ANALYSIS OF DATA CONNECTED WITH RIB FRACTURES OBSERVED IN SIMULATIONS OF IMPACTS PERFORMED WITH INSTRUMENTED CADAVERS.-

J. SACRESTE, A. FAYON, C. TARRIERE, Laboratoire de Physiologie et de Biomécanique de l'Association Peugeot-Renault, 18 rue des Fauvelles, 92250 La Garenne Colombes, France.

C. GOT, A. PATEL, I.R.O. - I.R.B.A., Hôpital Raymond Poincaré, 92380 Garches, France.

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Several research teams are performing experiments on human cadavers for the purpose of developing protection systems usable in a vehicle, or of determining human tolerances amid the conditions imposed by accidents. In this kind of experiments, a wide scatter exists in the level of injuries sustained by subjects exposed to identical accident simulations. Further more, the degree of seriousness of the injuries sustained by these cadavers differs appreciably from that of real-life victims of car accidents, which can be compared with the previous simulations in the light of their violence for the individuals concerned.

These observations illustrate two of the main difficulties involved in experiments with cadavers : inter-individual differences between the subjects, and differences between them and the population exposed to risk.

The purpose of this paper is to at least partially remedy these difficulties. The object is to show up the relations connecting the various parameters that influence the results of an accident simulation involving a cadaver. These parameters describe the violence of impact, the body measurements of the subjects, their bone condition, and the number of rib fractures found subsequent to testing, for both frontal and side impacts. For this purpose, the findings of a statistical analysis of data concerning over 100 subjects are presented.

The findings of this analysis make it possible not only to show up the influential parameters, but also to pinpoint those of the subjects whose grouping most accurately represents the population exposed to risk.

Following a review of the principles of the method, three sets of data pertaining to the subjects' bone condition, their responses to frontal impact and their responses to side impact will successively be analysed.

I - GENERAL REMARKS CONCERNING FACTORIAL ANALYSIS OF THE CORRESPONDENCES

The data are presented in the form of a rectangular table (kij), and, by convention, one line of this table is labelled "individual", with one column being headed "variable" or "character". In the present case, each individual subject is represented by a line grouping his characteristics, such as age, sex, number of fractures, etc., expressed in a numerical code.

The problem is to find out which are the principal factors responsible for the fact that, in a data table, not all the individuals show an identical response to the various characters.

The factorial analysis of correspondence (F.A.C.), developed by J.P Benzecri[1] proposes to answer this question by showing up the relationships (affinities or oppositions) between both individuals and variables. The F.A.C. also causes the emergence of relationships between each individual and all the other variables, or between each separate variable and all the individuals.

The advantages of this method lies in the fact that it requires only a very small number of hypotheses in order to be operational, thereby ensuring great flexibility of its use. The F.A.C. accepts any types of tables. In particular, the data can be either qualitative or quantitative ; example : sex and height, etc., the only conditions being those of homogeneity and exhaustivity.

Exhaustivity : This term must be taken in its weak sense. It is not a matter of taking into account all the individuals and all the variables ; it is merely a matter of having the greatest possible number of individuals, with the hope of thus getting a representative sampling and a sufficient number of variables for best describing the population within the framework of the study.

Homogeneity : A stage that is preliminary to the F.A.C. constits of making the data table homogeneous, if it is not already so. For this purpose, we use a division into classes.

If, for the individuals, the variable "j" takes on values included between "a" and "b", it is possible to divide the interval (a,b) into three or four classes, for example (a,x) (x,y) and (y,b). This breaks down the "j" column into three columns -"j1", "j2" and "j3"- in order to construct a (kij) table such that :

if (kij) $\in$ (a,x), then $kij_1 = 1$, $kij_2 = 0$, $kij_3 = 0$,
the classes have to be almost equally distributed.

In the case of the data dealt with here, the processing program begins with the automatic breakdown of the data into categ ories so as to homogenize the data table, which there upon consists solely of zeros and ones.

DESCRIPTION OF THE METHOD

A cloud N(I) of "n" points is defined ; each point represents the profile of one individual.

To describe the cloud N(I), its centre of gravity is used ; its coordinates Wj are calculated.

Starting from the centre of gravity "G", the cloud's shape is described by specifying the principal directions of elongation or principal axes of inertia. This raises a second problem, i.e. in order to describe the shape of a cloud in a space "E", it is necessary to define a distance between points of "E". This leads to defining as metrical the metrics of the χ^2 of the centre "G" : "x" and "y" being two profiles : $d(x,y) = \sum_{j=1}^{p} \frac{(xj - yj)^2}{Wj}$

This enables the finding of the principal axes of elongation, designated here as factorial axes. The first axis determines the line that best fits the cloud (in the sense of the least squares) ; axes 1 and 2 determine the plane that best adjusts the same cloud, etc.

With every factorial axis "α", there is associated a number "λ_α", designated as the eigenvalue, which is nothing else than a measurement of the inertia or of the variance of the cloud relative to this axis. The sum "$\sum\lambda_\alpha$" of the eigenvalues thus represents the cloud's total variance or total inertia in relation to its centre of gravity. From this remark, we get the concept of rate : $\tau_\alpha = \lambda_\alpha / \sum \lambda_\alpha$ expressed in %, which indicates the relative extent of inertia along the axis "α".

The only remaining step is to project the cloud points onto the axes, or, for an improved presentation, onto planes defined by pair of factorial axes, in order to show up, on the cloud shape, the proximities and distances between the various points. It should be noted that this method makes it possible to represent simultaneously, on the factorial planes, the points representing the individuals and the characters.

ANALYSIS OF RESULTS

The decrease of the "τ_α" (and, consequently, of the "λ_α") informs us as to the cloud's general profile : a very high $\tau 1$ (70 to 80 %) indicates a cigar shaped elongation of the cloud in the direction of axis 1 ; a very high $\tau 1 + \tau 2$ characterizes an extremely flat cloud ; an extremely slow decrease of the τ_α is synonymous with a spherical-shaped cloud.

