement levels and even some of the parameters to be measured. The group has felt great pressure to reach an agreement on as many points as possible and - where this has not been possible - to indicate the reasons for the various opinions. Most of the group, however, believes that the levels put forward are the best available at the present time. In accidents where they are not exceeded it is expected that many of the adult car occupants involved would escape serious injury. Thus a very significant advance in car safety should be achieved by designing to these protection levels.

The Italian delegation joins in the statement that the most advanced tolerance levels indicated represent a synthesis of the present knowledge. It considers nevertheless optimistic the belief that such levels might signify, if applied to vehicle design, a significant advance in car safety. On the contrary, Italy believes a design trend based on tolerance levels not sufficiently corroborated by experimental research and therefore susceptible of being corrected, or even based on parameters which might be varied in the future, will eventually result in a certain cost burden without a compensation in terms of improved and certain passenger protection levels.

2. INJURY CRITERIA AND RECOMMENDED REQUIREMENT LEVELS

2.1. NON-SYMMETRICAL FRONTAL IMPACT

2.1.1. The test situation

The test car is supposed to decelerate mainly in a frontal direction and any rotation in the horizontal plane to begin at a relatively late phase of the car frontal linear deceleration sequence. Restrained front seat dummies will decelerate under forward displacement relative to the ground. The relative displacement between the dummies and the car will depend mainly upon the characteristics of the car and the restraint system. "Normal" slack in current 3-point inertia reel belts will probably delay the linear deceleration of the dummies towards the end of the car linear deceleration sequence when a possible rotation begins. The relative displacement between the dummies and the car will therefore probably take place at a small angle with the longitudinal axis of the car and this angle may increase as a function of time. Any rebound of the dummies may therefore not bring them back to the center of the seat.

2.1.2. Injuries to the head

This type of injury was considered by the group to be "very important".

2.1.2.1. Brain injury

The brain will be subjected to inertial loading during the forward deceleration of the body but in current restraint systems this does not seem dangerous unless the head impacts car interior structures. It is therefore important that a possible head impact can be detected.

* Linear acceleration

The parameter to be measured is linear acceleration of the centre of gravity of the head. It should be measured in three directions and each of these should be recorded as a function of time. Human tolerance levels for this type of loading are supposed to vary with amplitude and duration of the center of gravity deceleration. However, peaks shorter than 3 ms are not supposed to be of significance in this situation.

Any head deceleration below 80 g and within the time duration applicable here has been considered not to cause brain injury. However, some studies indicate that pulses of long duration even below this value may be hazardous and in order to take this into consideration, the head injury criterion (HIC) has been developed and a value of 1000 (3) is at present the most widely applied as a tolerance limit, although higher values have been recorded in situations where no injury is supposed to have occured such as in forward deceleration with no head contact. The group has considered this situation and would recommend that any head contact be recorded very carefully. If there is a contact, a value of HIC 1000 or 80 g for more than 3 ms should be considered as a tolerance level until further data become available and both values combined, whichever is exceeded first, is recommended as **requirement** levels for the resultant acceleration. The group felt that if there is no head contact, with present safety belt restraint, accident data indicate there is no need for a requirement level in particular a HIC value above 1000 should not be considered as dangerous.

The group felt (in line with the car industry) there was a great need for increased research into brain injury mechanisms, tolerance levels and assessment methods. Studies on the effect of filters on measurements of this kind are also needed

* Rotational acceleration

Rotational acceleration of the head has in some studies been considered to have a deleterious influence on the brain especially in combination with linear impact accelerations. Various figures have been suggested as tolerance levels, for example 1800 rad/sec^2 (4) but the group felt that there was need for further research to confirm this value. Some improvement of the necks of the dummies will probably also be needed before measurements of rotational acceleration would be meaningful in standard tests. Consequently, neither tolerance nor requirement levels are suggested for this type of loading.

2.1.2.2. Skull fracture

In case of head contact with interior car structures localized force against the cranial vault may result in skull fracture. Experimental studies indicate that a force of more than 2.5 kN (5) over an area of less than approximatively 6.5 cm^2 may lead to skull fracture. If the area is larger than this limit, a force of more than 4 kN is required to produce skeleton damage (6).

At present, contact force cannot be measured on the head of standard dummies. The group felt that research and development is needed to make such measurements possible in the future. In the meantime, the group felt unable to recommend definitive requirement levels but would advise that interior details in the head impact zone should have an area of at least 6.5 cm^2. If this requirement is fulfilled, it was felt that the recommended requirement level for brain injury might possibly prevent skull fractures though the genuine relevant parameter, not yet measurable, is contact force or contact pressure.

2.1.2.3. Face fracture

Fractures to facial bones seem to occur in about 10 % of seriously injured front seat occupants and thus in a much lower proportion of all injury producing accidents. However, the group felt that this type of injury, if it is accompanied by concussion, may occasionally become a very serious complication when the inhalation of blood from the naso-pharynx and the consequent possibility of asphyxia occuring. Current restraint systems do not seem capable of preventing all facial contacts with the steering wheel. For these reasons, a requirement is desirable but not easily realized.

As force measurements are not yet possible with present dummies, the group was unable to recommend any requirement level for the in-vehicle test. If the test indicated tnat head contact occured with the 50th percentile dummy or was likely to occur with other sizes of occupants than the 50th percentile, a subsidiary test with a head form might be performed if the object struck was capable of producing localized loading of the face. The group felt that in such a test, a tolerance level of 0.7 kN for small impactors (5) would perhaps correspond to an acceleration of 15 g for 3 ms measured on a suitable head form. Some members of the group were of the opinion that such a subsidiary test should not be recommended now because further research is needed in this area.

