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Posture and muscular behaviour in emergency braking: An experimental approach

Michel Behr[a,*], Georges Poumarat[b,2], Thierry Serre[a,1], Pierre-Jean Arnoux[a,1], Lionel Thollon[a,1], Christian Brunet[a,1]

[a] Laboratoire de Biomécanique Appliquée, UMRT24 INRETS/University of Mediterranée, Bld Pierre Dramard, 13916 Marseille, France
[b] Laboratoire d'Anatomie, ERIM EA3295, Université Blaise Pascal 28, Place Henri Dunant, 63000 Clermont-Ferrand, France

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ABSTRACT

In the field of numerical crash simulations in road safety research, there is a need to accurately define the initial conditions of a frontal impact for the car occupant. In particular, human models used to simulate such impacts barely take into account muscular contracting effects. This study aims to quantify drivers' behaviour in terms of posture and muscular activity just before a frontal impact.

Experiments on volunteers were performed in order to define these conditions, both on a driving simulator and on a real moving car. Brake pedal loads, lower limbs kinematics and muscle activation were recorded.

Coupling instantaneous data from both experimental protocols (simulator versus Real car), a standard emergency braking configuration could be defined as (1) joint flexion angles of 96°, 56° and 13° for the right hip, knee and ankle respectively; (2) a maximum brake pedal load of 780 N; (3) a muscular activation of 55% for the anterior thigh, 26% for the posterior thigh, 18% for the anterior leg and 43% for the posterior leg.

The first application of this research is the implementation of muscle tone in human models designed to evaluate new safety systems.

1. Introduction

In dynamic impact situations and in the field of road safety research in particular, it is widely admitted that muscle tissue contraction can alter bone stress to potential injury inducing levels (Duda et al., 1998; Ono and Kanno, 1996; Tencer et al., 2002). As skeletal muscle is the most abundant tissue in the human body, and as it induces force generation and motion, one could expect some influence of the muscular contraction level in terms of kinematics, stress distribution, or even energy dissipation. However, human models commonly used to validate car safety systems (dummies, cadavers or numerical models) do not or barely take into account the property of active muscles to generate a force: in the best of cases, either artificial tensions or friction torques are applied on particular joints, such as knees, or muscle action lines are set to model the muscle behaviour (Arnoux et al., 2005; Hoy et al., 1990; Wittek et al., 2000). A particular emphasis is now put on how to model specific physiological aspects of muscle tissue behaviour, such as protective reflex reactions or fatigue, as discussed in a previous paper (Behr et al., 2006).

As it seems today that the need to implement the muscular contraction factor in human models is widely accepted, another issue is to accurately describe this muscular behaviour that should be simulated by the models.

The use of volunteers to characterize car occupant's behaviour was done in several previous studies. Up to the eighties, sled tests were performed on volunteers subjected to sudden sled accelerations/decelerations, with sometimes even footwell intrusion (Armstrong et al., 1970; Begeman et al., 1980; Gordon et al., 1977; Hendler et al., 1974). The main results of these studies are:

- The brake pedal loading showed a great variability, from .2 to 2.3 kN;
- Comparison of responses for braced and relaxed volunteers showed significant differences;
- The difference in restraint force between tensed and relaxed states is relatively constant so that at high accelerations the influence of muscle tone on occupant dynamics diminishes (Begeman et al., 1980).

More recently, the behaviour of volunteers in driving situations has been studied: (1) driving posture (McFadden et al., 2000; Reed

* Corresponding author. Tel.: +33 04 91 65 80 14; fax: +33 04 91 65 80 19.
E-mail address: michel.behr@inrets.fr (M. Behr).
[1] Tel.: +33 04 91 65 80 14; fax: +33 04 91 65 80 19.
[2] Tel : +33 0 4 73 17 81 96; fax: +33 0 4 73 26 99 90.

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et al., 2000; Reed et al., 2002); (2) emergency braking behaviour (Manning et al., 1997; Owen et al., 1998; Palmertz et al., 1998). Among the main results, we noted:

- The mean brake pedal loading was approximately 700 kN, i.e. lower than for sled tests;
- The right foot was set to 15° of plantar flexion (mean).

Whereas the brake pedal load is well documented in the cited studies, little information was found on muscle activation. In particular, the identification of muscles implicated in the joint torques generation, and the level at which these muscles are implicated, still need to be discovered. Significant differences of response (kinematics, applied loads and muscular activity) were also found according to the experimental apparatus (sled versus simulator, simulator versus real driving situations (Reymond et al., 2001). And these differences might not only be attributed to inertial effects (the simulator being rather static as compared to the sled that can induce strong inertial effects) but also to the braking stimulus that is fundamentally different in the two cases. On one hand, the driving simulator is an optimal solution concerning visual aspects and car insight environment realism. The volunteers should have more realistic driving sensations than those sat on a sled. On the other hand, sled tests offer realistic dynamic conditions.

