

Development of objective discomfort evaluation indicators for a task-oriented motion using less constrained motion concept: application to automotive pedal clutching task

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Abstract. This paper presents a method to develop objective discomfort evaluation indicators for a task oriented motion using the concept of less constrained movement. The basic idea is to compare imposed and less constrained movements in order to identify relevant biomechanical parameters for defining objective discomfort indicators. The task of automotive pedal clutching was chosen for illustrating the proposed method. Based on discomfort questionnaire and motion analysis of the experimental data, four discomfort indicators were proposed. Two of them were based on the ankle joint angle around flexion/extension axis at the beginning and the end of the clutch pedal depression. The third one was defined using knee flexion/extension joint torque at the end of the clutch pedal depression. The last indicator was defined as the relative lateral position of the heel compared to the average pedal lateral position for less constrained configurations. A global discomfort function was also defined as a weighted sum of all indicators. Globally, the proposed global discomfort indicator succeeded in differentiating the tested configurations in agreement with experimental observation. As expected, less discomfort rating is obtained for less constrained movement when compared with the corresponding imposed one.

Keywords: discomfort, biomechanics, ergonomic assessment, motion analysis, clutch pedal

1. Introduction

The evaluation of motion related discomfort is one of the critical issues for Digital Human Modeling (DHM). Existing ergonomic assessment methods such as OWAS [7], RULA [8], REBA [5] and OCRA [9] were initially developed for ergonomic assessment of working postures in industry. Only a very rough estimation of posture is usually required either from direct visual posture or from recorded video. In addition, the postural evaluation criteria were decided by a group of ergonomics experts. These methods can certainly be helpful for detecting main risk

factors of a workplace. But they can hardly be used for ergonomic evaluation of a product such as a vehicle. Despite recent progresses in motion simulation, current DHMs are mainly limited to geometric and kinematic representations of human. But objective discomfort criteria for evaluating a task are still missing, making it difficult for a design engineer to choose one solution among several alternatives.

Discomfort is believed to be induced by interactions between human and environment affecting the musculoskeletal system. Because any task oriented motion is more or less constrained by the environment, it can be suggested that a better comfort may

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be obtained when people can make their own appropriate adjustments. These less constrained motions, called also “neutral” motions by Dufour and Wang [3], can then be used as reference data for comparing a proposed solution.

Moreover biomechanical parameters such as joint angles or joint torques may be relevant for comparison between less and more constrained configurations for motion related discomfort assessment. From experimental data, inverse kinematics and inverse dynamics procedures can be integrated to a DHM to access joint angles and torques.

Based on an approach presented by Wang et al. [11], the aim of this study is to define objective discomfort indicators by comparing imposed and less constrained movements in order to identify relevant biomechanical parameters.

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2. Materials and methods

Since the details of how data were collected have been described in a previous work [10], only a brief description of the experiment and the main results used for the discomfort indicators definition are given here.

2.1. Data collecting and processing

In the case study of automotive clutching task, six real pedal configurations were randomly tested by 20 subjects using a multi-adjustable experimental mock-up. The subjects were divided in four anthropometric groups according to age and gender and with stature close to the group’s 50th percentile value: 5 younger males, 5 younger females, 5 older males and 5 older females.

After having tested each of the imposed pedal configurations, the participants were asked to only change the pedal position without modifying other car parameters. For each trial, discomfort feelings were collected through a questionnaire. A global discomfort rating was assessed using the CP50 scale. Prior to the clutch pedal experiment, data for characterizing subject’s individual physical capacity of the left lower limb, joint range of motion (ROM) and joint maximum voluntary torque at the hip, knee and ankle, were collected.

Whole body motions when clutching were measured using the optoelectric system (VICON, Oxford,

UK) with external reflective markers as well as 3-axes force applied on the pedal, etc.

The whole body motion was reconstructed by an inverse kinematics procedure [1]. Joint forces and torques were then computed using a 3D inverse dynamics method based on homogeneous matrices [2]. Inertial properties of the body segments were calculated from subjects’ anthropometric dimensions using the regression equations of Dumas et al. [4].