2.1.2.4. Facial laceration

The group felt unable to recommend any method for the assessment of facial laceration but would recommend that research be carried out in this field. Investigations to determine the frequency of face laceration and that of eye injuries in particular are of great importance. If this should appear to be a problem of grave dimension, further development will also be needed on possible test methods.

2.1.3. Injuries to the neck

The group felt that injury by direct impact is very rare and did not consider a requirement level was needed.

The other types of injury, i.e. fracture and dislocation of the cervical spine, spinal cord injury, were considered by the group to be "important".

Possible types of loading are in the first place extension, flexion, rotation and lateral flexion and shear force. Possible parameters would then be angular movements of the head where head angles vs torso line should be measured.

The group felt unable to recommend any tolerance limits for flexion of the neck and felt that a survey of the accident statistics and experimental research are needed to know if flexion is a more important cause of injury than extension. For extension of the neck, the group agreed that 80° of angular movement of the head relative to the torso could be considered as a tolerance level (7), but did not think a requirement to be needed at present in frontal impacts.

Another possibility will be to determine relative head to thorax acceleration in three directions and calculate the load on the neck. However, the group felt that there was not yet enough experience from such calculations. Other types of loading such as traction, compression, bending may be of importance for the development of neck injury in some situations and tolerance levels of 1.6 to 2.2 kN of traction have been suggested in the literature (8), but the group was unable to give any recommendation at this stage. It felt that improvement of the dummy neck behaviour is necessary if such measurements should be considered.

2.1.4. Clavicle

This type of injury was considered by the group to be "not important", specially compared with thorax injury.

The type of injury would be clavicle fracture and this would result from bending caused by, for instance, a shoulder strap. The parameters of importance here would be strap angle and strap tension. It was shown in the United-Kingdom that, for an angle of 35°, the limiting tension observed was 8 kN measured on a OPAT dummy (9) ; but these conditions are not universal enough for the group to accept them. The group would advise however that the upper anchorages of straps should be in such a place as to minimize the load on both the calvicle and the spine without increasing the risk for thorax injury.

2.1.5. Thorax

The group felt that injuries to the thorax were "very important".

Thorax fracture was at present considered to be caused either by shoulder strap load or steering wheel impact or a combination of these. The group considered that the parameter of interest would be strap tension and this could be measured by a load cell, the tolerance levels would then be between 6 and 8 kN in most current restraints (8). However, the group could not agree to recommend a level for this type of loading at present.

Another parameter which could be measured in tests of this kind and which the group could recommend is chest deflection. This would be measured as displacement of the sternum relative to the spine. The tolerance level suggested in this type of loading would be 45 mm of deflection (9) and this value could be used as a recommended level provided the dummy has the same force-deflection characteristics as man. If not, the level of 45 mm will have to be transformed into corresponding levels for other types of dummies. To have the error resulting from such a transformation as slight as possible, it is important that the chest stiffness and damping of the dummy approximate as closely as possible to that of the human.

If it is not possible to measure chest deflection in the near future, then, as an interim measure, acceleration levels could be used. The recommended levels will have to be different for dummies with different load-deflection characteristics :

- the United Kingdom suggested that 35 g for the OPAT dummy would probably correspond to between 35 and 60 g measured in other dummies.
- France suggested the value of 50 g as resultant acceleration for HYBRID II dummy.
- Germany suggested 60 g resultant acceleration.
- Sweden suggested 45 g in G_x direction combined with 20 g in G_z direction.
- Italy and Netherlands were unable to support any fixed value.

These figures will have to be measured for a duration of at least 3 ms.

The steering wheel impact could be measured as force in a load cell and tolerance levels between 5 and 6.5 kN are mentioned in the literature (10). The group felt that such values are probably not sufficient and that it would be perhaps necessary to measure the force distribution. The group could not agree on any recommended level here. It felt however that improvement of the dummy to allow measurements of force and pressure would probably be needed in the future.

The loading of internal thoracic organs would be due to inertia and parameters to be measured would be spine acceleration in three directions. The tolerance levels found in the literature are very confusing and the group felt that this, to a large extent, depends on the type of human substitute which has been used for measurements. The group felt that protection against thoracic fracture at a given severity of impact would, with present belt systems of restraint at least, protect against most cases of intra-thoracic injuries. Therefore, for this kind of injury, the group did not propose any requirement limit. If however the restraint systems are improved to reduce the risk of rib fracture, intra-thoracic injuries may become relatively more important. For these reasons, the group recommend research in this topic, particularly on the effect of g_z component on the intra-thoracic organs as well as on the spine in car accidents.

2.1.6. Spine

The group has considered the question of spine injuries very carefully. This is thought to be a type of injury which could be caused by loading from the rear and as the group was unable to recommend any particular kind of measurement, it would like to advise car manufacturers and the authorities that this type of injury could probably to a great extent be avoided by securing loads in the rear of the vehicle, by using seat belts for rear seat passengers and also by strengthening the back rest of the front seats. The group also would like to propose research in the form of a survey of accidents to define the importance of this kind of injury and to study the injury mechanisms. Experimental studies are also needed for determining human tolerance levels.

2.1.7. Abdomen

The group considered injuries to the abdomen to be "very important".

