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Concepts for the reduction of the discomfort generated by the prolonged static posture during the driving task, part II: Experiments and validations

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ABSTRACT

The Prolonged Static Posture (PSP)[i] is among the leading causes of discomfort generated during car driving. The focus of our study is the founding of new design parameters of the car seats that might reduce the effects of the discomfort generated from the PSP. This paper aims to validate the work introduced in a companion paper (Concepts for the reduction of the discomfort generated from Prolonged Static Posture during the car-driving tasks. Part I: Basic theories and concepts) where the main characteristics of the design were presented, using axiomatic and participatory design approaches. A finite element model was developed, a prototype was built and a focus group was made to evaluate the new design function introduced in the previous study: "Dynamic commutation of the backrest angle during the car driving task" in terms of safety and discomfort reduction. The results of the exploratory study show a decrease in the amount of the discomfort level, and the number of macro reposition movement during the swing movement of the backrest angle compared to the ordinary case (static posture).

Relevance to industry: This paper may assist the improvement of the design aspects of the car seats that consequently leads to a reduction of the musculoskeletal injuries caused by the Prolonged Static Posture during the driving task.

1. Introduction

According to Helander and Zhang (1997), Discomfort and comfort are different entities. Discomfort is more related to physical exposures, and comfort is more influenced by other factors such history and emotions. Comfort is very subjective, and the best way to measure comfort is by questioning, for that reason, user participation is needed in product development, because users are the only ones who can evaluate comfort during normal use of a product, to anticipate on that, user participation is the only possibility for the comfort evaluation (Eikhout et al., 2005).

This article aims to evaluate the discomfort generated from the prolonged static posture (PSP) during car driving, using participatory design approach. The results of the exploratory study made previously, show that the most drivers suffer from low back pain after the driving task. This information coincides with Vergara's findings With regard to pain while seated, Vergara states that low-back pain is the most important feature of discomfort in sitting posture (Vergara and Page, 2002). This is because of the direct relation between the articular loads and the perception of discomfort (Vergara and Page, 2002; De Looze et al., 2003; Karwowski and Marras, 1999). Thus, studies show that the relation between LBP and discomfort caused by sitting posture could be explained by the fact that the intradiscal pressure applied during this position is greater than the pressure caused while standing (Callaghan and McGill, 2001; Wilke et al., 1999).

Additionally, different research studies indicate that the perception of discomfort caused by LBP in sitting posture, increases gradually over time (Vergara and Page, 2002; Na et al., 2005; Dunk and Callaghan, 2010). In order to diminish the perception of discomfort over time, postural changes while sitting are often performed as a natural body response (Vergara and Page, 2002; Na et al., 2005; Vergara, 1998). Two postural changes have been found; the macro movements (large movements) and micro movements (very small and fast in motion) (Vergara and Page, 2002; Dunk and Callaghan, 2010). These movements allow the release of internal loads and provide nutrients to the intervertebral discs in the

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lumbar area through an influx of fluids from the nucleus pulpous to the vertebral plateaus and vice versa (Adams and Hutton, 1983). The question that we should ask whether the drivers could perform such movement while driving. Considering the particular limitations of the car seat and the driving activities, the answer is obviously negative, the drivers must maintain a rigid posture, which offers less possibilities of making significant postural changes, thus, increasing the risk of developing this pathology.

Taking into account the previous information, it is suggested to design a new car seat that could reduce the static position problems during driving task, a car seat that allows more possibilities of making significant movements while performing the usual driving task.

A lot of researchers have demonstrated the need of an adjustable seat to decrease the pain of the lower limb, (D.M.Antle et al., 2015) demonstrate that an adjustable sit-stand stool and foot support system appear to have significant benefits to vascular outcomes and reported discomfort in the lower limb.

Designing a postural changing seat is an advanced ergonomical prospect solution that might reduce the discomfort caused by the PSP during car driving. The current paper examined associations between a dynamic postural changing seat during car driving, the "pressure distribution between the buttock and the seat" {section 3.2} and three subjective ratings ("Discomfort" {section 3.1.1}, "Macro-repositioning Movement" {section 3.1.2} and "Driving accuracy" {section 3.1.3}), using the participatory approach.

At the moment there is no universal agreed approach to design a car seat that increases comfort and health, but the positive effects of a participatory design process have been demonstrated before.