The graphs : The foregoing is not sufficient to convey information about the reality described by the data table. It is the examination of the plane graphs that provides the greatest amount of information. Most of the data scatter is summarized in the plane of factorial axes 1 and 2 ; this plane will be examined first, and then planes 1 - 3 or 2 - 3 followed by 1 - 4, 2 - 4 will be examined.

In plane 1 - 2, we begin by investigating the way in which the points (individuals or variables) are arranged along axis 1. The proximities or distances observed are such that it is generally possible to assign a meaning to this axis (examples : violence axis, bone fragility axis, etc.). The same procedure is employed for axis 2, then for axis 3, etc.

As regards the interpretation of an axis, it should be borne in mind that the factorial axes are uncorrelated two by two.

Aids for interpretation : Two major concepts may aid in the interpretation of the results : the contributions and the correlations.

Contribution of an element to an axis : $CTR_\alpha(i)$, expressed in %, indicates the relative importance of the element (individual or variable) "i" for the determination of the axis "α".

Correlation of a point with the axis : $COR_\alpha(i)$ is a number included between 0 and 1 that characterizes the position of point "i" in relation to the axis "α".

$COR_\alpha(i) = 1$ if point "i" is located along axis "α" (not in projection onto a plane but in space).

$COR_\alpha(i) = 0$ if the vector joining the centre of gravity to point "i" is orthogonal to the axis "α".

II - APPLICATION TO ANALYSIS OF SUBJECTS

The method described above was used on three sets of data pertaining to 110 subjects.

A. Analysis of the bone properties of 62 subjects for any type of impacts, the only intervening factor being the results of various bone characterization tests.

B. Analysis of response to frontal impact :

- for 43 subjects, bone condition not taken into account.
- for 30 subjects, bone condition taken into account.

C. Analysis of the responses of 24 subjects who sustained lateral drop tests, bone condition taken into account.

These three sets of data are linked, and comparisons make it possible to identify the most important factors intervening in the occurrence of rib fractures.

ANALYSIS OF BONE PROPERTIES

The 62-subjects sample considered here consists of 15 subjects who were given static thoracic deflection tests, 43 subjects tested in simulations of all types of accidents, and four subjects who had met sudden deaths without prolonged hospitalization.

The variables considered are relative to the following items :

- Age (AG)*
- Results of rib mineralization tests :
  - C/M : mineral-salt content per unit of rib-fragment mass (CM)
  - C/L : mineral-salt content per unit of rib-fragment length (CL)
- Results of static bending tests :
  - Maximum force exerted during the test (FF)
  - Slope of the force/deflection curve in its elastic part (LA)
  - Maximum bending stress (SG)
  - Young's modulus (MY)
- Results of shearing tests :
  - Maximum force exerted during the test (PK)
  - Absorbed energy (WC)

The methodology for obtaining these informations was described previously.[2]

As noted in the description of the data-analysis method, the variables were divided into four classes. For each variable, Table 1, in the Appendix, lists the number of classes and the name of each individual class, its limits and the number of subjects belonging thereto.

ANALYSIS OF RESULTS

The first eigen value ($\lambda_1 = 0.51$) represents 17 % of the total inertia ($\tau_1 = 17$ %) ; the second ($\lambda_2 = 0.31$) represents 10 % of it ; and the third ($\lambda_3 = 0.24$) represents 8 % of it.

The first two axes account for 27 % of the cloud ; it will be seen that analysis of the factorial plane 1.2 suffices to explain roughly the phenoma.

Analysis of the contributions for the first axis shows a considerable contrast between classes 1 and 4. Those in class 1 are on the negative side and those in class 4 are on the positive value side, while those in classes 2 and 3 occupy intermediate positions. It thereupon becomes possible to assign a name to this axis, corresponding to bone characteristics in an ascending order ; in fact, on plane 1 - 2 (Figure 1-a), we note a parabolic distribution of the variables. This is called the Guttmann effect (1) : it can be interpreted as the emergence of a unidimensional effect. In fact, it will be seen that if we move along the parabola, we find that the classes are following one another (CL1, then CL2, then CL3, then CL4, and the same for other variables). This parabola can therefore be interpreted as a parabola of increasing bone strength, this factor being of primary importance for the interpretation of the data.

If, on the same plane 1 - 2, we no longer consider the variables but instead consider the individuals (Fig. 1-b), we again find this parabolic distribution. It can then be stated that the sequence of the subjects occurs along the parabola in accordance with the ascending order of bone characteristics. Subjects 109, 112.3 and 28, who have weak bone conditions, form a contrast with subjects 156, SD5, SD6, 48, etc. This graph hence supplies a classification of the subjects on the basis of bone strength, and makes it possible to pinpoint those among them whose bone conditions are closest to those of the subjects who had met sudden deaths (these subjects are indicated here as SD). It will be noted that subjects 102, 156, 31, 48 and 21 display a bone condition comparable to that of the four SD subjects. In terms of bone condition, the previous subjects 102 to 21 are closest to the real-life population exposed to risk.

(*) - The letters between parentheses indicate the codification used.

However, this statement must be nuanced for certain variables, as follows :

Age : Only the AG1 class contributes to axis 1, with AG1 being located on the side of the best bone conditions. Hwever, classes AG2, AG3 and AG4, i.e. those containing the subjects over 45, are randomly scattered along plane 1-2. On the negative side of axis 1, toward the poor characteristics, a threshold effect appears, with the younger subjects clearly standing out from the older subjects ; but, beyond a certain age, there is no longer any relationship with the bone condition.

Characterization tests : If the variables FK, LA, CL, CM, WC and FF are located approximately along the parabola in order of increasing value, the same is not true of SG and MY. SG 1, 2 and 3 are scattered, and only SG 4 is located with the other class 4 variables. From this it can be deduced that if a subject has a very good bone condition, his fracture stress will be high, but for the low or average stress values it will not be possible to classify him. Young's modulus is located more toward the interior of the parabola : this is particularly true for MY 4, which is clearly detached from the other class 4 variables. The reason for this is that a subject can have an extremely high Young's modulus result, whereas his other characteristics are low. This case is well represented by subject 149.4, with heterogeneous characteristics (AG3, CM4, CL1, FF3, MY4, SG3, FK1, WC1, LA3).