Injuries to the lower abdomen would probably be caused by loading from the lap portion of the restraint system. The parameter would be deformation of the lower abdomen and the measurements should aim at detecting any submarining tendency or contact with the steering wheel. It was felt that human tolerance levels were always liable to be exceeded if the lap portion of the restraint was moved upwards on to the abdomen. The group therefore proposed that the requirement be that the lap part of the belt shall be below the iliac crests in the normal sitting position and be shown not to have slid up off the iliac crests during the loading phase of the impact. Means to do this for current dummies need to be developed. The group also recognized that the risk of intra-abdominal injury increases if hard components of the seat belt can get in contact with the soft abdominal wall and cause rupture of intra-abdominal viscera and would therefore recommend that hard parts of the restraint system such as buckles should be positioned in such a way that they could not get into contact with the abdominal wall. The group also felt the need for research on the dynamic behaviour of various dummies and their ability to disclose any tendency to submarining.

Injuries to the upper abdomen could probably be caused by loading from the shoulder strap of the restraint system. The deformation of the abdomen in general and consecutive to the deflection of the lower ribs was considered as a parameter of interest. The group also felt that this type of loading could be avoided if the specifications for thorax protection were regarded and would like to propose that the position of the anchorage points of the seat belts be carefully studied.

2.1.8. Knee, femur and hip

The group agreed that injuries to this part of the body were "very important".

One injury to this complex could be a knee-cap fracture. The group felt that the probability of the occurance of such fractures could be decreased if protruding objects with an area of less than the small impactors which have been used in experimental works (i.e. 1 in^2 or approximately 6.5 cm^2) be avoided in the knee impact zone. Fracture to the femur and compressive components may cause posterior hip dislocation.

Compressive force can be measured at present but the tolerance levels quoted in the literature vary considerably. It was indicated by the U.K. delegate that accident investigations indicated that hip injuries could occur at thigh compressive loads as low as 2 kN but that a more realistic level would be 4 kN (10). On the other hand, experimental tests which have mainly been carried out on cadavers indicate tolerance levels

of 7 or even 10 kN if the thighs are in a straight ahead position at the time of the impact. The majority of the group agreed that a recommended level of 4 kN should be used as long as it is not quite clear that the loadings will take place in a straight anterior-posterior direction. The German delegation however would like a value of 7.6 kN (11).
As an additional item of information, it is reported that the Swedish and Franch car industries let their respective national WG 4 delegate know that they would prefer the value of 7.6 kN.

Bending load is a more difficult measurement and not yet in current use in standard dummies. The group did not recommend any requirement level for this type of loading.

2.1.9. Lower leg and foot

The group considered injuries to the lower leg and foot to be "not important" and could not prescribe any measurements or tolerance levels. However the group recommended a requirement of no trapping for the feet because it is necessary that an injured accident victim can be extracted from the car easily. The group also recommended studies on the design of pedeals.

2.2. LATERAL IMPACT

2.2.1. The test situation

The group discussed the test situation and the problems of side impacts very carefully and found that very little is known about this accident situation. It is apparent that the intrusion of the side of the car might at present be used as a measurement of accident severity, but a requirement of limitation of the intrusion in the test situation would not necessarily lead to less severe situations for the occupants. The stiffening of the lateral stucture of the vehicle might lead to higher acceleration levels of the struck car.

The group also agreed that ultimately one might wish to aim at measuring forces on a standard dummy if this is practical. It is not possible at present. Because the use of a special side impact dummy was not accepted by all, the only parameters presently available with which to assess injury potential were dummy accelerations and vehicle intrusion.

The group however would like to warn that the use of such parameters might result in a misleading conclusion and they strongly urged that research be conducted into the measurement of loads on dummies in side impacts. At the same time, the acceptability of the current side impact dummy should be investigated. Most of the group hoped that it would be possible to develop a practical universal dummy for front and side impacts, but some members supposed that a more practical solution might be the use of two types of special dummies.

The group agreed that, for side impact as for frontal impact, the 50th percentile dummies were adequate for assessing occupant protection, but attention needs to be given to the problems likely to be rised by the other adult sizes.

2.2.2. Injuries to the head

2.2.2.1. Brain injury

The group considered this type of injury to be "very important".

The loading would be inertial with or without head impact. The parameters of interest would be acceleration and its duration and the measurements should be linear acceleration in three directions. The only tolerance level refering to this situation in the literature is the Mean Strain Criterion of .0061 cm/cm (12), while the HIC has no scientific foundation for side impacts. In this situation, the group however would propose a level of HIC 1000 or 80 g for 3 ms as a requirement if head contact occurs until further research has been carried out in this area.

2.2.2.2. Skull fracture

It was agreed that protrusions with a surface area of less than the small impactors which have been used in experimental works (i.e. 1 in^2 or approximately 6.5. cm^2) should neither be placed nor created in the zones likely to be impacted by the head in the lateral impact situation. It is yet not quite clear if this will protect the occupants against skull fracture but the group could not propose any other requirement until force measurements are possible.

2.2.2.3. Face fracture

This type of injury was considered to be "not important" for side impacts, but the group proposed further research in this field be carried out.

2.2.3. Neck

The group found injuries to the neck to be "important".

The type of injuries would be fracture, dislocation and spine cord injuries and the type of loading would be side flexion, rotation, flexion traction, compression, bending and shear force. The parameters to be measured would be angular movements to the head, relative head accelerations and forces. As far as angular measurements are concerned, the group would like to give a tolerance level of 60° for pure side flexion (13). For all the other parameters, there are no tolerance levels available in the literature and the group felt the need for research to define the tolerance levels in order to set up requirement levels and to improve the dummy neck behaviour to allow angular measurements. Therefore, at present, the group does not recommend any requirement level.

2.2.4. Clavicle

The group felt that injuries to the clavicle were "not important" and could be dealt with in connection with the thorax. (*)

2.2.5. Thorax

The group felt that injuries to the thorax were "very important".

