TRIDIMENSIONAL CINEMATOGRAPHIC ANALYSIS OF THE HEAD KINEMATICS UNDER LATERAL IMPACT CONDITIONS

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Introduction

The frequency of frontal crashes in road accidents has led to a large number of studies devoted to the body response to this type of impact. Actually a lot of crashes are oblique and it seems interesting to investigate the consequences of an angulation on the dynamic behaviour. It can be assumed that the head-neck system response is particularly affected by such an angulation. Therefore an experiment has been conducted whose aim was to define the characteristics of the head-neck system response to impacts of increasing incidence angle (from frontal to lateral). This experiment has been performed on a baboon (Papio-papio).

Methods

Experimental set up (see fig. 1)

The impact has been produced on a decelerator composed among others of a sled propelled by an inertial reel launching system and abruptly decelerated by steel bulbs forcing through polyurethane tubes. The sled supports a seat which can be revolved in the horizontal plane. The subject (a baboon weighing 28 kg) is firmly fastened to the seat by a rigid restraint system so that only the head and the neck can move freely. The head position and orientation can be controlled by means of a mechanical device which releases it only a few milliseconds before the impact occurs.

The animal has been fitted with metallic plates screwed on the skull eventually enabling to fix an additional mass on the head in order to artificially displace its center of gravity and providing a rigid link between the head and the targets and transducers assembly which will be used to determine the head kinematics.

Data collection and processing

The head movements following the impact were recorded by two high speed cameras at 2000 frames/second for the first one (HITACHI 16 HM) and at 500 frames/second for the second one (PHOTO SONIC 1B). The shooting axes were perpendicular to each other and perpendicular to the displacement direction.

Data from film analysis were processed through a program which enables, all along the impact duration and from the target trajectories, to determine the head orientation in three dimensions and to compute the trajectory

