CHANGES IN THE DYNAMIC BEHAVIOUR OF THE BABOON'S HEAD AND NECK SYSTEM SUBJECTED TO A FRONTAL DECELERATION (-Gx), RELATED TO THE ACTION OF CERVICAL MUSCLES

by

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INTRODUCTION

The use of restraint systems such as safety belts during a traffic accident, prevents the body, and so the head, from hitting the car structure. Therefore, it fairly reduces the risk of death or serious injury. (GARRET 1962, SYSTERMANS 1974). But, by belting up the thorax, it emphasizes the movements of the head relative to this latter. But, it's well known that head and neck injuries can occur without any head impact. The protection of the head neck link isn't only limited to the prevention of head impact, but consists in lessening the stress applied to the neck and in reducing the acceleration level undergone by the head. It seems rather difficult, in a near future to develop a specific head restraint system (except the headrest whose efficiency is limited to rearward impacts situations) because of its constraining aspect. Then, other solutions have to be faced : for instance, fit the performances of the restraint systems to the dynamic behaviour of the head-neck system and try to reduce the risk of injury by selecting better adapted postures or by making use of the energy absorbing function of muscular systems. With a view to such solutions, it's important to know precisely the dynamic behaviour of the head neck system when submitted to a strong deceleration.

The aim of this work was to make a study of this dynamic behaviour and, mainly, the problem of the muscular influence. The muscular stiffness is a parameter defining the dynamics as well as mass (or inertia) and widely varying from a passenger asleep to the driver who anticipates the shock and contracts his muscles. Muscles are known for their ability to absorb a part of the body kinetic energy during an impact. This has been pointed out by ARMSTRONG (1968) for the lower limbs. Considering the power of the neck musculature, its effect on the head neck system dynamic behaviour is not to be neglected. That's why a trial has been made to estimate the effects of this muscular stiffness through an experiment analysing the dynamics of the head and neck for three distinct physiological muscle states : hypotonic, normal, hypertonic.

To ease the analysis of the results, a schematic representation of the head-neck system has been used. Thus it will be possible to make a further use of these results to design an anthropomorphic dummy neck.

This research, in its first stage, has been limited to the study of frontal impact situations. But,non frontal impacts, well known to produce serious trauma, are not to be forgotten and will be studied in a further step.

METHODS

Subjects

The animal chosen for the tests is a cynomorph monkey : the baboon (Papio papio). On the whole, 7 adult baboons (6 males, 1 female) whose weight ranged from 10 to 24 kg, were used for the tests including the preliminary ones.

The baboon's shape is rather near the man's though the shoulders are closer and the thorax much narrower. This latter is continued upward by a strong neck,which suggests a powerfull cervical musculature. The head shows an important development of the facial part and mainly the maxillaries. As a consequence, the head center of gravity is shifted forward (fig 1).

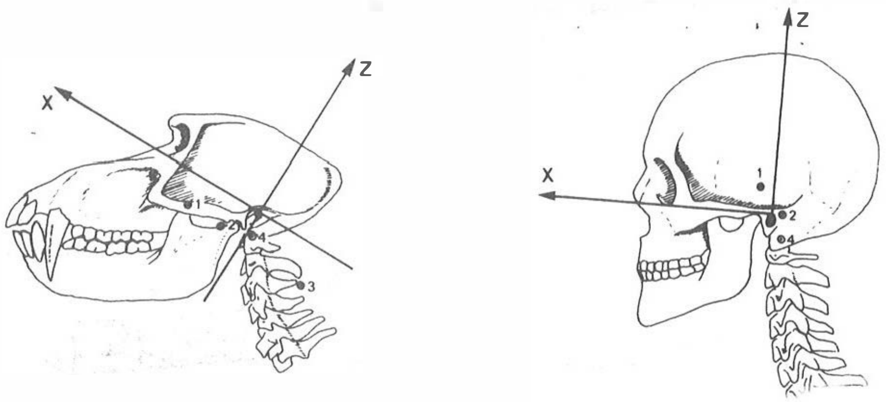


Fig 1 : Location of the head center of gravity (1) of the baboon (left) and man (right) with respect to the head-neck hinge point (4)