It thus seems particularly difficult to reproduce the feeling of danger experienced by a driver launched at high speed and surprised by an obstacle he could not avoid. And yet this feeling of danger could have an appreciable influence on his behaviour and in particular on the brake pedal loadings. Consequently, it appears that in order to simulate drivers behaviour prior to an impact, realistic postures and corresponding muscular activations are required.

The objective of this study is to define a standard initial condition for the frontal impact of a driver (i.e. emergency braking condition) in terms of brake pedal loading as well as driver's position and muscular activation, using volunteers. It was decided to perform experiments with volunteers driving a real car (on a test track) and suddenly faced with an obstacle forcing them to brake suddenly. In parallel, driving and braking postures were recorded on a static driving simulator, as the motion-capture system could not be used with a moving car.

2. Methods

2.1. Simulator tests

Experiments on a static driving simulator were performed: 34 healthy volunteers (24 men and 10 women) were asked to sit in the driving simulator and brake suddenly as if in an emergency situation, in response to a visual signal in front of them. The volunteer population was chosen as heterogeneous as possible, so as not to support any particular arbitrary criteria (mean age 36 (s = 16) where s is standard deviation, mean weight 75 (s = 7) kg and mean height 174 (s = 7) cm). They all wore flat sole shoes.

The car cabin was extracted from a Renault 19, cut at the back 10 cm behind the B-pillar, on the right lateral side along the central tunnel, and at the front 10 cm ahead of the A-pillar. The front door, roof and engine were also removed, in order to make every corner of the cabin visible from outside, including the pedals area. The hydraulic braking system was kept, from the brake pedal to the four pistons, in order to ensure sensory feedback and realism of the braking maneuver for volunteers. Instrumentation of the simulator can be summarized by (1) a force transducer on the brake pedal, made of strain gauges previously calibrated in the loading direction

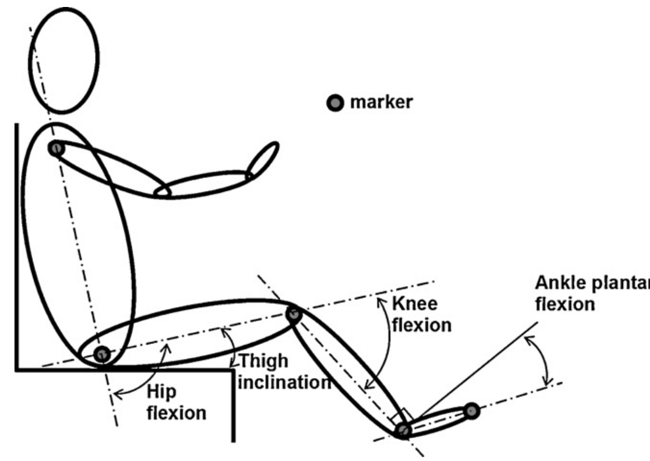

Fig. 1. Marker locations and computed angles definition.

with a hydraulic press; (2) a contact sensor on the accelerator. The visual signal was made of brakelights located approximately 3 m ahead of the volunteer.

The car model itself was surrounded by a six-cameras passive-stereovision motion-capture system (Biogesta Ltd., Denain, France). This system enables us to determine the trajectories of anatomical points of interest during the braking experiment, that are materialized by reflective retro markers (Scotch lite®) directly stuck on the skin. Several markers were located on the car model and on the laboratory floor, in order to keep one constant reference system. The markers on the volunteers were located on the right side of the body at 5 different anatomical points (Fig. 1): distal foot (distal end of big toe), tibial malleola (ankle), lateral femoral condyle (knee), greater trochanter (hip), and acromion (shoulder). The six cameras were placed around the simulator in such a way that every marker could be seen by at least two of these cameras. The sampling frequency of this motion-capture system is 50 Hz.

Prior to each braking experiment, the new volunteer is first informed of the protocol. He also fills in a questionnaire on his driving habits and physical condition. The reflective markers are stuck on the volunteer, who is then asked to sit in the cockpit, putting the right foot on the accelerator and waiting for the visual signal. The emergency braking consists in loading the brake pedal and holding the load a few seconds (at least 3 s for each trial) until the subject is told to relax.

Five different emergency brakings were recorded for each volunteer, and recorded data can be summarized as follows:

- Time delays involved in the various sequences of the braking: (1) the reaction time, which is here the time between the lighting of the signal and the beginning of the first right foot movement; (2) the braking time, which is the time involved between the lighting of the signal and the first contact of the right foot on the brake pedal; (3) the load rising time, which is the time between the first contact of the right foot on the brake pedal and the time at which the pedal load has reached a steady (maximal – 5%) value;
- Marker displacements, from which are deduced joint angles variation for the three main joints of the right lower limb. Computed angles are illustrated in Fig. 1.
- Brake pedal load against time (sampling rate of 100 Hz);
- Hip, knee and ankle torques evolution were predicted using an analytical inverse dynamics model. Geometries of the lower limb were averaged from lengths and circumferences measurements performed on volunteers. Inertia parameters were then estimated according to Winter (1990). Mean joint torque for hip, knee and ankle could then be predicted by solving Euler's equa-