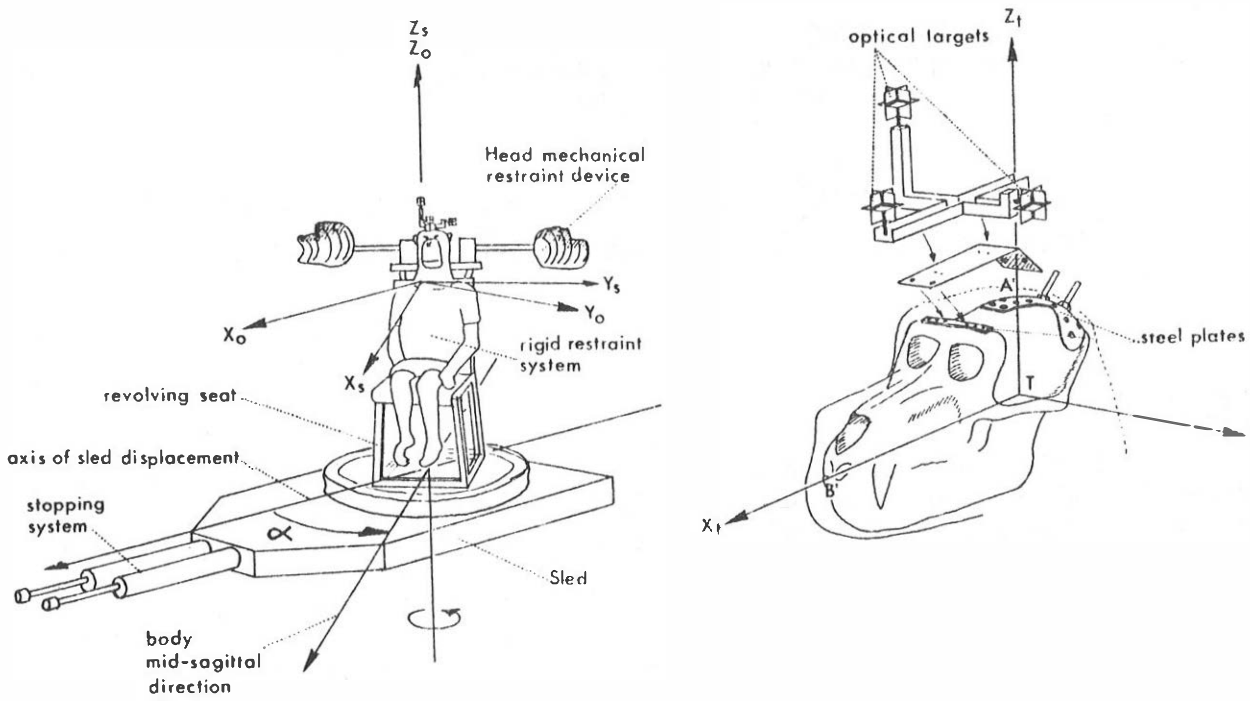


Fig. 1 Experimental set-up and coordinate systems
- left : subject installed on the sled
- right: position of optical targets

of three particular points of the head.

The coordinate systems used to give the results are :
- the R_O System whose origin S is a point of the seat and three axes are SX_O (parallel to the sled displacement direction), SZo (vertical) and SY_O (transversal) ;
- the R_S System whose SZs axis is identical to SZo. The angle α between SX_S, SY_S and SX_O, SY_O respectively is the impact angle. The SZ_SX_S plane always remains parallel to the plane of symetry of the seat when this latter rotates.
- the R_T System related to the head of the subject. The origin T lies at the occipital condyle level. TX_T axis is in the mid-sagittal plane and passes by the extremity of the central maxilla incisors. The TZ_T axis is also in the mid-sagittal plane and is perpendicular to TX_T. TY_T is perpendicular to the mid-sagittal plane.

The trajectories of T, A' and B' are represented by their projection on the reference planes of R_S and R_O systems. The head orientation is given by three angles Ψ_S, Θ_S and ϕ_S corresponding to the three elementary rotation movements depicted by figure 2. A set of curves refering to one test is shown on figure 3. (On this figure, the arrow indicates the impact direction and the point K locates the 7th vertical vertebra at rest).

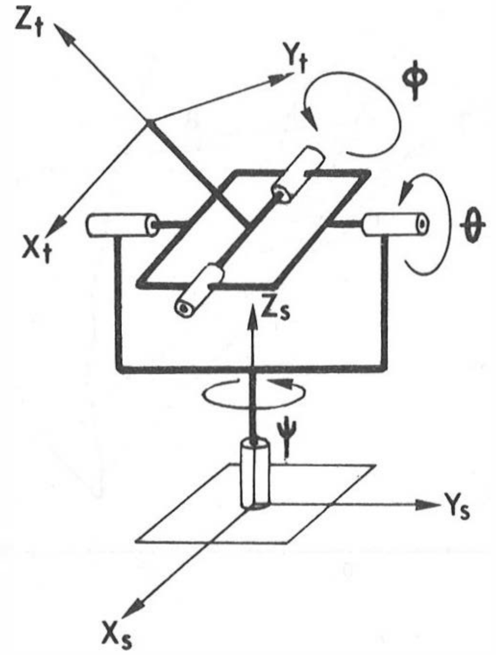


Fig. 2 Mechanical analog of head orientation angles

In addition to these cinematographic data, head acceleration measurements were performed (3 triaxial transducers) ; however they won't be exposed here.

Tests procedure

25 tests have been conducted with one subject, without any additional mass and with 5 impact angle values (0, 30, 45, 60 and 90°) from frontal to lateral. For all these tests, just before the impact, the head was held in an upright position so that ϕ and ψ were close to zero. On the contrary, a certain amount of initial flexion-extension was permitted. The impact velocity was 30 km/h (± 1). The sled deceleration shape was trapezoïdal, the duration was 70 ms and the amplitude was about 20 Gs.