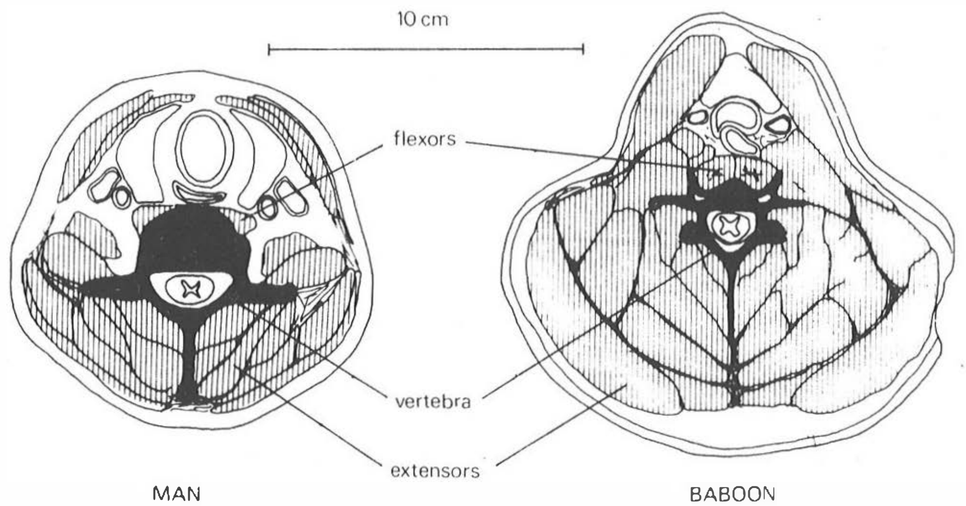
The cervical spine is composed of 7 vertebrae with much developped transverse and spinous processes. These vertebrae are moved by groups of muscles rather similar to the human ones, but much more powerfull, considering their cross sectional area (fig. 2).

Decelerator

It is composed of three chief elements : (fig 3)

. a rigid steel sled supporting the seat and the animal, and whose own weight is 420 kg.

. a catapult able to propell the sled up to 80 km/h. The energy necessary for the launching is first loaded in a flywheel, then transmitted to the sled by means of a clutch and a drum around which the pulling cable is wound.



ig 2 : Cross section of the neck at C6 level of the baboon (right) and man (left). The respective areas are 120 cm2 and 112 cm2.

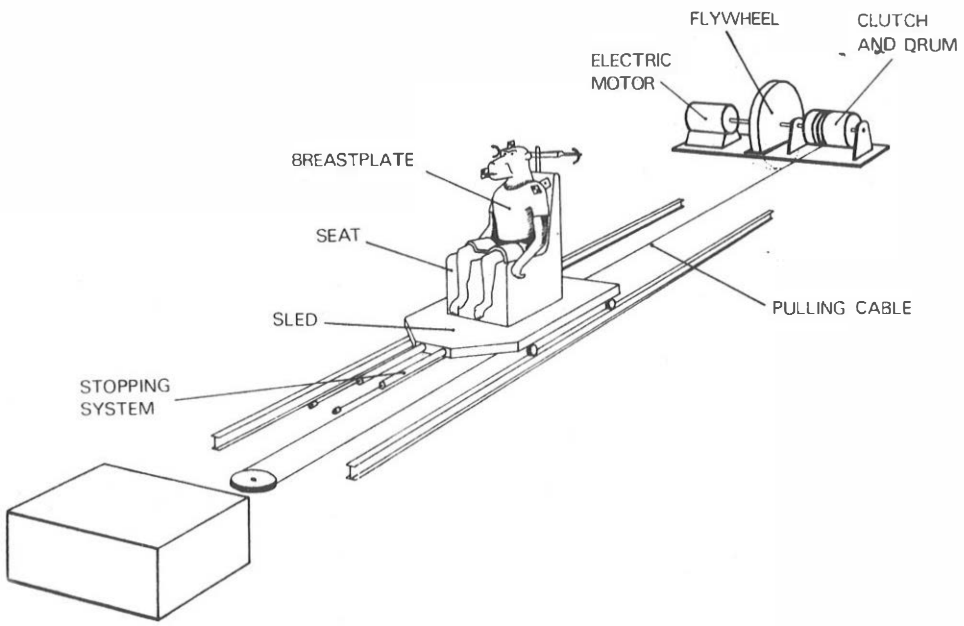


Fig 3 : Experimental set up for the tests

. a stopping system made of steel bulbs which force through polyurethane cylinders. The shape of the deceleration wave, determined by the longitudinal section of the cylinders and the bulbs diameter, is, here, a half sine wave. Its amplitude and duration in function of the launching speed are given in table 1.