Thorax fracture in side impact would be caused by transversal force-deflection or acceleration and the limitation of intrusion could be discussed as mentioned earlier. The group could not agree on any specific requirement level to be used here and would like to point out the need for further research and development studies which has been mentioned earlier. (*) (**)

As far as the intra-thoracic organs are concerned, the group felt that if the requirement to prevent thorax fracture were respected, there was very unlikely to be an intra-thoracic injury problem but that the accident situation should be monitored. It is also recalled that Zaborowski mentioned a 14 g tolerance level for volunteers (14).

(*) U.K. delegation proposed the use of a side impact dummy on which a force of 6 kN at shoulder level, 1 kN at each of the four rib stations and 5 kN total at hip and pelvis level would be considered as injury criteria.

(**) The Swedish delegation proposed 20 g_z acceleration as a requirement level.

2.2.6. Abdomen

The group considered injuries to the abdomen to be "very important".

The side impact load from the straps or from the intruding structures would cause compression and shearing of the abdomen or transverse force. Forces or accelerations can be measured at the pelvic level. The group felt that the recommendations for hip and pelvis injuries should also guard against injuries to intra-abdominal organs as long as the recommendation to monitor the position of the lap portion of the restraint system is carried out.

2.2.7. Hip and pelvis

The group felt that injuries to these are "important".

The type of injury would be fracture of the pelvis or fracture-dislocation of the hip and the type of loading would be side impact causing transversal load or acceleration. Measurements should be made of forces on the pelvis and hip joint if possible (*) or maximum resultant acceleration. At the present situation, the group could not agree on the use of a side impact dummy, but would strongly advocate research in this field to find tolerance levels and to clarify the effects of intrusion. Improvement of the dummy to measure forces easily in this region are also urgent. In the meantime, the group was not able to reach agreement on recommended levels for force, acceleration or intrusion.

(*) U.K. delegation proposed the use of a side impact dummy on which a force of 6 kN at shoulder level, 1 kN at each of the four rib stations and 5 kN total at hip and pelvis level would be considered as injury criteria.

2.2.8. Femur

The group considered the injury to the femur to be "important".

The type of injury would be fracture caused by the side impact and the parameter should be bending load or bending moment. This would require the use of force load cells and the tolerance levels found in the literature reached from 2 to 3.2 kN and 200 to 400 Nm respectively (15). The group could not agree on any recommended level here, but would strongly suggest research in order to measure force and a survey of the accident statistics is needed to establish a connection between intrusion and femur injury.

REFERENCES

(1) ALFFRAM, P.A., BAUER, G.C.H.
Epidemiology of fractures of the forearm. A biomechanical investigation of bone strength.
J. Bone and Joint Surgery, 1962, 44-A, 105.

(2) VOIGT, E., LÖWENHIELM, P.
"Gliding contusions des Grosshirns"
37 Jahrestagung der Deutschen Gesellschaft für Unfallheilkunde, Berlin 1973, "Hefte zur Unfallheilkunde, 1973, 117, pp 329-335.

(3) U.S. Motor Vehicle Safety Standard 208.

(4) OMMAYA, A.K., HIRSCH, A.E.
Tolerance for cerebral concussion from head impact and whiplash in primates.
J. Biomechanics, 1971, 4, 1, pp 13-21.

(5) SCHNEIDER, D.C., NAHUM, A.M.
Impact studies of facial bones and skull.
Proceedings of 16th Stapp Car Crash Conference, 1972, paper 720965, pp 186-203.

(6) HODGSON, V.R., BRINN, J., THOMAS, L.M., GREENBERG, S.W.
Fracture behaviour of the skull frontal bone against cylindrical surfaces.
Proceedings of 14th Stapp Car Crash Conference, 1970, paper 700909, pp 341-355.

(7) PATRICK, L.M., ANDERSSON, A.
Three point harness accident and laboratory data comparison.
Proceedings of 18th Stapp Car Crash Conference, 1974, paper 741181, pp 201-282.

(8) CLEMENS, H.J., BUROW, K.
Experimental investigation from injury mechanisms of cervical spine at frontal and rear front vehicle impacts.
Proceedings of 16th Stapp Car Crash Conference, 1972, paper 720960, pp 76-104.

(9) WALL, J.G., LOWNE, R.W.
Human injury tolerance level determination from accident data using the OPAT dummy.
Paper presented to the 5th International Technical Conference on Experimental Safety Vehicle, London, U.K., June 1974.

(10) Transport and Road Research Laboratory, Leaflet 311, Jan. 1972.

(11) KING, J.J., FAN, W.R.S., VARGOGIK, R.J.
Femur load injury criteria. A realistic approach.
Proceedings of 17th Stapp Car Crash Conference, 1973, paper 730984, pp 509-524.

(12) Mc ELHANEY, J.H., STALNAKER, R.L., ROBERTS, V.L., SNYDER, R.G.
Door crashworthiness criteria.
Proceedings of 15th Stapp Car Crash Conference, 1971, paper 710864, pp 489-517.

(13) GADD, C.W., CULVER, C.C., NAHUM, A.M.
A study of responses and tolerances of the neck.
Proceedings of 15th Stapp Car Crash Conference, 1971, paper 710856, pp 256-268.

(14) ZOBOROWSKI, A.V.
Lateral impact studies. Lap belt shoulder harness investigation.
Proceedings of 9th Stapp Car Crash Conference, 1965, paper 6, pp 97-127.

(15) KRAMER, M.
Verletzungs-Index bei unfallähnlicher Traumatisierung von Brustkorb und Unterschenkeln.
1976, Unfallheilkunde 79, pp 61-69.