Results

In order to give the results in a synthetic way, and as they were quite reproducible, an average has been established from them for each impact angle condition. If we considerer the head as a solid, having its orientation and the displacement of one of its points is enough to know the entire movement. So, only the trajectory of the condyle (T) which is necessary to determine the neck movements, and the curves of ψ, θ and ϕ will be examined. It can be seen on the figure 4-a, (XY projection R_s, system) that the condyle trajectory is roughly composed of a forward phase in which T moves towards the front of the sled and a backward phase where T moves in the opposite direction. The forward course draws a straight line parallel to the sled displacement axis from pointK. As for the backward course, except for the condition $\alpha = o$ where the two courses can be perfectly superposed, it curves and makes a loop. The direction and width of the loop vary as the impact angle. It seems that a loop inversion occurs for α value close to 60°.

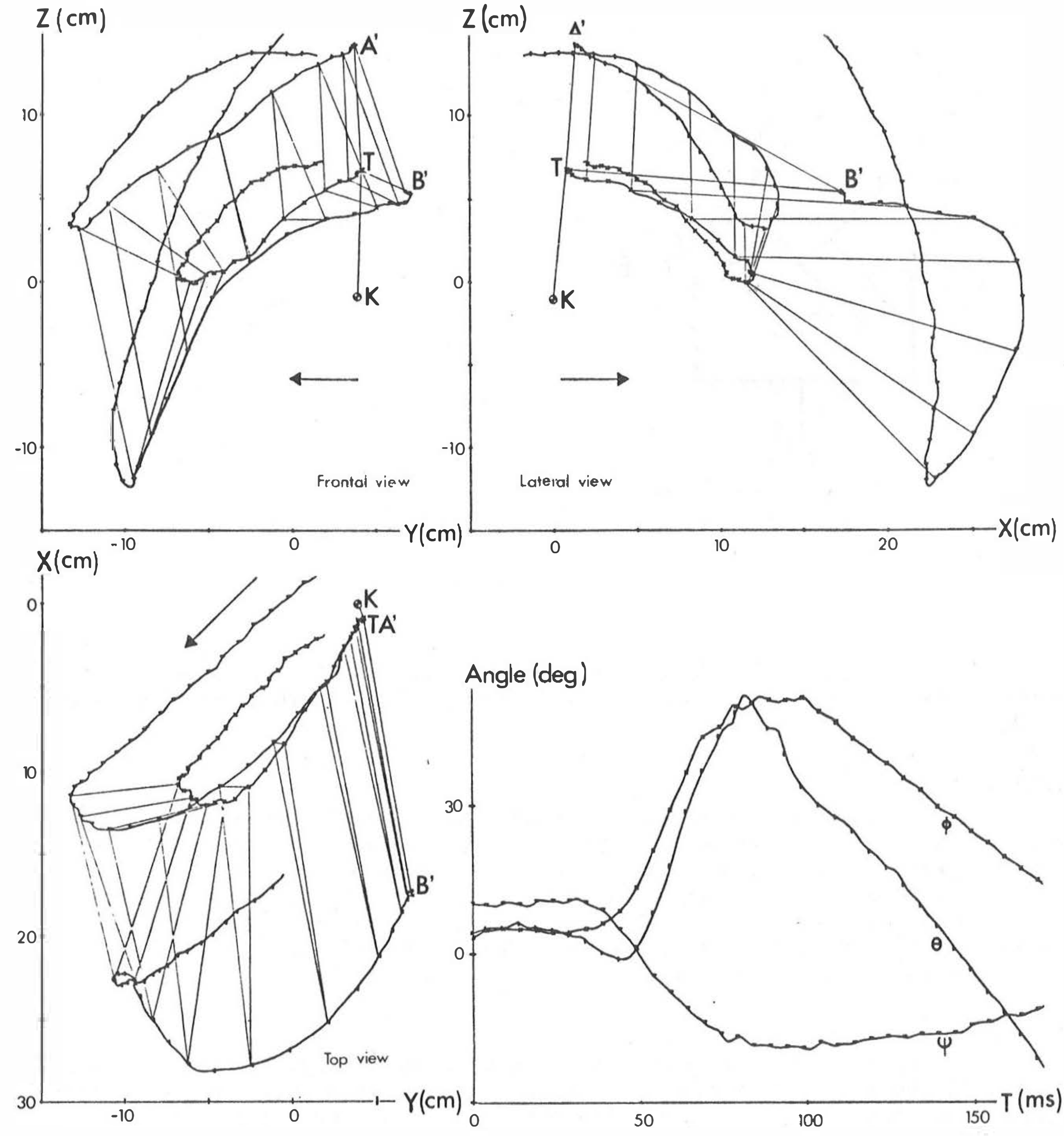
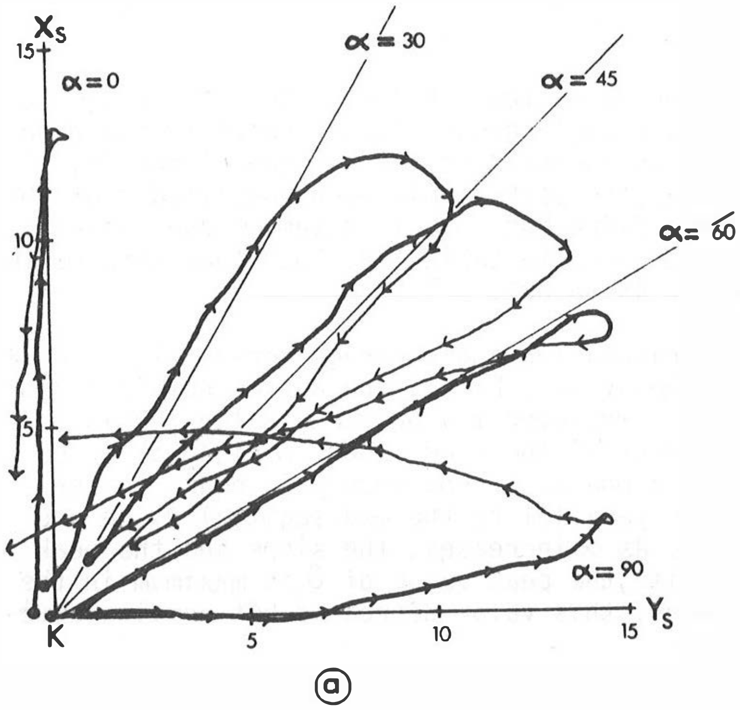