Speed of launching (km/h)	Max sled deceleration (G)	Duration of deceleration (ms)
12	12	48
18	15	50
30	20	67
35	22,5	72
40	22,5	80

Table 1 (see text)

Animal retention

Its aim is to fit tightly the animal's body to the sled in order to enable only the head and neck movements. So, the thorax is restrained by a rigid polyester breastplate moulded on the animal's body. Other moulded parts fix the pelvis and the lower limbs. Moreover, to control the initial position of the head, an electro-mechanical device holds the head during the sled run and releases it a few milliseconds before the beginning of the shock.

Kinematic data collection

Preliminary tests had shown that the movements only occurred in the sagittal plane. The tests which didn't fit with this condition have been eliminated. So, the kinematic data of the head movements have been measured in two points of the sagittal plane of the head, mouth and vertex, with two complementary techniques.

. Accelerometry : Acceleration has been measured with ENDEVCO piezoresistive accelerometers (type 2264/150 - Range : ± 150 G ; sensitivity : 2,5 mV/G ; frequency range : DC to 800 Hz). In each point, two accelerometers set on a trihedral plate gave the X and the Z components of the acceleration in the sagittal plane. The plates were fixed to the head at the vertex point by a metallic supporting plate screwed on the frontal bone, and, at the mouth point, by a moulded mouthpiece.

. High speed cinematography : Each measuring point was materialized by a target stuck on the lateral face of the trihedral plate. The displacements of the targets were recorded with a HITACHI high speed camera (type 16 HM) at 2000 frames per second. Time was displayed on a chronoscope placed inside the camera field (fig 4). The shooting distance was great enough to neglect the parallax errors.

The films and acceleration curves were then analysed and the collected data punched on cards for further computer processing (IBM 1130).

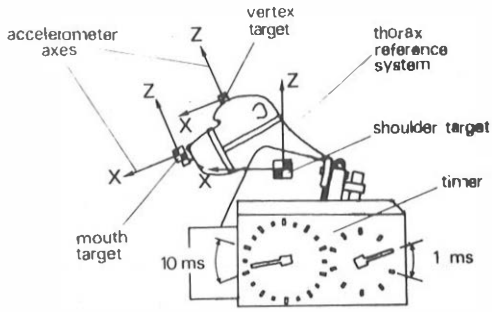


Fig 4 : Picture analysis references used for displacement data collection.

Muscular tonicity

- Hypertonicity was obtained just before the shock by electric stimulation of the neck muscles. Electric impulses of 20 volts high, 7 ms width were delivered at a frequency of 70 Hz through two needle electrodes inserted at the C4-C5 level. This stimulation determined a maximum tetanic contraction.

- For Hypotonicity, the animals were anesthetised by EPONTOL, a 5 % propanidide solution, providing a brief but deep narcosis just after the injection.

Geometric parameters measurement

The distances were measured by X ray. After the experimental series, one animal has been sacrified and the mass, the center of mass location and the mass moment of inertia have been measured on each separate body sequent (head, neck, trunk, limbs). These last data will be used later to modelize the head neck system.

RESULTS

On the whole, 95 tests have been conducted with different conditions of launching speed and muscular tonicity. The general characteristics of the results will be brought out through the analysis of three representative tests.

Displacement analysis

- Description of the trajectories

The analysis of the film pictures enable to plot the relative trajectories of the vertex and mouth targets in the sagittal plane with respect to the thorax figured by the shoulder target (fig 5). For each movement, a flexion phase followed by an extension one can be seen. The change of direction is sometimes marked by an impact of the lower maxillary on the breast plate. For the vertex trajectory, the flexion and extension curves coincide fairly well. On the contrary, for the mouth trajectory, the curves are different and delimit a loop whose area is much greater for the hypo curves.