This leads us to use caution in considering the variables SG and MY in connection with a bone characterization, while the bone condition is found unambiguously in the variables such as CL, CM, FF, LA, FK, and WC. In order to increase the number of subjects whose responses can be investigated, the bone conditions of the subjects involved in forthcoming analyses to be performed will be approximated by 3 parameters -CL, CM and WC- which clearly represent the phenomenon examined here. The scatter observed on SG and MY does not mean that a bending test is of no interest ; rather, it indicates the scatter of the results obtained because of the numerous processes required in order to obtain these values (bending test, enlargement of the section, calculation of the moment of inertia). This privileges the raw data such as the maximum force, or the elastic slope.

In conclusion, this initial analysis has enabled a ranking of subjects on the basis of their bone conditions, pinpointing those that are closest to the real-life population exposed to risk as concerns bone condition. A threshold effect for age has been identified. The most significant parameters of bone condition were selected from among the ones available for the investigation.

RESPONSE TO FRONTAL IMPACT

Out of 49 subjects, the bone condition data were available for only 30, and it was possible to measure restraint forces for only 6 of them. This brought us to constitute two sampling subgroups, as follows :

- 43 subjects whose anthropometry, ages, forces and accelerations were known.
- 30 subjects whose bone conditions were also known but for whom force was not taken into consideration.

1. First sampling group

The variables considered were the following : age (AG), sexe (SX), height (TA), weight (PD), thoracic acceleration measured in T4 (GA), maximum force sustained at the shoulders (FO), this same force corrected by Eppinger formula (3)^x, impact velocity of the test vehicule (DV), maximum intrusion (DL), type of seatbelt (static TC1 , with retractor TC2 , with pyrotechnical retraction TC3), and number of rib fractures (NF).

(x) - corrected force = Measured force $\times \left(\frac{75}{\text{subject's weight}} \right)^{2/3}$

The breakdown into classes is shown in Table I.

Analysis of results : The first eigen value (λ_1 = 0.31) represents 13.5 % of the total inertia, the two following eigen values represent, respectively, 9.5 and 9 % of this inertia. Analysis of plane 1 - 2 and, accessorily, of axis 3, should enable the conveying of reliable data.

Factorial plane 1 - 2 (Figures 2-A and 2-B) : Analysis of the contributions of the various parameters at axis 1 shows up sharp contrasts between the extreme-limit cases ; in particular, NF1 contrasts with NF4, DV1 with DV2, FC1 with FC4, and DL3 with DL1. To this axis a signification of violence, both for the impact and for the individual may be given.

This axis corresponds to an increase from right to left of the number of fractures related, principally, to the corrected restraint force, which increases with the number of fractures and the violence of the test ; the impacts at 50 kph, involving extensive intrusion, are located in the positive aera, while the impacts at 60-65 kph are located in the negative aera.

Axis 2 seems to be a dimensional axis, since we find a sharp contrast between SX1 and SX2, between PD2 and PD4, and between TA1 and TA3. A sex-linked signification may exist, with the mean low characteristics PD2 and TA2 for the female subjects, SX2 contrasting with the higher dimensional characteristics (TA3 and PD4) of the male subjects, SX1. The factorial plane 1 - 2 hence represents a combination of two factors : a horizontal violence axis and a vertical dimensional axis.

Analysis of axes 3 and 4 does not enable a simple explanation. We shall investigate only the position of the variables in plane 1 - 2.

Age : No simple relationship emerges between age and the first two axes ; the contributions of the various age classes on axes 1 and 2 are low, with the exception of AG3 and AG4, which contribute 6.5 % and 5.8 % to axis 2. This connection between AG3 and short heights and between AG4 and tall heights seems to be due to chance.

The relation between the number of fractures and age does not emerge, either except for the younger individuals in the NF1 range.

Acceleration : Thoracic acceleration increases with impact violence and number of fractures, and seems to bear very slight relationship to axis 2 ; but the various classes are widely scattered on plane 1 - 2.

Dimensional parameters : The shorter subjects appear to be more vulnerable than the taller ones : TA1, SX2 and PD1 are located on NF4, TA3, TA4 and PD4, with SX1 located near NF1 and with sensitivity associated more with stature (7.7 % contribution of TA1 to axis 1) than with weight.

Kind of seat-belt : TC1 and TC2, i.e. static belt and retractor belt, have no link with axis 1 ; only TC3 (belt with pyrotechnical retraction) brings a slight contribution to axis 1. It is difficult to estimate the influence of this equipment. The proximity of NF1 and TC3 seems to indicate a favorable influence, but if the population contained in TC3 is analysed, it appears that five subjects were tested at 50 kph as against only two at 65 kph. This brings TC3 close to DV1 ; the gain contributed by this equipment will be evaluated by other methods if a larger number of cases fail to become available in the near future.

Subjects' positions on plane 1 - 2 : The subjects' positions on factorial plane 1 - 2 are of interest only in comparison with the results pertaining to bone properties.

(It should be noted that the subjects numbered 1 to 30 whose bone properties were analysed. The numbers coincide only from N° 33 on.)

It can be seen that, if we consider the subjects common to the two analyses, subjects N° 148.2, 154.2, 47, 44, 33, 41, 53 and 54 lie along an axis of decreasing fractures in plane 1 - 2 (frontal impacts), whereas they lie along an axis of increasing bone strength in plane 1 - 2 (bone properties) following a quasi-identical sequence (148.2, 47, 154.2, 44, 41, 53, 33, 54).

This comparison makes it possible to state that the number of fractures is strongly linked to the bone condition defined in the initial analysis, in addition to impact violence and restraint force.

