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Ranges of the least uncomfortable joint angles for assessing automotive driving posture

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ABSTRACT

Few investigations have been performed on how the ranges of preferred angles should be used for vehicle interior discomfort evaluation. This study investigated the ranges of the least uncomfortable joint angles considering both inter-individual and intra-individual variability. The driving postures of sixty-one subjects were collected using two multi-adjustable vehicle mock-ups under four test conditions by gradually adding the number of control parameters (constraints), from the "least-constrained" driving condition to the configurations close to currently existing vehicles. With help of subjective discomfort evaluation, the intra-and inter-individual variation ranges of least uncomfortable postural angles were quantified. Results show that intra-individual variation ranges of postural angles were much smaller than those of inter-individual variation as expected. An individual may not feel comfortable throughout the whole range of comfortable angles from all participants. Possible relationships between perceived discomfort and ranges of inter and inter individual variations in least uncomfortable angles were explored, suggesting that the inter ranges could be used to detect potential problems of postural discomfort and the intra ranges could be considered as optimum ranges. A three color model, based on the intra-and inter-individual variability ranges of comfortable driving postures, was proposed for ergonomics assessment of a vehicle configuration.

1. Introduction

In the expanding global competitive automotive market, vehicles are required to be designed and manufactured in a short term and also to provide a high level of comfort for the target population of more than thousands or even millions of people. To meet these challenges, Digital Human Models (DHMs) are being more and more used for proactive as well as retrospective ergonomics analysis in the automotive vehicle interior design process. With help of a DHM tool, preferred comfortable driving postures can be used for optimizing the vehicle interior layout including the adjustment range of interior components, such as seat, steering wheel at the early phase of design. For example, Vogt et al. (2005) tested four seating concepts for vehicle interior design with help of the RAMSIS digital human modeling tool. For this, a comfortable driving posture regardless of driver's anthropometry was used. Comfortable driving postures can also be used to assess different design propositions in a later phase of vehicle design. Actually, the ergonomics requirements may not be 100% satisfied because of other considerations such as styling, legal requirements, aerodynamics, and safety. It means that the compromised design may not accommodate all target drivers. Postural discomfort could be assessed by comparing the ranges of comfortable joint angles with the posture adopted by a driver, as implemented in RAMSIS (Meulen and Seidl, 2007).

In the past, a few studies recommended the range of 'comfortable' or 'preferred' joint angles for automotive driving. Rebiffé (1969) analyzed the main driving tasks and suggested the ranges of comfortable joint angles in the sagittal plane. It should be noted that, Rebiffé's recommendation was based on the author's experience without experimental evidence. Some other researches (Seidl, 1994, Porter and Gyi, 1998; Park et al., 2000; Hanson et al., 2006) experimentally investigated the preferred driving posture using a

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multi-adjustable vehicle mockup with extended range of adjustments by assuming that preferred driving posture would also be comfortable. Kyung and Nussbaum (2009) questioned whether the preferred posture is necessarily a comfortable one. They suggested considering subjective discomfort and comfort ratings for selecting comfortable postures to determine the comfortable joint angle ranges. In the past, the comfortable joint angle intervals were obtained from all participants, representing rather inter-individual than intra-individual variation. As intra-individual postural variation is much smaller than inter-individual variation in general, a driver may not feel comfortable throughout the whole inter-individual range of comfortable postures from all participants. Thus, it would also be interesting to define the ranges of comfortable angles based on intra-individual variation. Moreover, few investigations have been performed to see whether the range of preferred angles could be used for discomfort evaluation. Could we assume that a vehicle configuration allowing all joint angles of a driver inside the suggested intervals is comfortable for driving? If one or several angles are outside the comfortable intervals, how does the discomfort change? These were rarely discussed in the literature. As argued by Zhang et al. (1996) and more recently by Vink and Hallbeck (2012), discomfort and comfort are two distinct concepts. Discomfort is related to physical characteristics of the environment like posture, stiffness and fatigue, whereas comfort is related to luxury, relaxation or being refreshed. In the present paper, postural discomfort was investigated.

The main goal of this study was therefore to investigate the range of comfortable joint angles considering both inter-individual and intra-individual variability for automotive driving postural discomfort evaluation. For this, data were collected from less-constrained vehicle configurations with low discomfort, more constrained ones close to real vehicles as well as unrealistic ones with high discomfort. Comfortable joint angles and their range of variation were first obtained from the configurations with low discomfort. Then a three color model, based on the intra-and inter-individual variability ranges of comfortable driving postures, was proposed and tested using data from more constrained test conditions.