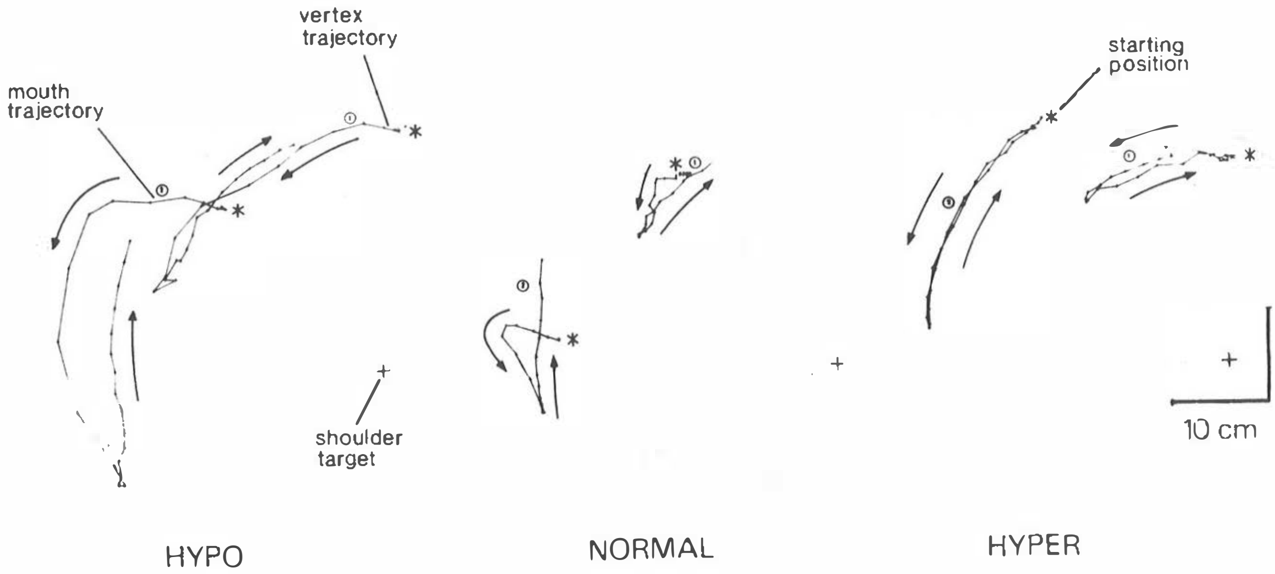


Fig 5 : Relative trajectories of vertex and mouth targets with respect to the shoulder one for three tests at a 30 km/h speed

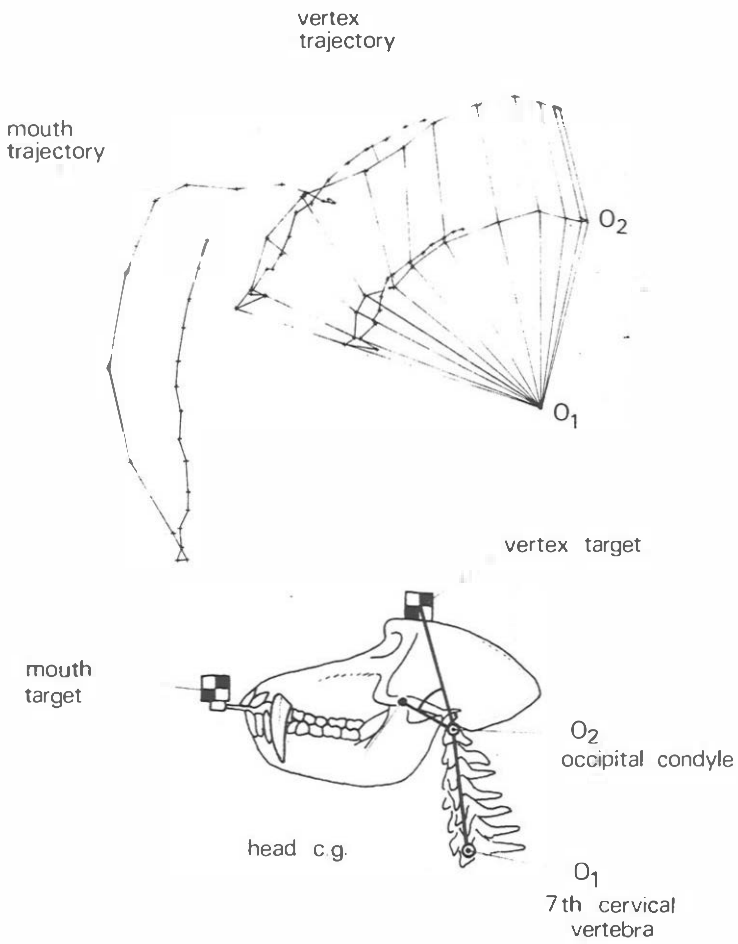
- Reconstruction of the head and neck movements