2. Second sample : frontal impacts with bone condition taken into consideration

The analysis covered 30 subjects tested under frontal impact conditions, concerning whose bone conditions three meaningful parameters were known. The variables taken into consideration were as follows : age (AG), sex (SX), height (TA), weight (PD), bone data (C/L noted CL, C/M noted CM, WC), impact velocity (DV), maximum intrusion (DL), type of seat-belt (TC1 : static belt or retractor belt ; TC2 : belt with pyrotechnical retraction) and number of rib fractures (NF).

The breakdown into classes is shown in Table 1.

Analysis of findings : The methodology was the same as before. The first two axes represent 25 % of inertia, while the third axis represents 9 % thereof.

Factorial plane 1 - 2 (Fig. 3) : It will be noted that along axis 1, there is a sharp contrast between the extreme characteristics pertaining to age and to bone condition. CL1 and WC1 contrast with CL4, WC4 and AG1. This axis can be assigned a signification of bone condition. It is interesting to note the position of NF1 (number of fractures lower than five in the group CL4, WC4, AG1), with NF4 located in almost direct opposition, toward WC1 and CL1. One is allowed to think that this confirms the strong influence of bone condition and age on the number of rib fractures.

Similarly, it will be seen that the female subjects (SX2, TA1) are located close to CL1 and WC1, and that they consequently seem to be more vulnerable.

Axis 2 is less clearly explainable ; it is marked by a strong opposition between DV1 and DV2, and between GA2, GA3 and GA4. We are tempted to assign a violence signification to this axis, with violence intervening here on the number of fractures and a very high number, on the basis of a population of average subjects.

For the age factor, we find the threshold phenomenon described in the first analysis ; bone condition is related to age for the younger individuals only. Similarly, the under-50 age group is associated with the low numbers of fractures.

Bone-condition characteristics : C/L and WC are strongly linked to the number of fractures ; the contrary is true of C/M, whose four classes are randomly scattered along plane 1 - 2. From this it can be deduced that this parameter is not convenient for pinpointing a subject's overall resistance.

If we consider the subjects' positions on plane 1 - 2, we again find approximately according to axis 1, the ranking in terms of bone condition defined in the first analysis.

Other variables : The dimensional characteristics -height and weight- show but slight relationships to the first two axes ; only TA1 tends toward CL1, WC1, SX2, but this is due to the female subjects' small size.

Acceleration seems to be only faintly linked to the number of fractures, except for GA4, i.e. for a thoracic acceleration greater than 80 g, we are close to NF4. It was not possible to show up the effect of the different seat-belt types, for the same reasons as before.

In the light of the results of this investigation, there is reason to feel surprised by the relative importance of bone condition in the total injury pattern. The importance of impact violence appears secondary. In fact, it should be noted that although the subjects' conditions are highly variable, this does not hold true for the violence, since all the frontal impacts considered here are located on a very short range of violence. Other analyses concerning the results of more varied tests covering a large number of differing test conditions would doubtless yield different results without being contradictory.

As a conclusion to these two frontal impact analyses, one of the main findings that emerge is that, in addition to the violence of the test and of the restraining forces, bone condition does have a great influence on the total thoracic injury pattern. Among the bone characteristics noted, two display a close relationship with the number of rib fractures : one is the mineral-salt content per unit of length (C/L) and the other is the energy recorded during a shearing test (WC). (This relationship between WC or CL and NF is primarily verified for the extreme classes.)

RESPONSE TO SIDE IMPACT

The corresponding tests have already been described (4). Sufficient data were available for only 24 subjects ; in addition, it was possible to measure thoracic deflection for 14 subjects only. In view of this extremely low number, we discarded the idea of including this latter measurement in the analysis, despite its interest. This remark indicates the limits of the method : the number of 24 subjects represents a small population when we realize that the number of variables broken down into classes amounts to 44.

The conclusions of this investigation must therefore be viewed cautiously. Eleven variables were taken into consideration : age (AG), sex (SX), values related to bone condition (C/L noted CL , C/M noted CM and WC), the thoracic perimeter (DI), the drop height (NC), the type of shock-absorbent material used (PA)-(PA1, rigid surface ; PA2, thin rigid shock-absorbent material ; PA3, thick rigid padding ; PA4, more flexible padding)- force exerted on the chest (FD), thoracic acceleration measured in T4 (GA) and the number of rib fractures (NF). The breakdown into classes is shown in Table 1.

The first two axes account for 26.3 % of the inertia.

Factorial plane 1 - 2 (Fig. 4) : On axis 1, the contribution of all classes of variables is almost identical (2.4 %) ; only SX1 (male subjects) represent a neglictible contribution. This axis corresponds to a violence axis as concerns both the impact parameters (HC, FD and GA) and the total injuries (NF). Similarly, it will be noted that this axis corresponds to the bone condition : CL4, AG1, AG2 and WC4 are in opposition to CL1 and WC1.

Axis 2 has a less clear signification. It is marked by the opposition between HC1, PA1 and HC2, PA4. The positive values are linked to the rigid-surface impacts (PA1, HC1) ; the negative values are linked to the impacts against a prepared surface (PA4) from higher falling heights.

If we consider the subjects' distribution in plane 1 - 2, we note that if we compare the subjects' positions along axis 1 with their positions on the bone-condition parabola, we do not find the same subject classification as with the previous frontal-impact analysis. This is due to the variety of the testing methods whose effect is preponderant in relation to the differences in bone resistance.

Age : As in the other analysis, a threshold emerges : AG1 and AG2 (subjects aged under 47) are in opposition to AG3, AG4 and AG5.

Shock absorbent materials : In view of the heterogeneity of testing conditions and the small number of subjects, it is difficult to make a judgment.

Nevertheless, it can be seen that along axis 1, PA1 and PA4 are in opposition to PA2 and PA3, i.e. that the impacts against rigid surfaces and yielding shock absorbent materials are in opposition to those occurring against hard shock-absorbent materials. This contradiction, which associates rigid-surface impacts with prepared-surface impacts, is merely a seeming contradiction ; actually, all the rigid-surface impacts were performed at drop heights of 0.5 or 1 meter (HC1), and those against prepared surfaces were performed at drop heights of two meters (HC2). This enables us to deduce the advantageous features of type 4, which distinguishes itself from the two others (PA2 and PA3) under similar testing conditions.

