

Dynamic Analysis of Car Ingress/Egress Movement: an Experimental Protocol and Preliminary Results

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ABSTRACT

This paper focuses on full body dynamical analysis of car ingress/egress motion. It aims at proposing an experimental protocol adapted for analysing joint loads using inverse dynamics. Two preliminary studies were first performed in order to 1/ define the main driver/car interactions so as to allow measuring the contact forces at all possible contact zones and 2/ identify the design parameters that mainly influence the discomfort.

In order to verify the feasibility of the protocol, a laboratory study was carried out, during which two subjects tested two car configurations. The experimental equipment was composed of a variable car mock-up, an optoelectronic motion tracking system, two 6D-force plates installed on the ground next to the doorframe and on the car floor, a 6D-Force sensor between the steering wheel and the steering column, and two pressure maps on the seat. Motions were reconstructed from measured surface markers trajectories using inverse kinematics. Joint loads were calculated by an inverse dynamic approach using a recursive Newton-Euler procedure.

The validation of the computing method and the relevance of a dynamic approach are also discussed.

INTRODUCTION

The ease of getting in and out of a car is one of the ergonomic issues that catch the attention of many car manufacturers (Wegner et al. [23]). It represents the first

physical contact of the customer with the car. Therefore, it is important to ensure a pleasant sensation while accessing the car. The accessibility motion is also a very challenging research topic because of its complexity in motion control and its difficulty in modelling discomfort perception. Indeed, almost all body segments are involved in the motion and a high number of factors may affect the discomfort perception.

In recent years, several research groups have launched research programs trying to simulate the car ingress/egress motion (Cherednichenko et al. [5], Lempereur [14] and Rigel [18]) and to understand the associated discomfort (the British Department of the Transport [8], Giacomini et al. [11], Petzall [17]). For instance at INRETS, a data-based motion simulation approach was proposed and successfully applied to very complex motions like car accessibility (Monnier et al. [15] and Chateauroux et al. [3]). The neutral motion concept was also suggested to associate motion with the perceived discomfort (Dufour et al. [9] and Wang [22]).

However, most of these studies on car accessibility were either based on video observation (Gransitski [12], Petzall [17]) or on kinematic motion analysis (Giacomini et al. [11], Cherednichenko et al. [5], Rigel [18]). The kinematic approach is probably enough to have a visually human-like motion simulation, but it is not sufficient to propose objective discomfort criteria for evaluating car ingress/egress motion, making difficult for a design engineer to judge if a car will be appreciated in terms of ease-of-use and comfort. We assume that discomfort is

mainly induced by interactions with environment and internal biomechanical constraints affecting the musculoskeletal system. A dynamic approach appears therefore necessary to evaluate the discomfort.

To our knowledge, only Debril et al. [6] tried to use a dynamic approach to analyse car ingress/egress motion. But, this study has several restrictions, especially because it was limited to the lower limb analysis of one single subject. For a complex motion such as the car accessibility, which brings in all body segments, it is necessary to study the whole body.

The aim of this paper is to propose an experimental protocol adapted for a dynamic analysis of car ingress/egress motion. First, two preliminary studies based on video analysis are presented in order to identify the main driver/car interactions and the main design parameters affecting driver's discomfort. Then, an experimental protocol allowing the full dynamic analysis of car ingress/egress motion is proposed and applied to a pilot study. This pilot study aimed at verifying the feasibility of the proposed experimental protocol, by comparing two car configurations tested by two different subjects. The validation of calculated joint torques and forces will also be discussed as well as the relevance of a dynamic approach.

JUSTIFICATION OF A DYNAMIC ANALYSIS

Recently, Chateauroux [4] analysed the ingress/egress motion of elderly and disabled people, by focusing on the interactions between the subject and the vehicle. The author observed that many hand/car contacts occurred during the motion. However, because of the use of a purely kinematics approach, it was not possible to fully explain the reasons of these contacts and to understand their influence on the motion control. For example, for a "one foot" strategy, as named by Ait El Menceur et al. [1], during the ingress, Chateauroux [4] suggested that the hand contacts with the car might help to keep the balance during the unipodal phase.

The interactions with the seat may also play an important role. For the egress, different motion strategies were defined according to the torso and the pelvis position when the left foot is getting out of the car. This kinematic approach is not sufficient to understand the differences between these strategies. Indeed, the subjects may use the seat as a support, to reduce the left hip load required to transport the foot outside. Furthermore, during an egress motion, the subject has to transfer his weight from a seated posture to a standing posture. Egress motions can be compared to sit-to-stand transition (Riley et al. [19] and Bernardi et al. [2]) but are much more complicated because of their strong interaction with the environment; e.g. control of the centre of mass displacement, while maintaining body equilibrium, avoiding head/doorframe collision, etc.

A kinematic approach is not sufficient to fully understand the influence of the car geometry during this weight transfer. Some questions remain unanswered: What are the roles of the hand interactions? How the weight transfers between the feet and the seat?

Following Chateauroux's work, the present research project aimed at performing a full body dynamical analysis of car ingress/egress motion. Two preliminary studies were carried out for identifying hand/vehicle contact points and critical car design parameters affecting discomfort.