ANNEX 2 - DUMMIES AND RELEVANT PARAMETERS FOR STANDARD TESTS

In order to transform the human tolerance levels into recommended levels on the dummy, the group had to examine the different existing dummies and, if necessary, propose improvements for the measurements of injury criteria parameters.

1. GENERAL REMARKS

Dummies are approximate substitutes for human beings and a number of shortcomings can be demonstrated among the different types. The main ones are thought to be lack of reproducibility, poor dynamic behaviour, poor reliability. Though some recent dummies, specially the HYBRID II, seem to be improved, they still leave something to be desired. Their poor dynamic behaviour is particularly marked at some anatomical locations such as the neck, thorax and pelvis. These deficiencies, though they have been recognized and steps have been taken to rectify them in new dummies (as, for instance, the OPAT dummy), question the value of measurements at those locations. In some cases, these deficiences may make a valid assessment of injury potential impossible.

The group points out that, assuming the dummy behaviour is good enough in other respects to express human tolerance, its strength requirements to enable it to remain unchanged during a large number of tests make it difficult to obtain an accurate representation of human behaviour (comparing the thorax force-deflection characteristics of both man and dummy can be quoted as an example). It seems that this aspect has received special attention in the design of the new dummies. Nevertheless, a careful calibration of the dummy needs to be carried out in order to transform the human values of parameters into corresponding levels for the dummy. Similarly, for reasons of reliability, all the variable parts of the dummy (specially the joints) have to be ajusted before each test by a method defined according to the response characteristics in connection with the human tolerance data.

The dummy size is another problem discussed by the group. Indeed, 50th percentile dummies cannot take into account the protection of the whole population : the risk of impact may be increased for the tallest people and bad fitting of the seat belt may become more likely when the size increases or decreases from the medium one. Nevertheless, the group recommends the use of the 50th percentile dummy, but points out the problem of protecting other sizes of occupants.

The parameters to be measured on the dummy are in fact the chief problem. Indeed, on the one hand, most of the available human tolerance data are force levels required to produce the bone fracture because they are the easiest ones to be determined. On the other hand, current standard dummies (HYBRID II for instance) were not designed to measure forces at some locations of interest with regard to tolerace data, but they enable acceleration measurements. From a general point of view, two ways are possible to solve this question. Either force data may be changed into acceleration levels and standard dummies can be used or force measurements may be kept as recommended levels. This needs the use of special dummies. The choice between these two options gave rise to discussion in the group and no general agreement could be reached for the moment. This question will be examined more precisely later in this paper with parameters to be measured at every body location.

2. ANALYSIS OF THE DIFFERENTS PARAMETERS ACCORDING TO THE BODY LOCATIONS

The group has to classify the different possible parameters in terms of their utility and feasibility of measurement on the dummy. So, it was discriminated between :

- parameters of little or no interest
- parameters which can be measured at present
- parameters which it is desireble to measure on the dummy in the near future
- interesting but less useful parameters which could be measured later on.

The main body locations were reviewed.

2.1. HEAD-FACE AND NECK

The head linear acceleration in three directions is regarded by the group as presently measurable.

The head angular acceleration and the head to thorax relative angular displacement were taken as interesting. But the group thinks that although the neck of the dummies may be good enough to estimate the injury potential at the head level, it is not so for the injuries of the neck itself in frontal and lateral impacts. It is proposed to adapt these measurements as soon as possible for head injury estimation purposes and to improve the neck of the dummy for a later assessment of neck injuries.

Head impact force and pressure are quite desirable parameters to be used in an in-vehicle test. But, the question is : what part of the head-face will impact a structure of the vehicle during the test, i.e. where is the force to be measured ? Therefore, where is the load cell to be placed ? Moreover, the dummies are not designed to measure force at the head-face level. So, it is proposed to look for head contact or for its probability to occur with other sizes of occupants during the global test. Then, if head contact is deemed as possible, a separate test with a head form could be performed and knowing the mass of the head form an acceleration measurement could be used instead of a force measurement. The number and conditions of these tests would need to be carefully defined.

Neck forces were not considered by the group as a measurement of pressing necessity.

2.2. CLAVICLE

The problem of clavicle loads was examined by the group. It did not keep the clavicle bending load as a parameter and would better have a geometric recommendation for shoulder belt.

The clavicle compressive load could be an index of the lateral impact severity and the English delegate recommends its measurement using a special side impact dummy. But as there is no agreement at present for the use of such a kind of dummy, the group felt the clavicle compressive load measurement should be delayed.

2.3. THORAX

The thorax three axis acceleration measured at the spine is deemed as a presently measurable parameter.

The thorax deflection measurement is not yet possible on standard dummies but the majority of the group thinks it could be achieved relatively easily. Therefore, though the thorax deflection characteristics of most standard dummies are not considered as very realistic and the correlation with the human is not clearly defined, the group recommends thorax deflection as a presently measurable parameter. In the case of the OPAT dummy, this measurement is considered by the English delegate as realistic and is carried out in test at present.

Thorax anterior-posterior load was not considered as necessary if the load-deflection relationship of the dummy is known.

The group thinks that thorax lateral load is the most suitable parameter for thoracic injuries resulting from side impacts. But except on the special side impact dummy, its measurement is impossible. So, the group proposes research in order to make this measurement feasible as quickly as possible if, in fact, such measurement proves to be practical on standard dummies. In the meantime, other criteria such as acceleration or limitation of vehicle lateral structure deformation might be used unless an agreement can be reached concerning the use of a special side impact dummy.