Other variables : Like the two previous analyses, this analysis failed to point up any dimensional effect ; the various classes of the thoracic perimeter (DI) are randomly distributed on plane 1 - 2.

The female subjects are located toward the high number of fractures. Among the three bone-condition parameters, two appear to be linked to the subject's overall resistance (C/L and WC). The various classes of C/M are randomly distributed on plane 1 - 2. We find the same result as for frontal impact.

Analysis of side impacts shows up the limits of the method. We nevertheless confirmed the advantageous features of two parameters -bone condition (C/L and WC)- as compared with the third one used (C/M). Another interesting result is the ascertaining of the relative quality of type - 4 padding, the number of rib fractures being primarily dependent on impact violence. This shows the attractiveness of the method for comparing protection systems.

III - CONCLUSIONS

1. In order to asses the influence of various parameters available after simulation of frontal or side impacts involving cadavers, a data-analysis method was used on four sample groups.

2. A hierarchical classification of subjects in terms of bone conditions was defined.

3. The strong influence of two bone-condition parameters (mineralization content per unit of rib length and rib shearing stress) on the overall injury pattern was verified, for both frontal and side impacts.

4. A resistance threshold was detected. The subjects aged over 45 to 50 appear to be much more vulnerable, but no specific relation can be found linking the overall injury pattern to age.

5. The female subjects emerge as more vulnerable in the three sample groups of frontal and side impacts.

6. The subjects' overall dimensional characteristics seem to have but little influence on the number of fractures, except as concerns the small-sized subjects, without its being possible to make a distinction between the effect due to sex and the effect due to size, which are two linked parameters.

7. As concerns frontal impacts, the subjects emerge as more sensitive to variations in bone condition than to variations in the violence parameters. However, the corrected maximum restraint force increases significantly with the number of fractures. Such a strongly-marked phenomenon is not observed for thoracic acceleration ; however, extremely high values lead to severe total inju-

ry patterns.

8. Analysis of side impacts, since it concerns a less numerous population, yields a lesser amount of information ; it nonetheless confirmed the influence of bone condition and the value of the method in the assessment of protection systems.

9. Aiming at drawing conclusions from sets of biomechanical results, the use of F.A.C allowed the release of useful informations about human thorax impact tolerance.

However, more precise conclusions were possible when this method uses more numerous samples. This emphasizes the interest in a pool of data among several research teams. With more subjects, the 3 and 4 axes could be analysed, for example.

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TABLE 1 - FOR THE FOUR ANALYSED SAMPLES, SUMMARY OF CLASSES FOR EACH PARAMETER

(1) - Bony condition (2) - Frontal impacts

(3) - Frontal impact with osseous condition (4) - Lateral impacts

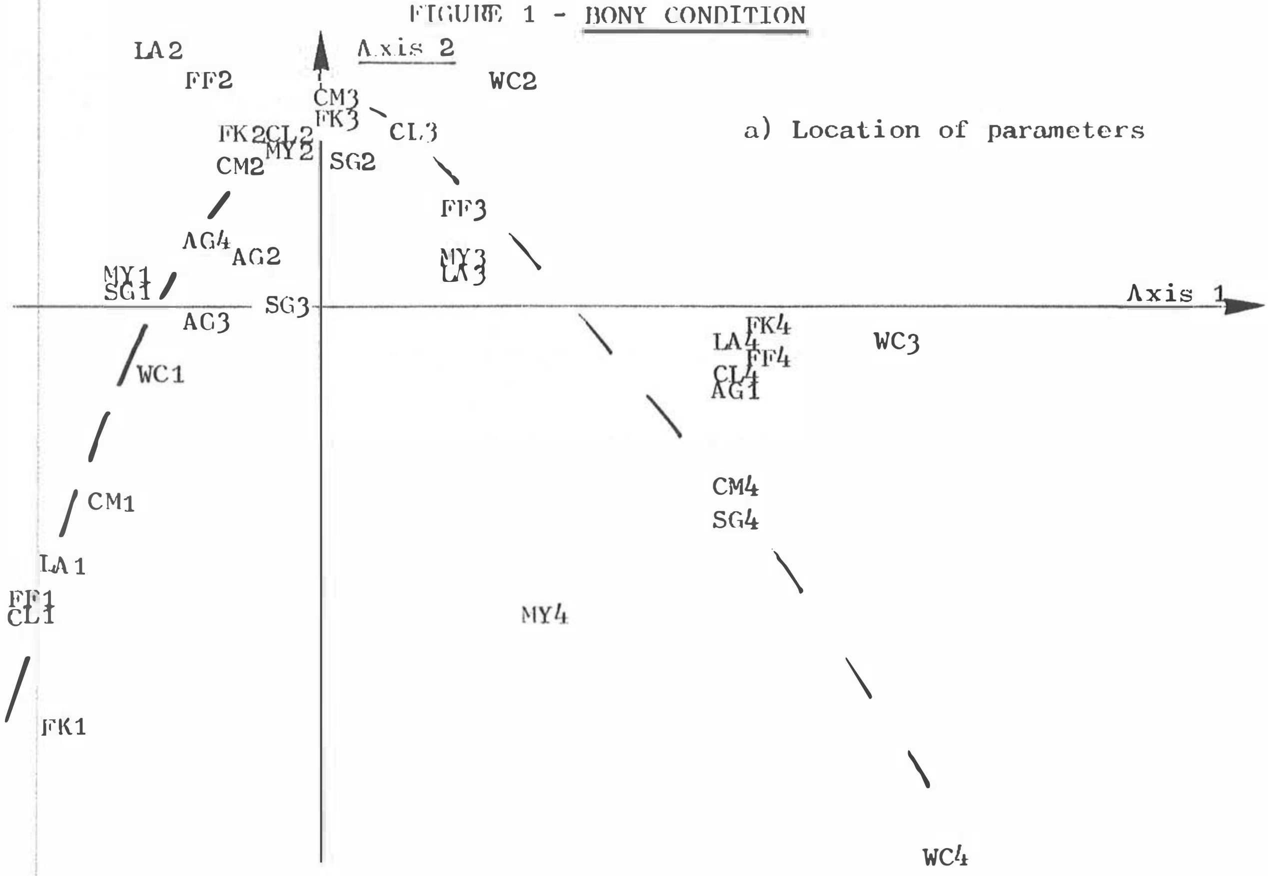
(1)	A G YEARS	C M %	C L g/cm	F F N	L A N/mm	M Y daN/mm2	S G daN/mm2	W C J	F K daN
NAME LIMITS N	A G 1 0-46 16	C M 1 0-24,3 16	C L 1 0-0,19 17	F F 1 0-127 16	L A 1 0-92 16	M Y 1 0-429 16	S G 1 0-5,8 16	W C 1 0-2,3 37	F K 1 0-41 16
NAME LIMITS N	A G 2 47-55 18	C M 2 24,4-29 17	C L 2 0,2-0,23 16	F F 2 128-170 16	L A 2 93-146 16	M Y 2 430-622 16	S G 2 5,9-8,5 16	W C 2 2,4-4,1 17	F K 2 42-63 16
NAME LIMITS N	A G 3 56-68 15	C M 3 29,1-33,9 15	C L 3 0,24-0,29 16	F F 3 171-242 16	L A 3 147-218 16	M Y 3 623-990 17	S G 3 8,6-13,2 17	W C 3 4,2-5,9 5	F K 3 64-87 16
NAME LIMITS N	A G 4 69-94 13	C M 4 34-48,1 14	C L 4 0,3-0,53 13	F F 4 243-509 14	L A 4 219-950 14	M Y 4 991-2260 13	S G 4 13,3-42 13	W C 4 6-7,6 3	F K 4 88-233 14