Fig. 3

Average results from cinematographic data processing. Projected trajectories of T, A', B' on R_S reference planes and orientation angle curves. Arrows indicate sled displacement direction.



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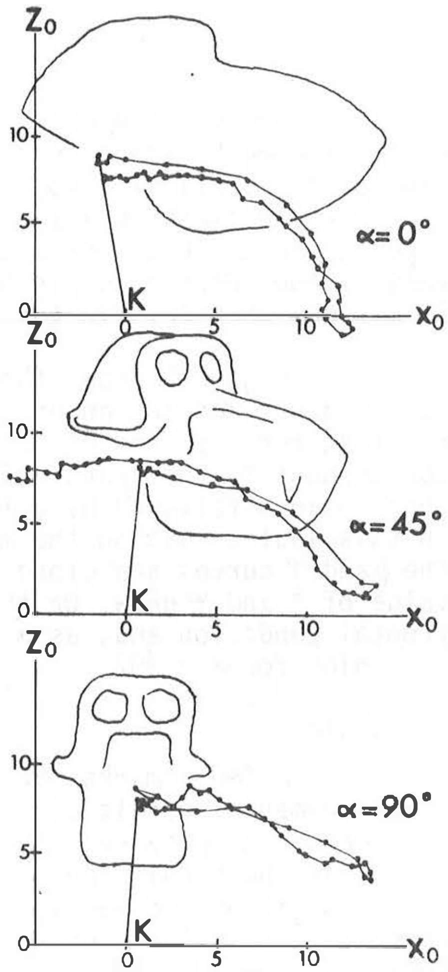