For thorax loading, thorax surface pressure is thought to be a convenient measurement. The group recommends considering the possibility of using a contact pressure measurement on standard dummies. In several countries, such a parameter is regarded as very important to assess rib injuries under the shoulder strap. Further research is considered necessary to find an adequate measurement device.

2.4. ABDOMEN

From a general point of view, abdominal injuries might be assessed by recording parameters such as abdomen acceleration, abdomen applied force, abdomen contact pressure, abdomen wall displacement on the dummy. But, these extremely difficult measurements are not yet possible on standard dummies. The group suggests research for the development of transducers particularly those enabling contact pressure measurement and wall displacement estimation at the abdomen level. Similarly; on the Italian delegation's proposal, the group thinks it would be interesting to obtain information about internal pressure during the impact ; but such a measurement seems difficult and needs important changes in the dummy such as provision of liquid filled sac at the abdomen level enabling a fluid pressure measurement. Research is called for to investigate the feasibility of this measurement in the future on a dummy which must not be too sophisticated and which must be easy to use for standard tests.

If the restraint system includes a lap strap, an abdominal injury can be induced by the displacement of this lap strap before or during the crash. The group recommends that means should be developed for detecting incorrect positions of the lap strap before and during the impact to guard against so-called submarining. The term submarining is used to describe a relative movement between the lap portion of the restraint system and the pelvic part of the occupant resulting in a displacement of the lap portion from the iliac crests up onto the abdomen, indicating a risk for abdominal injuries during the loading cycle of the restraint system. In this connection, it has been noted that, under the same crash configuration, some dummies show a submarining behaviour while others do not. The first are generally standing dummies (as SIERRA 292-850) ; the second, seldom submarining, are sitting dummies (as ALDERSON VIP 50 A for instance) whose pelvis mobility has been modified in order to get an easier control and consequently a better reproducibility of the sitting position before the test. This aspect is of great importance because the upward displacement of the lap strap during the submarining depends on the pelvis ability to rotate. The group thinks sitting dummies are not completely realistic substitutes for the human concerning the submarining problem and consequently recommends research to improve their behaviour. However, pending this improvement, the group considers these dummies are suitable for use in crash tests.

2.5. PELVIS

Pelvis lateral load measurement was felt by the group to be a very realistic and desirable measurement but, as for the clavicle and the thorax, it requires a special side impact dummy the use of which is not generally accepted.

Pelvis three axis linear acceleration is usually measured but some delegates question its validity as a good index of injury potential.

2.6. FEMUR

The group recommends the measurement of femur compressive load. Femur bending load is also considered interesting, but it cannot be measured at present because as yet, no practical technique has been devised.

2.7. PATELLA

Knee-cap pressure was not deemed a needed parameter by the group.

2.8. SPINE

The group asked for research to obtain a better knowledge of the tolerance of the spine and to determine the relevant parameters. Following this it may be necessary to examine the possibility of measurement on the dummies.

3. PROBLEMS RELATED TO SIDE IMPACTS

From study of the different parameters to be measured on the dummy, it appears that the main difficulty, giving rise to disagreement between the members of the group, is the estimation of the injury potential in the side impact configuration. At present, the only generally accepted methods of assessing side impact protection are measurements of acceleration on dummies and, in the opinion of some delegates, the limitation of intrusion. The group feels however that it must warn that these parameters only give an imprecise indication of the protection provided for the occupant and might perhaps lead to wrong conclusions. It would be better to use force measurements on either a standard dummy or a specially developed side impact dummy. Work is being done on developing such dummies at the present time, but the results are not yet generally accepted. The Italian delegate considered that even if such dummies are used, intrusion limits should still be specified. On the other hand, a special side impact dummy, besides its ability to provide force measurements, should show a dynamic behaviour good enough to enable realistic measurements at other levels (head for instance). Otherwise, it could not be used instead of a standard dummy, but only in addition to it.

In conclusion, assessing side impact protection gave rise to several questions. Firstly, are special dummies needed for this purpose ? Some members want only one dummy for all standard tests. The others would wish for only one dummy but, noting the difficulty of making realistic assessments of side impacts with a standard dummy designed for frontal impact, agree to the use of special dummies for side impact. Secondly, what importance should be given to the limitation of intrusion ? In some members' opinion, it is not a desirable measure. For others, it would be a makeshift solution to be used instead of another more desirable measurement. For others, a limitation of intrusion, though it is not an injury criterion, is a quite realistic indication of occupant protection in case of side impact if associated with the measurement of a parameter such as force or acceleration. Thus for the particular problem of side impact protection at the thorax and pelvis levels, no general agreement was reached and the question remains open.

ANNEX 3 - PROTECTION FOR NON RESTRAINED CAR OCCUPANTS

1. THE NEED TO PROVIDE PROTECTION FOR NON RESTRAINED OCCUPANTS

When discussing protection for unrestrained car occupants, we are considering occupants of cars fitted with a form of restraint system requiring action on the part of the user to make it effective (active restraint system).

Although the wearing of seat belts is already compulsory in many European countries and may become so in all in a few years time, even with compulsory wearing, not everyone involved in an accident will be wearing a seat belt. Appart from those who choose to ignore the law, legislation is almost certain to permit exemptions in some cases such as delivery drivers travelling at less than a specified speed, people of unusual build unable to wear the belt safely, pregnant women during the later stages of pregnancy, people with a morbid fear of restraint, etc.... Thus, it is likely that we need to ensure a certain level of protection not only for seat belt wearers but also, as far as it is practical, for those who cannot or will not wear seat blets.

2. THE PRACTICAL LEVEL OF PROTECTION

In considering protection for unrestrained car occupants, we must ensure that the provision of such a protection does not lessen the protection afforded for restrained occupants. In most cases, it should be possible to devise means which enhance the protection for both classes of occupants.