In order to quantify the influence of the muscular state it has been necessary to represent the movements in a simple way. In this aim, the head-neck system has been figured by a system with two axes of rotation. This system is the plainest one enabling to account for the translational movement described by many authors (MARTINEZ, 1966 ; TISSERAND, 1967 ; CLARKE, 1971 ; MERTZ, 1971 ; CLEMENS, 1971 ; among others), and respecting the fundamental rotational movement (fig 6). The head and neck are represented by two rigid links hinged together and with the thorax. The hinge points have been located at C7 level for O1 and C1 level for O2, according to the results of an X ray study of normal head movements and to the distribution of the instantaneous center of rotation (VERRIEST et Al, 1975). The position of the links with respect to the thorax is measured by two angles θ1 and θ2.

The curves of θ1, θ2 and θ = θ2 - θ1 —this latter representing the head movements relative to neck— versus time, for three tests are shown on fig 7. These tests, at 30 km/h speed, correspond to the three muscular states.

For θ1, position of the neck relative to the thorax, the maximum value is reached for the hypo state ; the minimum one corresponds to the hyper state. However it is to be noted that the starting position is more flexed for the normal state. The increase slope of θ1, that is the angular velocity, is nearly twice steeper for the hypo state than for the normal one. In other words, in this last case, the flexion movement of the neck seems to be restrained by the musculature action.

As for θ = θ2 - θ1, the head movement relative to the neck begins with an extension and goes on with a flexion. For the hyper state, at the beginning, the head is in full extension so that there can't be any extra extension. Only a slight flexion can be seen, which reveals the efficient locking of the head to the neck.