PRELIMINARY STUDIES

Location of driver/vehicle contact points

In order to define the main interactions between the driver and the vehicle, a preliminary study was carried out. It aimed at defining how to instrument a car mock-up to record all contact forces. 18 subjects (4 women and 14 men: 33 ± 9 years, 174 ± 9 cm, 72 ± 13 kg) were filmed getting in and out of their own car, on the INRETS car park. The tested cars were selected to cover as largely as possible the car configurations currently available in France: one small sized car, two 3-Door compacts, five 5-Door compacts, and two SUVs (Sport Utility Vehicle).

Subjects were asked to get in and out naturally four times of their own car: twice with a closed door and twice with the door blocked to the first opening level (around 70°). Two door configurations were tested in order to identify the possible influence of the door handling on the motion strategy.

The contacts between the hand/arm and the car were determined by visual inspections of the recorded video. The idea was to identify the active contacts, which make the motion easier. The so called "active" contacts were identified by comparing, in an imaginary way, a motion with and without any hand/arm contact. Of course, it should be noted that this was based on a subjective interpretation of contact force role. The door opening and closing were not taken into account here.

Table 1 summarizes the number of trials having an active contact between the subject and a car element (door, steering wheel and seat). Figure 1 illustrates the main observed contacts between the hand/arm and the tested vehicles.

Table 1: Use of the car element during the ingress/egress motion (in % of all captures motions)

Car element	Ingress		Egress	
	DO	DC	DO	DC
Wheel	79	65	94	70
Door	50	79	50	87
Seat	0	0	9	9

DO: Door opened / DC: Door closed



Figure 1: Main subject/car interactions observed during the preliminary study

A high number of hand/steering wheel contacts ($> 65\%$ of observations) were observed. No hand contact with the sill and the doorframe was found in the present study. It was reported that the hand contacts with these last ones were in general used for older and disabled people (the British Department of the Transport [8] and Petzall [17]).

Furthermore, the hand/car contacts were quite different between the two door test conditions. The subjects took advantage of the door opening requirement to use it as a support and to make their motion easier. In case of a closed door configuration, an increase of 29% and 37% in the hand/door contact was respectively observed for the ingress and the egress (see Table 1). On the other side, a decrease of the steering wheel use was also noticed: 14% for the ingress and 24% for the egress.

We also intended to distinguish how the subjects made use of these car elements to facilitate their motions. Two categories of hand contacts were thus proposed: with force and without force. The same videos were analysed by three different observers. Big differences were noticed between their observations. It appeared almost impossible to clearly identify the role of hand contacts by video inspection.

A dynamic approach appears necessary to understand the influence of the contacts forces on motion control.

Study of the design parameters influencing the ingress/egress motion

A second preliminary study was performed in order to define the critical parameters influencing the ingress/egress motion and the perceived discomfort. Five subjects (1 woman and 4 men: 35 ± 8 years, 173 ± 6 cm, 68 ± 3 kg) were filmed getting in and out of 27 different cars, from different size classes and different car manufacturers, during an international motor show. All subjects worked at INRETS and were familiarized with biomechanical experiments and subjective discomfort evaluation. The tested cars were one minicompact, eight subcompacts, four compacts, four

midsize cars, two sports cars, five SUVs and three utility vehicles. The car segments were defined according to the car lengths and shapes.

Each subject was asked to test with the door blocked to the first opening level. After several trials, a complete car ingress and egress motion was recorded with the subject's comments on the tested car. The feedback concerned 1/ the general feeling about the vehicle and 2/ the design elements (seat height, sill width, etc) considered as being responsible for the discomfort.

The influence of design parameters on the discomfort was assessed from the subject's answers. Figure 2 illustrates the main difficulties encountered by the subjects during the ingress/egress, relative to the doorway height, the sill height and width. Figure 3 shows the critical design parameters identified as possible source of discomfort relative to the five most frequently cited complaints during the experiment. Table 2 summarizes three of these five most cited car elements according to the tested car configurations.

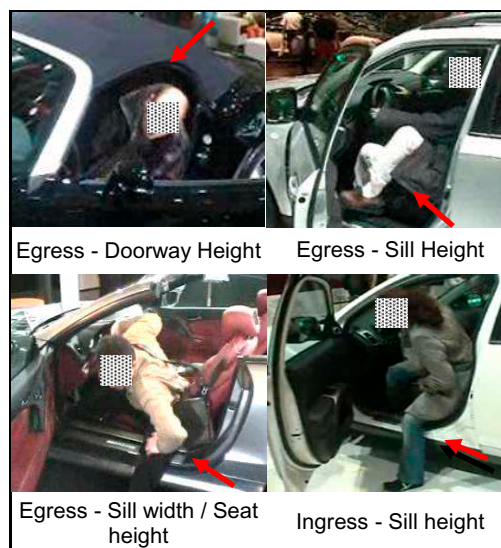


Figure 2: Main Difficulties met by the subjects during the second preliminary studies

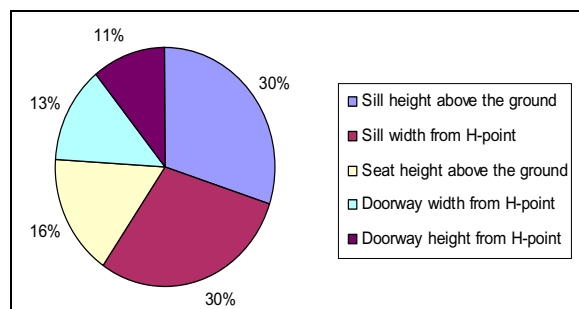


Figure 3: Relative importance of the five mostly cited car elements affecting the car ingress/egress discomfort