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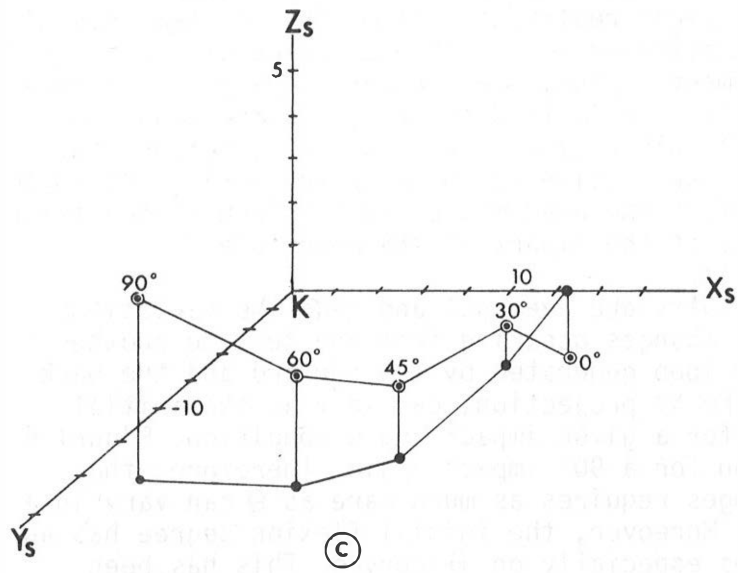

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α (deg)	X (cm)	Y (cm)	Z (cm)	KT (cm)
0	12.7	0	1.5	12.8
30	11.6	9.7	0.9	15.1
45	10	13.1	1.7	16.6
60	7.3	14.6	2.6	15.5
90	2.1	14.1	4.1	14.9

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Fig. 4 (all scales in cm)

a) XY projection in R_S system of condyle (T) trajectories for various impact angles. Arrows indicate motion direction. Thick lines : forward course ; thin lines : backward course.
b) ZX projection in R_O system of condyle trajectories for three impact angles.
c) Maximum condyle stroke in the three directions of R_S system for 5 impact angles. Note that Z scale is twice X and Y ones.
d) Coordinates in R_S system of maximum forward condyle position shown on part c and corresponding length of KT.

On the ZX projection in the R_0 system (see fig. 4-b) the trajectories get more horizontal as the impact angle grows. This results from a reduction of the vertical stroke (Z) and an increase of the horizontal one (X). Figure 4-c depicts in a synthetic way the peak displacement amplitudes of the condyle in three dimensions for the different impact angles. These values as well as the related length of KT are given in table 4-d. Note that this length is maximum when α is in the range of 45 to 60°.

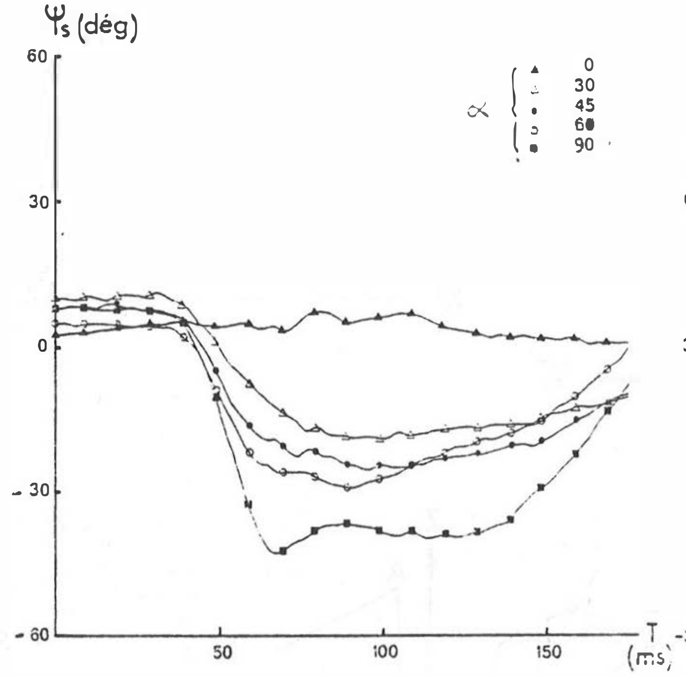
Figure 5 shows the head orientation angle curves versus time. These curves don't reflect an unexpected behaviour. First, the angles remain roughly constant for a period of about 40 ms, whatever may be the α value ; this corresponds to the translation movement of the head. Then, a high rate growing phase occurs followed by a lower rate phase, except when α is equal to zero. In this last condition the motion is parallel to the mid-sagittal plane and the ϕ and Ψ curves are close to zero. As α increases, the slope and the peak value of ϕ and Ψ grow. On the opposite, the peak value of θ is maximum in the frontal condition and, as α increases, this value decreases but remains somewhat high for α = 90°.