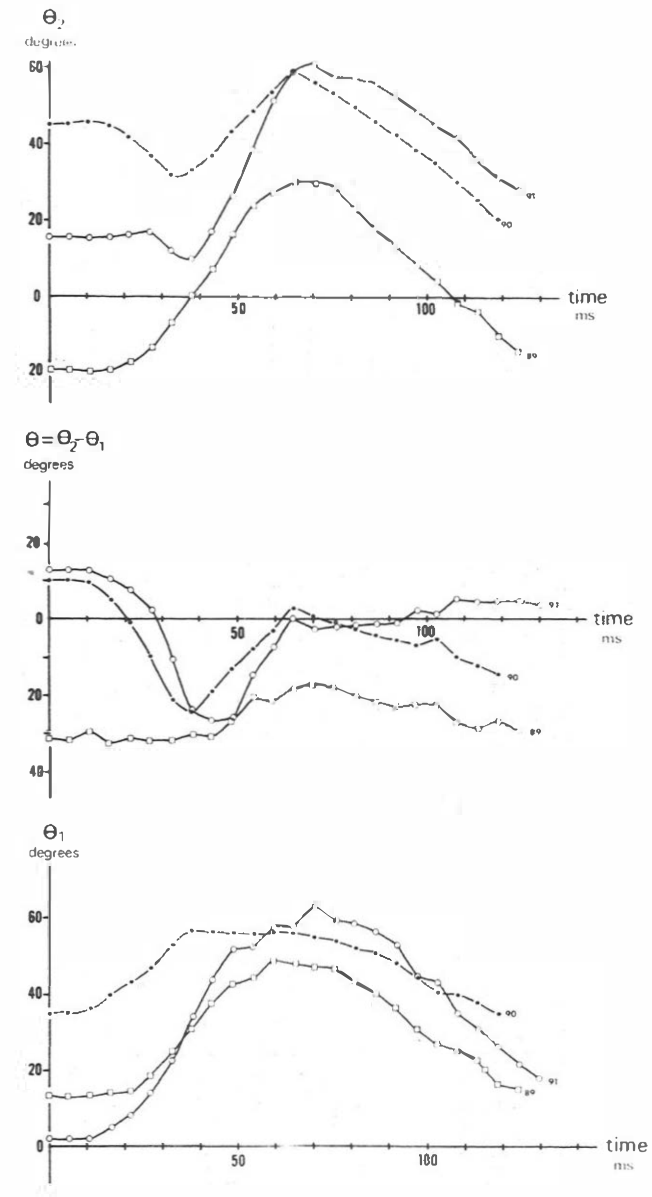


Fig 6 : Left : Schematic representation of the head neck system used for movement reconstruction (see text)

Fig 7 : Right : Curves of θ1, θ2 and θ = θ2-θ1 for three tests conducted at a 30 km/h speed (89 : hyper ; 90 : normal 91 : hypo)

It is to be remarked that no hyperflexion of the head on the neck ever occurs, even when there is no impact against the breastplate.

The head movement relative to the thorax θ2, out coming from θ and θ1, begins by a translation except for the hyper state. Then an extension of the head happens, followed by a flexion phase. This latter often ends by the maxillary impact against the breastplate, mainly for the hypo state and much rarely for the normal and the hyper. There also, the steeper slope, that is maximum velocity, is measured for the hypo state. Though the starting position varies with the state, it can be said that the whole head angular displacement is shorter for the normal state, intermediate for the hyper and greater for the hypo. In this last case, the head always ends its course by hitting the breastplate.

Acceleration

As for the linear acceleration components, the muscular state has an effect on the shape of these components, which can't be easily measured. The resultant nearly keeps the same maximum value, except when speed is low (12 or 15 km/h). On the contrary, for the head angular acceleration (fig 8) there is a marked decrease of the maximum value when the neck muscles are contracted. This decrease can reach 50 %.

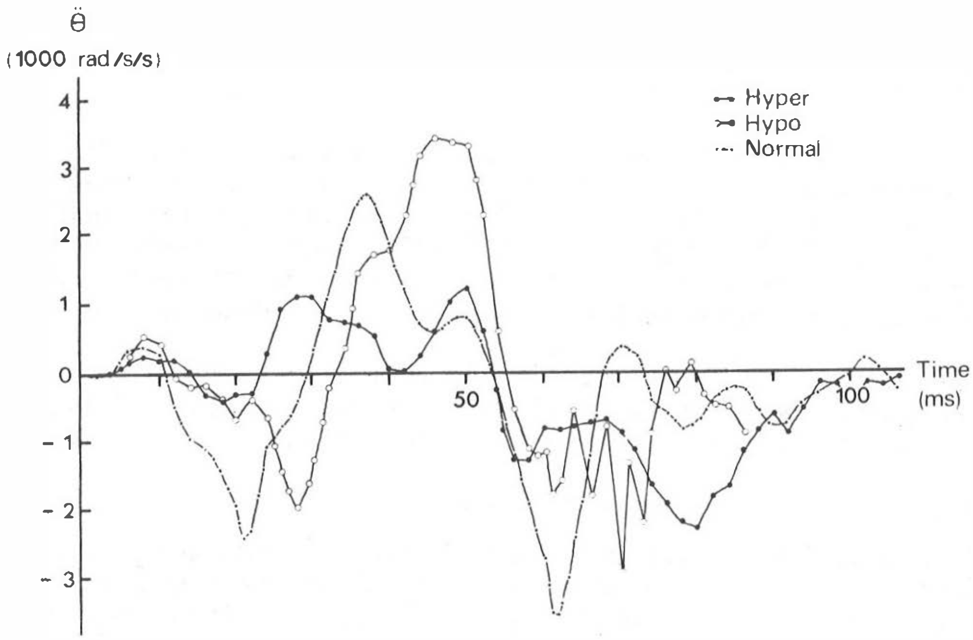


Fig 8 : Curves of θ2, head angular acceleration, for three tests conducted at 30 km/h.