The protection provided for unrestrained occupants should not be at such a level that the effort spent on providing the protection could have been more effectively spent in providing improved protection for restrained occupants or pedestrians struck by the car.

The mechanical strength of the human body structure is unaffected by whether or not a person is wearing a seat belt so that tolerance levels specified for restrained occupants must also be applied to unrestrained occupants. Not all these tolerance levels may be relevant and it may be necessary to specify some new levels.

Since we are dealing with cars equiped with active restraint systems, the group does not recommend an additional passive system which would give the same level of protection for unrestrained occupants. Therefore, if testing is felt necessary, it should be designed to represent impact conditions less severe than those used for restrained occupants.

3. SUITABLE TEST METHODS

Current legislation requires the use of conventional rig tests with simple impact forms to assess some of the protection afforded by vehicles for unrestrained occupants. This type of test is readily reproducible and is relatively inexpensive but recent research based on accident data (1) has indicated that these tests may not be sufficiently representative for the correct evaluation of design features intented for occupant protection. This deficiency may be, because the test form itself is not sufficiently representative of the relevant part of the human body or because its trajectory is not the same as that which occurs in the accident situation. It has been found, for example, that the stiffness and position of knee-padding can have a marked effect on the head trajectory of an unrestrained occupant. Because the trajectory of the unrestrained occupant is more difficult to predict than that of the restrained occupant and because modifications to the trajectory can be a valuable source of injury reduction for unrestrained occupants, it may be difficult to use a conventional rig test for solving this problem. There may be a stronger case for in-vehicle dummy testing when assessing the protective features provided for unrestrained occupants. On the other hand, in-vehicle testing includes many sources of variation and is much more costly ; therefore, the group did not recommend any type of testing for the moment.

REFERENCE

(1) P.F. GLOYNS and G.M. MACKAY.
The impact performance of some designs of steering assembly in real accidents and under test conditions.
Proceeding of 18th Stapp Car Crash Conference, 1974, pp 1-27.

ANNEX 4 - PEDESTRIAN SAFETY

This paper contains the synthesis of National E.E.V.C. answers and of some American, Australian and Japanese reports concerning pedestrian safety. The reports listed as references do not allow an exhaustive synthesis of the researches conducted in these countries to be made because they only represent a part of the research carried out in this field.

As the national delegation answers did not indicate many figures, it appears difficult to do an exhaustive synthesis concerning pedestrian accidents.

This concerns more particularly the first item : "Accident statistics".

So, some data of this synthesis have been obtained from the report published by the U.S. Department of Transportation concerning pedestrian safety project (CCMS report N° 27 - 1974).

1. ACCIDENT STATISTICS

From the national delegation answers, it appears that pedestrian accidents can be considered as an important problem of traffic safety. Table 1 points out the frequency of pedestrian casualties (1), (3), (4), (5).

The risk changes with age. It is high as soon as the child can walk alone, i.e. around five years, and the risk stays high up to 15 years. It can be noticed that the risk is high also for old people around 65 years

	FRANCE	GERMANY	ITALY	SWEDEN	ENGLAND
Pedestrian fatalities as a percentage of road traffic accident fatalities	18,8 %	30 %	25 %	19,6 %	37;9 %
Pedestrian injuries as a percentage of road traffic accident injuries	12,5 %	16 %	16 %	9,2 %	22,3 %
Pedestrian injuries in urban centre	90 %	93 %	90 %	86 %	94 %
Pedestrian fatalities in urban centre	65 %	73 %	65 %	67 %	81 %

TABLE 1 : FREQUENCY OF PEDESTRIAN CASUALTIES

(1), (3), (5), (6), (9), (10). But although the frequency of child involvement in pedestrian accident is higher, the severity of these accidents is lower than those involving adult pedestrians.

1.1. TYPES OF INJURIES

If we take into account the frequency of injuries, it can be noticed that the head is the body segment which is the most frequently injured followed by the lower limbs and the chest (1), (5), (10).

If we take into account the severity of these injuries, the head is followed by the chest (2).

1.2. MECHANISMS OF INJURIES

Some accidents studies point out that the secondary impact of the pedestrian on the ground involves injuries less serious than the first impact on the car (2), (5).

Other studies are more cautious within the determination of injury causation.

It seems that the severity of the injuries caused by the impact against the vehicle depends on the stiffness of the struck area, and increases with impact speed. The second phase of the accident is impact against the ground and the severity of this impact depends mainly on the body area hitting the ground first, and the velocity of this impact.

2. DATA OF EXPERIMENTAL STUDIES

Most of these studies are carried out with dummies although some use cadavers.

Many experimental studies concerning pedestrian safety are conducted in Europe, in the States and Japan (1), (2), (3), (5), (12), (13), (14), (15).

From these, it appears that many parameters have an influence on pedestrian kinematics : posture, impact speed, pre-crash and post-crash braking, car shape and area struck.

These studies are carried out in different conditions and it is difficult to compare their results. However, it is clear that the severity increases with the impact speed.

The pedestrian accident can be divided into two main impacts : impact against the car and impact with the ground.

The severity of the second impact can be evaluated in different ways by the experimental studies, but the severity of this second impact remains high when the head hits the ground first.

There are not many mathematical modelling studies of the impact pedestrian/vehicle. We can quote the study carried out by the JAMA (14) which uses a 7 degrees of freedom model and finds results which seem to square with experimental studies.

Other studies are in progress in Europe and in the States.