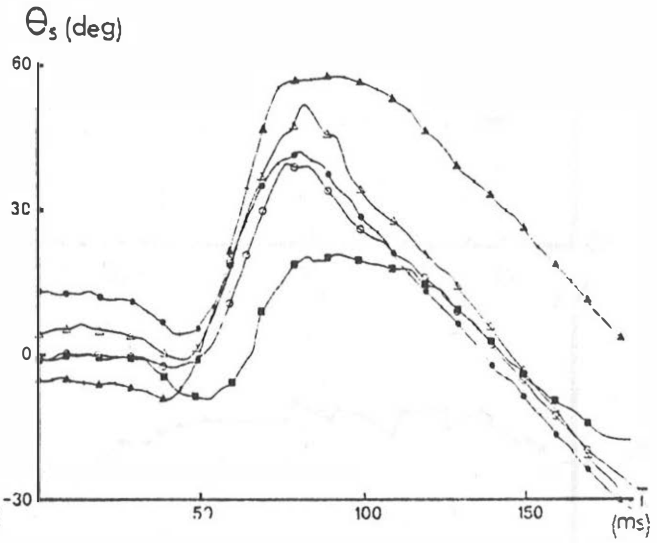
Discussion

A few remarks can be made about these results. First, they refer to experimental conditions with a rigid restraint system. This system has been chosen to provide a good immobilizing of the thorax. But a static X-ray study has shown that the displacement of the upper thoracic spine inside the restraint is not neglectible at all if efforts are applied to the head. So, point K represents C_7 only at rest. Since C7 motion is unknown, neither the cervical spine length nor the neck angulation can be computed during the impact. Moreover, this rigid restraint limits the head motion in the frontal condition or when θ is equal to 30°, because of the impact of the mandibula.

In fact, the present results are averages and thus the variations related to the initial condition changes occuring from one test to another don't come out. For instance, the loop generated by the forward and the backward courses of the condyle, on the XY projection, can vary as the initial degree of head and neck flexion, for a given impact angle condition. Figure 6 shows an example of this variation for a 90° impact angle. Therefore, the interpretation of trajectory changes requires as much care as θ can vary in a wide range (- 13 to 20 degrees). Moreover, the initial flexion degree has an effect on other movement variables especially on θ curves. This has been pointed out for the frontal impact in a previous work (BIARD et al., 1975) and this effect can be seen also for other impact angle values.

At last, the results have shown that as soon as the impact incidence is no more frontal, a head rotation in ϕ , but also in Ψ , occurs. The peak values of both angles grow as α and they correlate linearly (see fig. 7). It can be assumed that the extent of Ψ is due to the morphological characteristics of the baboon's head. The eccentric C.G. position resulting from the low weight ratio between skull and face, generates a torque relative to TZ_T axis. In fact, an experiment whose results will be brought up later, has pointed out that a backward shift of the head C.G. by means of an additional mass, reduces the