DISCUSSION

The results obtained thanks to the schematic representation with two axes of rotation are not without any error and the trajectories of O2 have just to be observed to see that they are sometimes quite different from a circle arc ; however, the chosen type of representation doesn't seem questionable. Actually the errors pointed out mainly consist in a variation of the length O1O2. If such variations resulted either from a lengthening or a bending of the cervical spine, they would threaten its integrity. But, no spinal injuries have ever been recorded among the subjects ; this hypothesis must therefore be eliminated. In fact, most errors seem, on one side, to come from the relative mobility of the thorax which can move inside its breastplate, creating a movement of the basis of the cervical spine, that's to say O1,and, on the other side, from the vibrations of the mouth target which make the calculation of the trajectory and, thereby, the position of O2, wrong. This last problem has been solved for another experiment (see BIARD et Al, 1975) whereas the measure of the movements of O1 relative to the sled, has not yet been succeeded.

So the values of θ1, θ2 and θ are roughly estimated, but, this is not to be minded as it is here, a comparative study. In spite of these restrictions the following remarkable events can be pointed out.

- the head movements in the sagittal plane with respect to the thorax consist in a translation followed by a rotation.
- among the tested situations, the normal animal seems to be the most able to compensate the effects of the deceleration
- the electric stimulation of the neck muscles, as it has been done on the hyper animal, mainly changes the head behaviour but much less the neck one.
- in the observed movements, the head hyperflexion with respect to the neck never appears, even when there is no impact on the breastplate.
- on the contrary, the movements always begin with a head extension, which is nearly always maximum except for the hyper tests.

Except the decomposition into translation and rotation, the results are quite different from those obtained by other authors as well with volunteers as with cadavers or animals (MERTZ and PATRICK, 1971 ; CLARKE and Al, 1972 ; EWING and THOMAS, 1973 ; HENDLER et Al, 1974). These differences seem to be in relation with the experimental conditions of the present tests and also with the muscular action. Three factors appear to have a determining influence :

- the use of a rigid breastplate as restraint system
- the particular characteristics of the experimental subject
- the way of bringing the muscles into action

. Use of a rigid restraint system

In opposition to webbing type restraint systems which can absorb a part of the kinetic energy, the rigid breastplate almost instantaneously transmits the sled deceleration in its whole to the thorax. Resulting from this, the acceleration sustained by the head is much higher and sooner. If the present results are compared with those obtained by CLARKE with a strap harness, an increase of nearly 50 % of the maximum value of the head acceleration can be seen in the case of a rigid restraint.

Another consequence of the use of a rigid breastplate is the limitation of the flexion of the head which can't reach the sternum.

. Experimental subject

The geometric characteristics of the baboon's head and, mainly, the center of gravity location, can explain the existence of the head extension which never appears in the tests conducted with human beings. In fact, the head inertia force and the resistive force resultant acting respectively at the head center of gravity and at the head-neck hinge, apply a torque to the head, whose amplitude and direction depend on the position of the head center of gravity with respect to the occipital condyle. So, considering the position of the center of gravity of the baboon's head and the man's one, for forces of same amplitude and direction, the torque can be different : flexion torque for man and extension one for the baboon. (fig 9). This torque can be different also for the baboon wether the initial position is flexed or extended. This problem has been examined in detail elsewhere (see BIARD et Al, 1975).

On the other hand, given the light mowing masses and the short body links of the baboon, the movements are faster than for man. For the baboon, the head acceleration peak occurs about 40 ms after the shock beginning whereas it appears much later for man (volunteer or cadaver).