2. Materials and methods

2.1. Experimental data

The data used in the present study were collected from 61 participants using two multi-adjustable vehicle mockups, as shown in Fig. 1 and Fig. 2. One, named 'Mockup 1 (M1)', could be adjusted easily by subjects themselves through an intuitive touch-screen, while the other, named 'Mockup 2 (M2)', had the adjustments mainly controlled by a computer and could easily load a predefined vehicle configuration. A same Peugeot 508 seat, considered as a high-end product with electric adjustments in fore-aft position, height, lumbar support, cushion angle and back inclination, was used for both mockups. Main characteristics of the two mockups are summarized in Table 1.

Sixty one drivers, recruited mainly based on stature and sitting height, included both French and Chinese drivers who lived in France. They all had a driving license for more than one year and drove regularly. They did not suffer any neurological or musculoskeletal disorders. The main characteristics of the participants are described in Table 2. The whole experiment was divided into four test conditions by gradually adding the number of control parameters (constraints), from the "least-constrained" condition to the configurations close to currently existing vehicles, as shown in Table 3. Only the fore-aft position of the accelerator pedal was controlled in Condition 1, meaning that participants were allowed to use all adjustments available as long as they respected the instruction for "a natural driving". In Condition 2, seat height was added as control variable and three levels were tested. In Condition 3, one more vehicle parameters (steering wheel fore-aft position, clutch pedal fore-aft position, seat cushion angle) was controlled in addition to the seat height fixed at 300 mm. Condition 4 simulated 27 different configurations close to currently existing vehicles. Only fore-aft seat position and seat back angle were allowed to be adjusted.

All 61 subjects participated in the "less-constrained" experiments (C1, C2 and C3) using the mockup 1 and only 55 of them participated in the "more-constrained" experiment (C4) using the mockup 2. For each test configuration, subjects were asked to find their preferred vehicle parameters by using all available adjustments according to experimental condition. The initial positions of available adjustments were set randomly to one of the two extremes such that participants had to use the available adjustments allowed by test condition. Once the subjects found their preferred driving positions, a full movement of depressing clutch pedal was recorded by a Vicon motion caption system. Reflective markers were attached to the body as well as to all moveable parts of the mock-up. The participants were instructed to place their hands on the steering wheel at the 10-to-2 o'clock position and to look forward as they were driving. They were asked to put their left foot on the foot rest, to fully depress the clutch pedal to its end, and then to move the left foot back on the foot rest. The right foot was asked to put on the accelerator without depressing. Subjects were required to leave the mockup after each trial and the adjustments were reset for a new test condition. Trial order was randomized within each test session while the four sessions were performed in order.

For each test configuration, after having found the preferred posture and before getting out of the seat for another test condition, participants were asked to verbally rate the configuration using a modified CP-50 category partition scale CP50 scale (Chevalot and Wang, 2004; see also Shen and Parsons, 1997 for a comparative study on rating scales), as shown in Fig. 3. The scale was put in front of the subject and was visible all the time. They were instructed to first select a category among seven responses (imperceptible, very low, low, medium, high, very high, extremely high), then to refine their judgement by choosing a number from 1 to 10 within the selected category. The real scale from 0 to 50 and more (original CP-50) was hidden from the subject in order to give priority to the category choice and not to a numerical value.

In total, a maximum number of 41 trials were asked to perform for each participant. The whole experiment took about 90–120 min for the experiment with Mockup 1 and 60–90 min for the experiment with Mockup 2.

The whole clutch pedal depressing movement was reconstructed using the RAMSIS human model by minimizing the distance between the captured and model-based markers positions (see Ausejo and Wang, 2008; for the principle of motion reconstruction). Three instants of a clutching movement were identified to describe the driving postures at the rest (Re), beginning (De) and end of clutch pedal depression (Fi). A set of postural parameters of each instant, defined in Table 4 and illustrated in Fig. 4, were calculated from reconstructed joint centers. If not indicated explicitly, the angles at the rest posture are presented.

The time spent on each trial was largely dependent on the number of available adjustments and on participant, varying from 2 min for Condition 4 with only two adjustments (fore-aft seat position and seat back angle) to 15 min for Condition 1 with 16 available adjustments. Not all planned trials were finished in time. Seven and thirteen trials under Condition 2 and Condition 3 were missed. Five trials under Condition 4 were discarded due to the problem of motion capture.