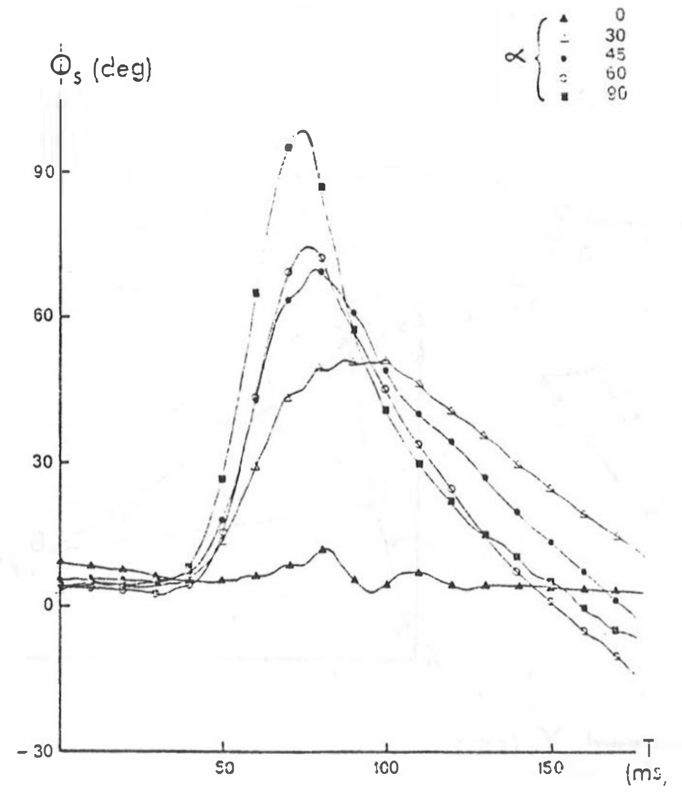


Fig. 5

Curves of Ψ_s (a), θ_s (b) and ϕ_s (c) versus time for 5 impact angle tests.