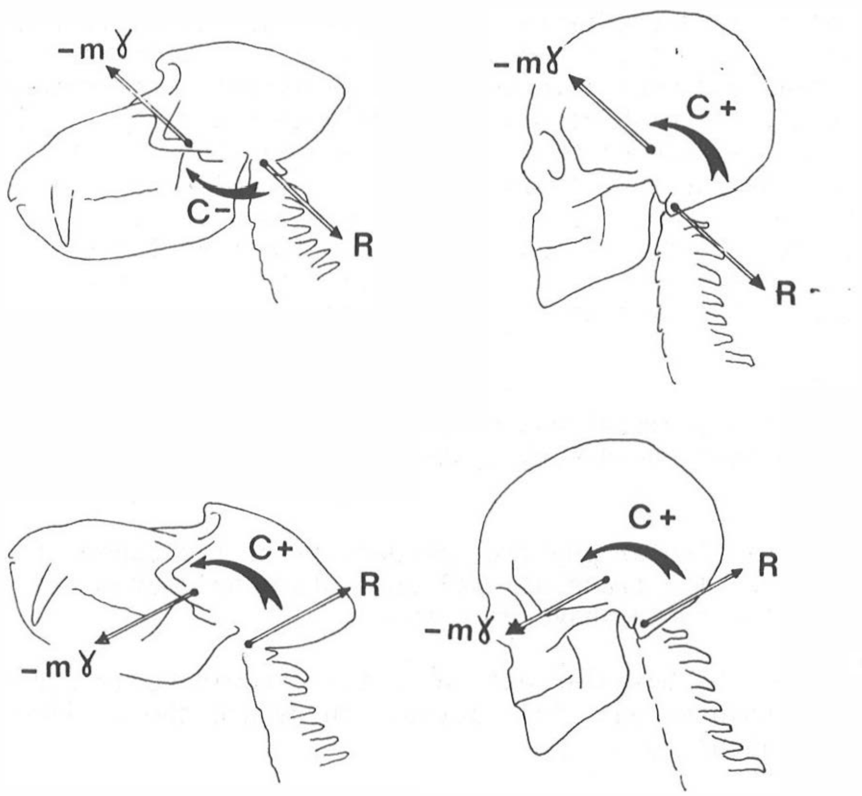


Fig 9 : Torque (C) applied to the head, resulting from the action of the head inertia force (-m) and of the resistive force resultant (R). Upper part : extension torque for baboon and flexion one for man (few milliseconds after the start of the shock ; lower part : flexion torque for both (about 40 ms after the start).

. Muscular action

When there is no muscular contraction, the resistance opposed to the motion by the ligaments and muscles is weak until the maximum neck flexion is reached. Almost all the head kinetic energy is dissipated by the neck components which act as thrusts. That's what happens during hypo tests, where the deceleration peak is very high and late.

On the contrary, when muscles are contracted, the restraining of the head occurs as soon as the movement starts, and this produces a much lower and longer deceleration. In the case of hyper tests, only the neck muscles which are mainly responsible for the head bearing, are stimulated. The head is nearly locked on the neck but the restraining of the neck is much less effective.

For the normal tests, there is not such a locking as for hyper tests. Nevertheless, there is almost never any impact of the head against the breastplaste, except for high speed tests (40 km/h). In other words, head and neck are restrained in a very efficient way. This leads to admit that the baboon is able to develop a strong and coordinated muscular action which is sufficient to limit the head and neck movements under a strong deceleration. Because of this contraction, and with respect to a relaxed state, the maximum angular head acceleration can be reduced by 40 %. This spontaneous voluntary activity - given the speed of the movements, it can't be a reflex one - is likely concerning a great number of muscles apart from neck ones, mainly the back and shoulder ones, because it appears much more effective than the simple electric stimulation of neck muscles. This is relevant to a preparing of the animal which anticipates the beginning of the shock.

CONCLUSION

The present experiment has shown the main characteristics of the dynamic response of a baboon's head-neck system submitted to a frontal deceleration (-Gx).

Given the particular physical properties of the baboon this behaviour is close to man's one. The translational and rotational movements of the head, with respect to the thorax have been found.

The part of the muscular action in the dynamic behaviour of the head-neck system has been pointed out. This action can reduce the maximum head angular acceleration by about 40 %.

The use of a simple representation with two axes of rotation enables to describe rather well the movements of the head-neck system thanks to six angular variables (angular displacement, velocity and acceleration for each of both axes).

The modelization started owing to this two axes system should enable the expression of muscular influence in terms of stiffness and viscosity variation. Then a contribution to the improvement of anthropomorphic dummies can be expected.

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