2. Material and methods

2.1. Participatory design approach

The participatory approach is the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals Wilson (1995). The defined goal of the project was the reduction of the discomfort generated from the PSP during car driving, driving task was studied using questionnaires and the problem seems to be physiological when the drivers were exposed to PSP, the design attention point that should be considered was the dynamic seating while performing driving tasks. Therefore, the conceptual solution discussed with ergonomic advisors was the use of a dynamic postural changing seat, where a swing movement of the Backrest angle is execute during car driving. The theoretical aspect of the concept need to be examined and evaluated properly by concluding the remaining steps of the participatory approach.

After the selection of the appropriate solution based on the participatory design approach, the new design should be *Implemented* in a real workplace to provide information about effectiveness {Step 4}, then it should be *tested in a virtual environment* (Virtual prototype should be made in this section) {Step 5}. To validate the results from different perspectives with the end-users an *evaluation* step {Step6} is needed to conclude the study (Fig. 1).

2.1.1. The implementation step

At this stage, a real prototype is implemented in a laboratory to test the safety and improvement of the seat design. As discussed by Arisz and Kanis (1999), under strict conditions and for comparison within a subject it is better to study fewer subjects thoroughly than a large number under varying conditions. For that reason, eight subjects accepted to pass the experiment for the evaluation of the seat design suggested in this study. All participants were male. The

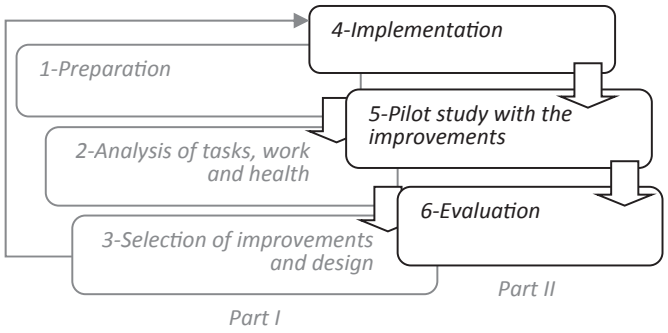

Fig. 1. Stages towards the design evaluation (Participatory Design).

average age, height, weight, and BMI were 28 years, 173.4 cm, 71.25 kg and 23.65 kg/m^2, respectively, the subjects had at least 3 years of driving experience, all the subjects were healthy and they never complain about low back pain.

The experiment main goal is to test the design parameter: "15–35° backrest sweep angle with lower variation frequency" in terms of safety and discomfort reduction. The seat prototype allows regular movement of the backrest angle with different movement frequencies (Fig. 2). Among the goals of the experiment, is to find the best possible movement frequency to decrease local perceived discomfort without affecting the safety of the driver. Knowing that there is a risk factor in allowing such movement of the driver's back and legs while driving; because of the particular limitations of the driving activities, different movement frequencies will be tested, in order to find the best and the safest one.

Three movement frequencies were used in the test, including the zero-frequency test ($frequency_0 = 0.00$ rad/s). The zero frequency test used to distinguish between the very different implicit modalities in either static or dynamic movement of the backrest angle, the optimal backrest angle of the seat was maintained to experience the conventional case, (Recommended driving backrest angle 25° from the vertical ascendant, consistent with the EMG-based recommendations of Andersson et al. (1974b)) While in the second frequency test, a slow and steady backrest movement was used to examined the effect of the angular velocity on discomfort and driving tasks ($frequency_1 = 0.029$ rad/s). In the last frequency, a swift movement of the backrest angle was set in the test ($frequency_2 = 0.07$ rad/s) (Table 1 shows the kinematic description of the three movement frequencies used in the experiment). Every frequency test last 30 min, the total experience time was 90 min. The Counterbalanced design was used in the experiment to avoid bias due to a learning transfer or an increase of the discomfort level with time, between each frequency test. Two video cameras (placed at different angles) were employed to record the macro-repositioning movement of each subject.

For every subject the test started by experiencing the local perceived discomfort (LPD) scale. Subjects were asked to rate their postural discomfort in one of the regions (Fig. 3) shown on a diagram, using a scale ranging from 0 (no discomfort) to 10 (extreme discomfort) modified after Corlett and Bishop (1976).

First, the subjects learned the LPD scale. For every region they had to rate their experienced discomfort every 2 min by holding a static sitting posture without movement until they were unable to hold the posture. After a rest period, the test started, but before each test, the LPD form was completed (pretest). The subjects were asked to rate their LPD every 15 min (according to Dunk's & Callaghan's method 2010) at the beginning and end of each of the six intervals. This allowed us to monitor the change in the discomfort level over the 90-min period.