3. CURRENT AND FUTURE STUDIES

In-depth accident studies are being increased in order to determine accurately the most frequent and the most severe configurations of pedestrian accidents. Moreover, some will enable a distinction between injuries caused by the vehicle from those caused by the impact against the ground.

Experimental studies which have been conducted in the past refered essentially to adult pedestrians and were often made with dummies designed to represent vehicle occupants. Therefore, the influence of protection measures proposed for the adult are beeing studied on the child and the dummies used will be more realistic.

With a better knowledge of real accident conditions, it will be then possible to study, using mathematical modelling, the influence of some parameters (design or materials used when designing the front part of the car) on the severity of injuries.

4. RESULTS OF STUDIES ON VEHICLE TECHNOLOGY

Studies dealing with the technology of the vehicle in order to reduce the severity of pedestrian accidents are proceeding along two lines.

4.1. Study of the shape and the materials of the outer part of the vehicle, to determine the kinematics of the struck pedestrian and to reduce the violence of head impacts especially on the bonnet, the windscreen or the pillars, and to locate the bumper to avoid knee impact and in this way minimize the severity of lower limb injuries.

4.2. Study and development of means to prevent or reduce the probability of the secondary impact of the pedestrian against the ground or to reduce the severity of injuries resulting from this impact.

Everybody is aware of the risk run during the impact against the ground, which can be increased if the pedestrian is run over either by the striking vehicle or by another car.

Both approaches are complementary : the first one protects during the first stage of the accident (impact against vehicle) ; the aim of the second one is to prevent the second stage (impact against the ground).

REFERENCES

(1) EEVC WG 4 Pedestrian Safety - French data

(2) EEVC WG 4 Pedestrian Injuries - German data

(3) EEVC WG 4 Italian document on pedestrian accidents and Injuries

(4) EEVC WG 4 Road accidents in Sweden - 1973 - Pedestrian accidents

(5) EEVC WG 4 Research on Pedestrian Safety in United Kingdom

(6) R.R. HALL, R.G. VANGHAN, A.J. FISHER
Pedestrian crash trauma and vehicle design in New South Wales - Australia
3rd int. Congress on Auto Safety - San Francisco - 1974

(7) A.J. Mc LEAN
Pedestrians and bicyclists : Vehicle factors in accident and injury causation
Road accident research unit. The University of Adelaïde
Australia - 1974 -

(8) A.J. FISHER, R.R. HALL
The influence of car frontal design on pedestrian accident trauma
Acc. Analysis and Prevention Vol. 4 - 1972 -

(9) Pedestrian Safety Project.
Committee on the challenges of modern society
CCMS Report N° 27 - NHTSA 1974

(10) D.F. HUELKE, ROLLIN A. DAVIS
A study pedestrian fatalities in Wayne country - Michigan HSRI Report N° Bio-Q University of Michigan 1969

(11) A.J. Mac LEAN
The man in the street - Pedestrian Accidents in the Empire State. Proceedings of the 15th Conference of the American Association for Automotive Medecine, pages 97-121 - 1971 -

(12) J.T. HERRIDGES, H.B. PRITZ
A study of the dynamics of pedestrians and generally unsupported transit system occupants in selected accident modes.
Proceeding of the 17th Conference of the American Association for Automotive Medecine, pages 70-86 - 1973 -

(13) SEVERY, H. BRINK,
Auto Pedestrian Collision experiments - SAE 1966 Paper N° 660080

(14) AKIRA WATANABE
Pedestrian (dummy) collision test made recently in JARI
Preliminary report Japan technical memorandum N° 3
Japan Automobile Research Institute, Inc. Tokio, Nov. 1971

(15) Road Accidents in Great Britain 1973. Her Majesty's Stationery Office - 1974 - London UK

(16) Highway statistics 1973. Her Majesty's Stationery Office 1974. London UK

(17) SABEY B.E., Accidents in Urban Areas. TRRL DOE. Presented at Conference on Traffic Engineering and Road Safety. Brighton 1973.

(18) Car Front End Design and Pedestrian safety TRRL Leaflet LF 394 1974

(19) JEHU N.J.
Towards Pedestrian safety TRRL 5th ESV Conference - June 1974

(20) Pedestrian Injuries TRRL Leaflet LF 317 - 1972

(20) ASHTON S.J., HRM. HAYES, G.M. MACKAY.
Child Pedestrian Injuries, Biomechanics of Trauma in children IRCOBI 1974.

(22) MACKAY G.M.,
Pedestrian and Cyclist Road Accidents Forensic Science Society Annual Symposium, 1971.

(23) MACKAY G.M.
Injury to Pedestrians. Department of Transport and Environmental Planning Report N° 42 University of Birmingham. March 1972

ANNEX 5

LIST OF PARTICIPANTS IN E.E.V.C. Working Group 4

Pr. B. ADLMAN	Chalmers University	SWEDEN
Mr. D. CESARI	ONSER	FRANCE
Dr. A. CHAPON	ONSER	FRANCE
Mr. E. FRANCHINI	FIAT	ITALY
Dr. B. FRIEDEL	BAST	GERMANY
Mr. M. HALPERN-HERLA	ONSER	FRANCE (Chairman)
Dr. K. LANGWIEDER	H.U.K. Verband	GERMANY
Mr. J. LEROY	ONSER	FRANCE
Mr. C. SCHINAIA	C.P.A.	ITALY
Mr. T. TURBELL	N.S.R.T.R.I.	SWEDEN
Mr. J.G. WALL	TRRL	UNITED KINGDOM
Dr. R. WEISSNER	Volkswagenwerk A.G.	GERMANY

Present as observer for the Netherlands :

Mr. P.W. HOEKSTRA	Rijksdienst voor het Wegverkeer