A G YEARS	S X	T A m	P D Kg	G A g	F O daN	F C daN	D V Km/h	D L m	T C	N F
A G 1 0-52 13	S X 1 ♂ 34	T A 1 0-162 12	P D 1 0-53 12	G A 1 0-32 11	F O 1 0-430 11	F C 1 0-520 11	D V 1 45-50 29	D L 1 0-0,65 15	T C 1 - 20	N F 1 0-6 11
A G 2 53-57 13	S X 2 ♀ 9	T A 2 163-168 10	P D 2 54-62 10	G A 2 33-51 11	F O 2 431-630 11	F C 2 521-700 11	D V 2 60-65 14	D L 2 0,66-0,75 13	T C 2 - 16	N F 2 7-11 12
A G 3 58-60 9	(2)	T A 3 169-171 12	P D 3 63-70 15	G A 3 52-80 12	F O 3 631-750 11	F C 3 701-892 11		D L 3 0,76-1,68 15	T C 3 - 7	N F 3 12-16 10
A G 4 61-65 8		T A 4 172-186 9	P D 4 71-95 6	G A 4 81-180 9	F O 4 751-1170 10	F C 4 893-1147 10				N F 4 17-40 10

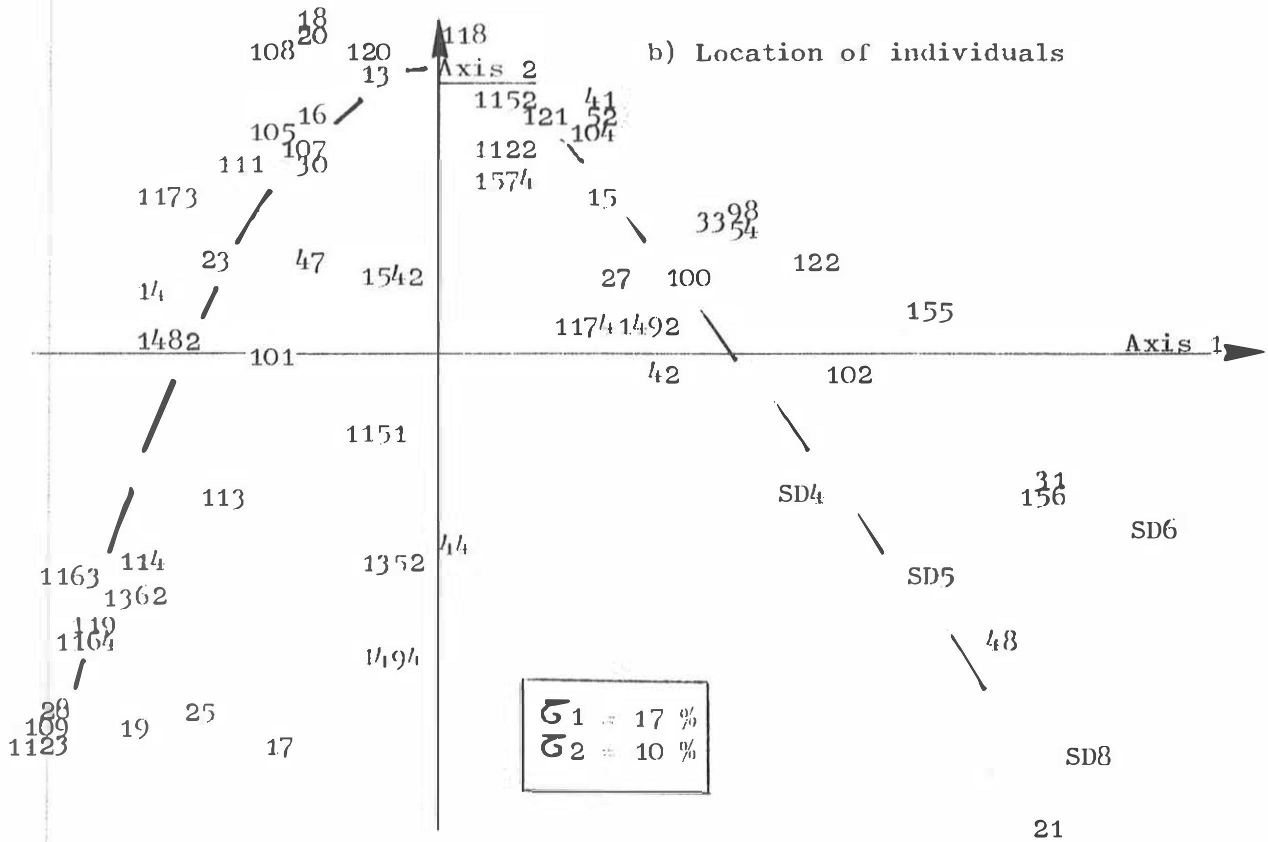
A G YEARS	S X	T A cm	P D Kg	G A g	D V Km/h	D L cm	T C	C L g/cm	C M %	W C J	N F
A G 1 0-52 9	S X 1 ♂ 23	T A 1 0-162 8	P D 1 0-50 10	G A 1 0-38 8	D V 1 45-50 21	D L 1 0-72 13	T C 1 - 21	C L 1 0-0,17 8	C M 1 0-25 8	W C 1 0-0,9 8	N F 1 0-5 8
A G 2 53-55 8	S X 2 ♀ 7	T A 2 163-168 8	P D 2 51-60 6	G A 2 39-64 8	D V 2 60-66 9	D L 2 73-92 7	T C 2 - 9	C L 2 0,18-0,22 8	C M 2 26-27 8	W C 2 1-1,7 8	N F 2 6-10 9
A G 3 56-69 7		T A 3 169-171 8	P D 3 61-67 8	G A 3 65-82 8	(3)	D L 3 93-163 10		C L 3 0,23-0,28 8	C M 3 28-32 8	W C 3 1,8-3 8	N F 3 11-15 7
A G 4 62-69 6		T A 4 172-180 6	P D 4 68-95 6	G A 4 83-180 6				C L 4 0,29-0,39 6	C M 4 33-39 6	W C 4 3,1-5,1 6	N F 4 16-40 6