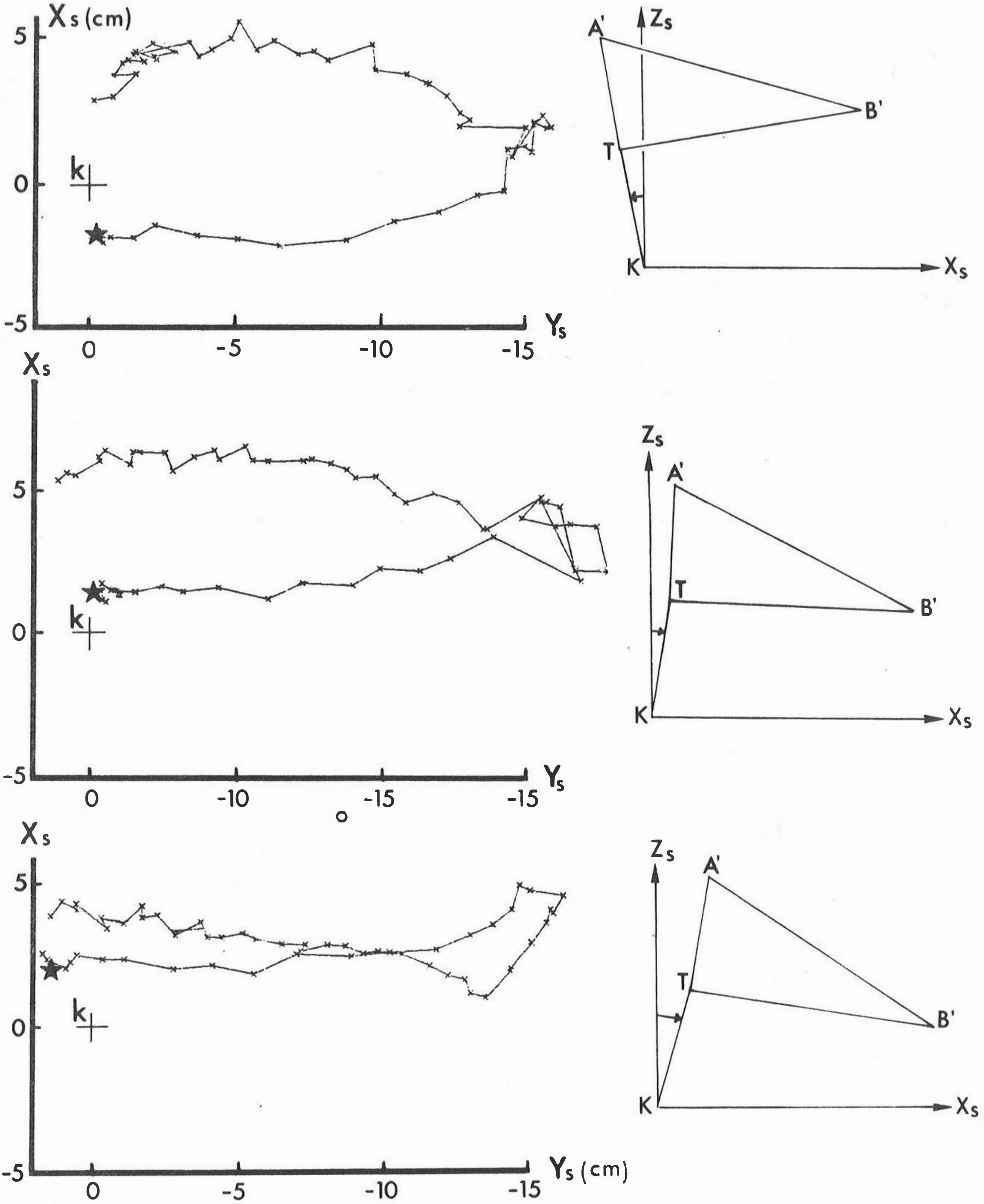


Fig. 6

Effect of initial head neck flexion degree (figured on right side) on condyle trajectory (left side) for 90° tests. Star indicates condyle initial position.

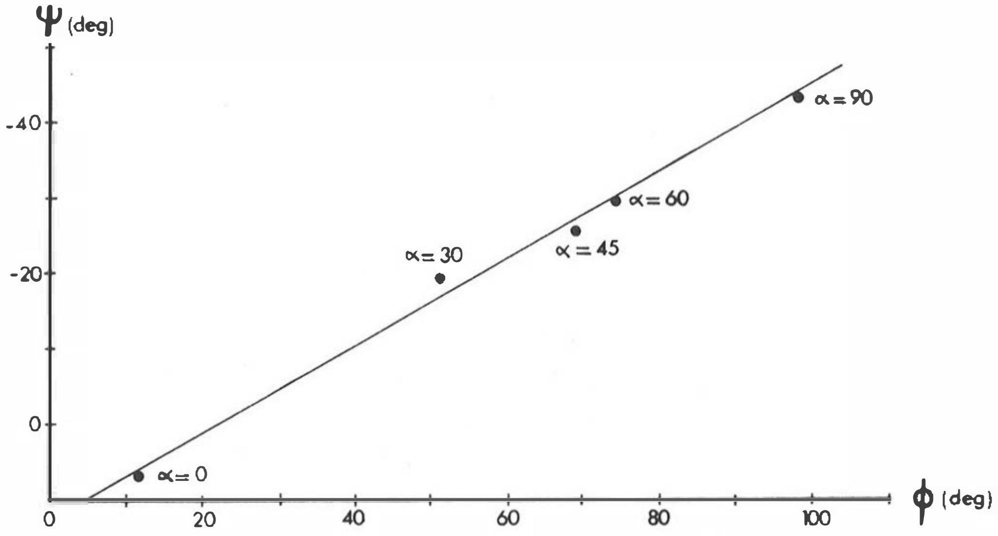


Fig. 7

Relationship between mean values of Ψ max and Φ max for 5 impact angles.

amplitude of Ψ. In the same time, there is an increase of Φ. These two combined effects result in a noticeable decrease of the Ψ/Φ relationship slope. This clearly exhibits the effect of such morphometric parameters on the dynamic behaviour and reminds it is important to take it into account for any tentative comparison with human behaviour.

Conclusion

The results from the cinematographic analysis have shown some of the characteristic features of the head-neck system response in various impact angle conditions. This enables a first step understanding of this system dynamic behaviour. At this time, the results only concern head displacements and, in order to get an extensive knowledge of the dynamic behaviour, going on with the study requires, one one hand, the processing of the accelerometric data and, on the other hand, an investigation to estimate the motion of C_7 under dynamic conditions.

Reference

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