A G YEARS	S X	C L g/cm	C M %	W C J	D I m	P A	H C m	F D daN	G A g	N F
A G 1 0-42 5	S X 1 ♂ 19	C L 1 0-0,19 6	C M 1 0-27 7	W C 1 0-1 6	D I 1 0-0,81 6	P A 1 - 6	H C 1 0,5-1 6	F D 1 0-630 6	G A 1 0-40 8	N F 1 0-4 6
A G 2 43-47 5	S X 2 ♀ 5	C L 2 0,19-0,21 6	C M 2 28-30 5	W C 2 1-2 7	D I 2 0,82-0,86 8	P A 2 - 6	H C 2 2 12	F D 2 631-800 6	G A 2 41-50 4	N F 2 5-12 7
A G 3 48-55 6		C L 3 0,21-0,26 6	C M 3 31-32 6	W C 3 2-3 5	D I 3 0,87-0,9 4	P A 3 - 3	H C 3 3 6	F D 3 801-950 7	G A 3 51-60 6	N F 3 13-17 5
A G 4 56-67 4	A G 5 68-71 4	C L 4 0,26-0,33 6	C M 4 32-42 6	W C 4 3-5 6	D I 4 0,91-0,97 6	P A 4 - 9	(4)	F D 4 951-1240 5	G A 4 61-78 6	N F 4 18-25 6

FIGURE 1 - BONY CONDITION



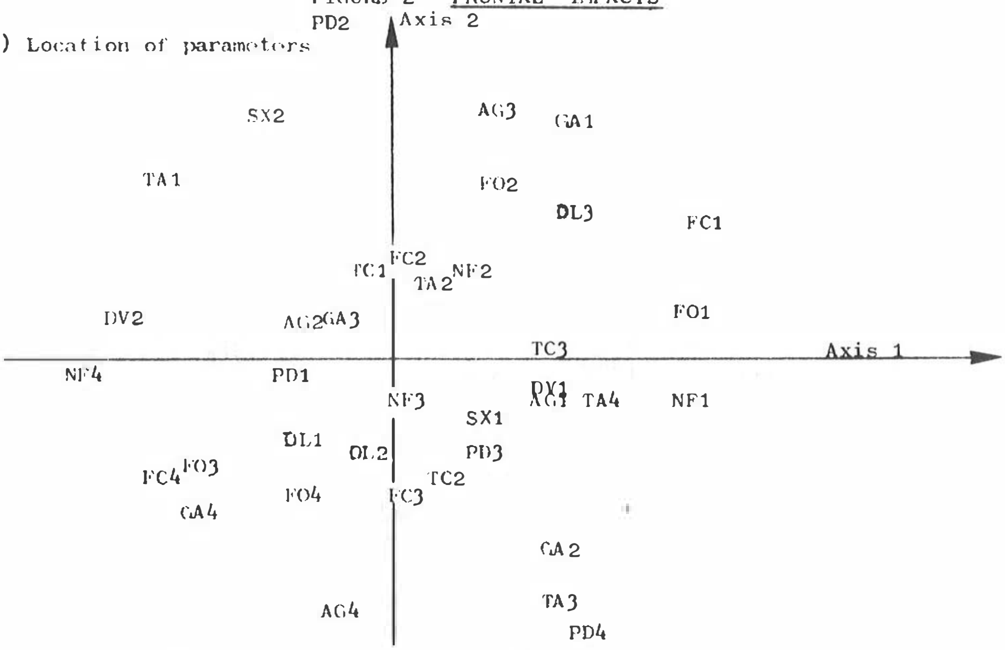
a) Location of parameters



b) Location of individuals

FIGURE 2 - FRONTAL IMPACTS

a) Location of parameters



b) Location of individuals

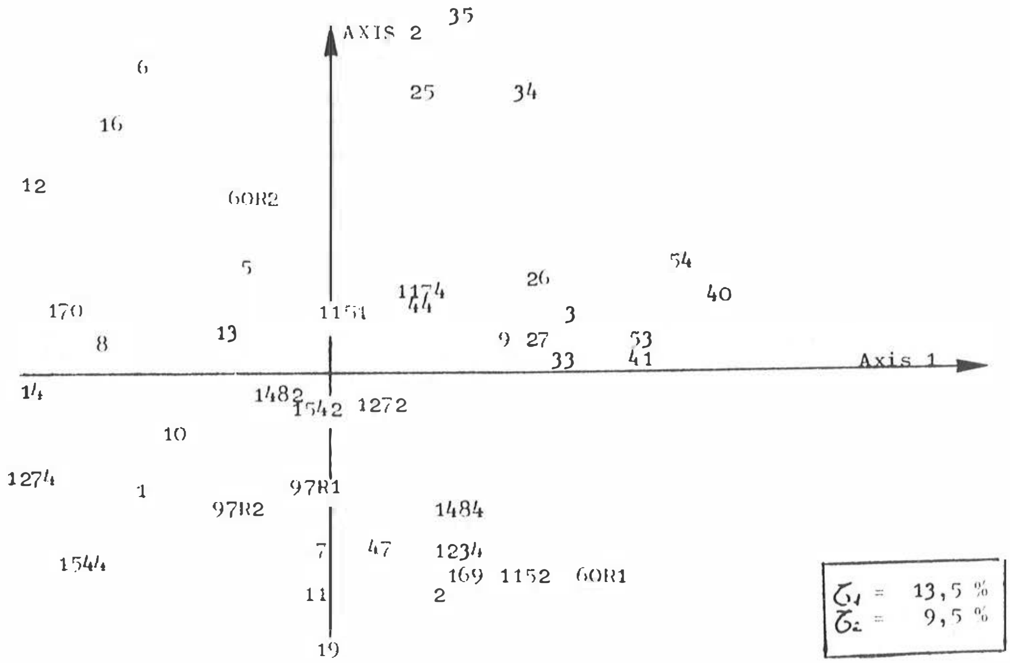


FIGURE 3 : FRONTAL IMPACTS WITH OSSEOUS CONDITION

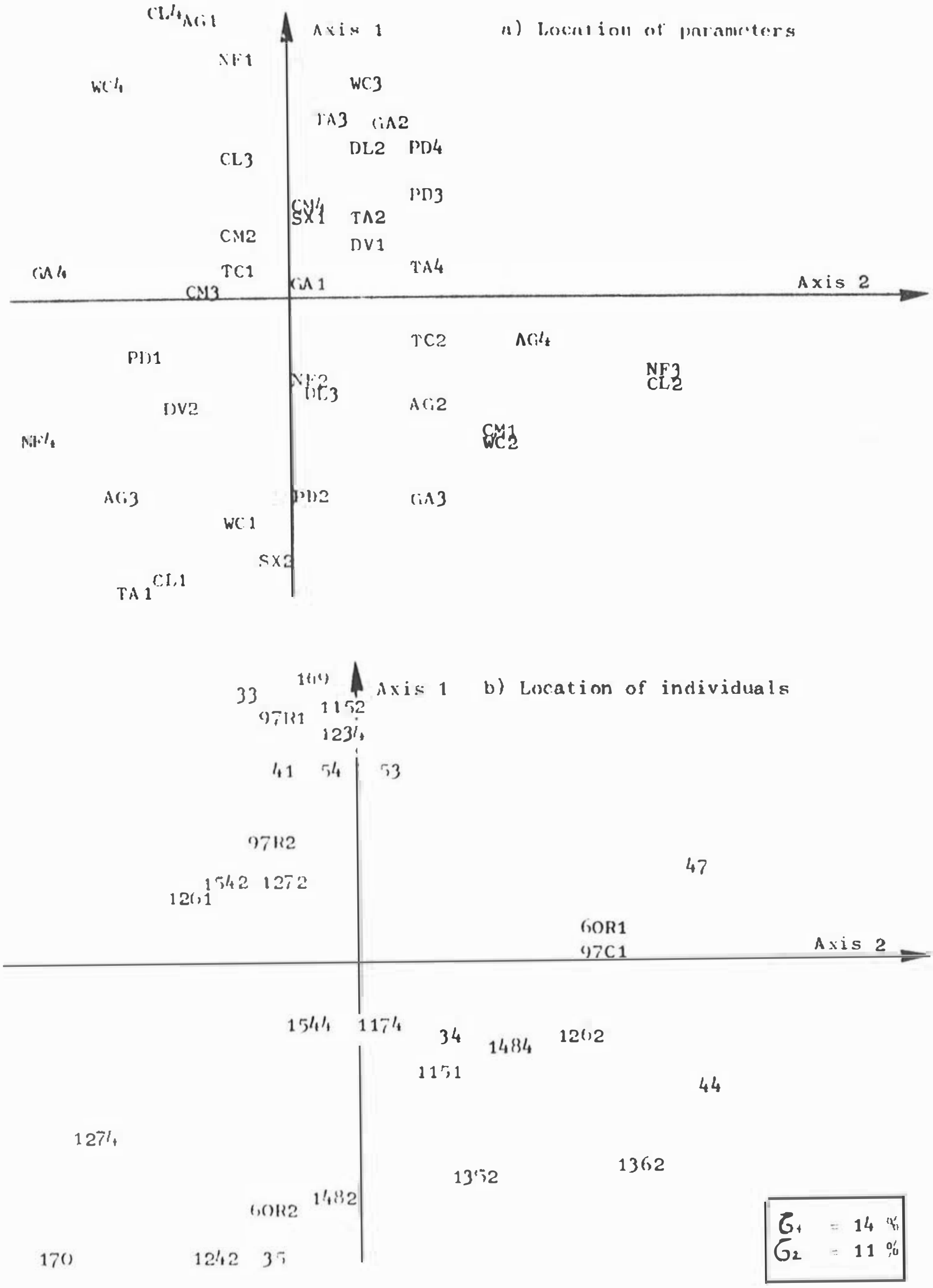


FIGURE 4 - LATERAL IMPACTS