2.2. Main experimental observations

The main observations by comparing imposed and less constrained configurations are [10]:

- Lower discomfort rating was obtained for less constrained configurations,
- Freely adjusted pedal position mainly improved the kinematics of the clutch pedal operation, in particular the pedal position at the beginning of depression,
- A clutch pedal position more on the left, from driver’s point of view, was usually preferred. In average, for the less constrained configurations, the distance from the seat axis was 100 mm,
- The pedal resistance perception was highly correlated with discomfort ratings and joint torques, especially knee joint torque,

2.3. Discomfort indicators

Based on the previous results, 4 discomfort indicators, 3 kinematic and 1 dynamic, were defined ranging between 0 and 1. Three indicators were based on the improvement of the clutching movement kinematics by the less constrained configurations. The first two were defined considering the ankle joint angle around flexion/extension axis at two key instants: the beginning (IndStart) and end (IndEnd) of the clutch pedal depression (Fig. 1).

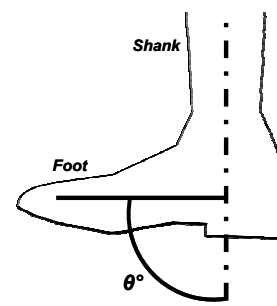


Fig. 1: Definition of the ankle joint angle θ

Indeed, among all the considered joints, the highest variations in flexion-extension angle between imposed and less constrained configurations were found at the ankle joint. These indicators were estimated using discomfort cost function based on the joint ROM for the ankle joint angle (Fig. 2). Based on the physiological joint limits from Kapandji **Fout! Verwijzingsbron niet gevonden.**, the cost function is characterized by 3 zones:

- The zero discomfort zone: discomfort is null for ankle joint angle around neutral ankle position, i.e. 90° angle between shank and foot
- The full discomfort zone: discomfort is maximal for ankle joint angle in the margin of individual variability defined by Kapandji **Fout! Verwijzingsbron niet gevonden.**
- The transition zone: discomfort is defined by a linear law between zero and full discomfort zones

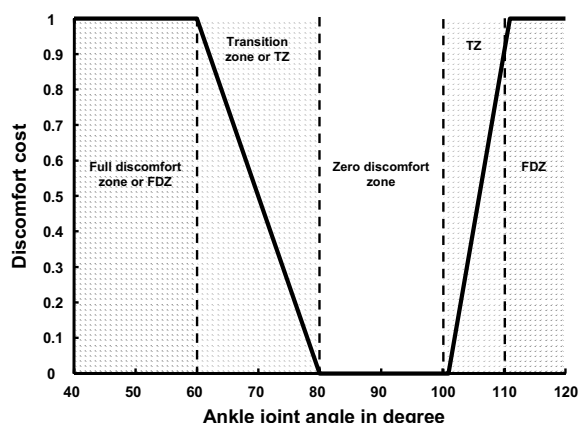


Fig. 2: Discomfort cost function for ankle joint angle

Then the third indicator was defined as the relative lateral position of the heel (IndHeel) compared to the average pedal lateral position for less constrained configurations. A cost function based on the distance from the seat axis for the heel position was used to estimate this indicator (Fig. 3). It was assumed that on the one hand, for a pedal lateral position at 100 mm or more from the seat axis, the discomfort is null, and on the other hand, the discomfort is increasing linearly when approaching to the seat axis. Of course, the range of the zero discomfort zone depends on the space available for the pedal placement which is restricted by the vehicle lateral structure.

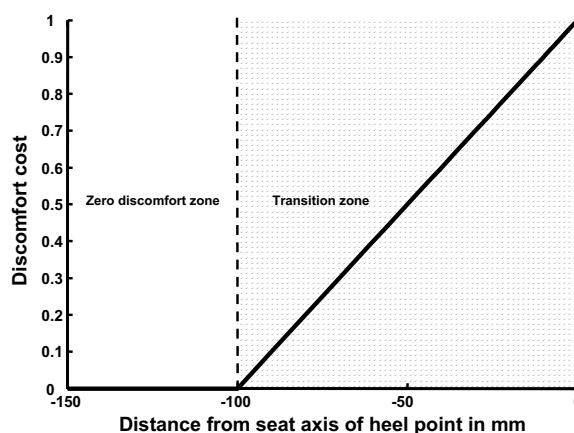


Fig. 3: Discomfort cost function for heel point position

The last indicator was based on the high correlation between knee joint torque and discomfort ratings. It was defined as the joint load due to pedal depression. In our case, the normalized knee flexion/extension torque using the maximum voluntary knee torque value of each subject was considered (IndJT).

3. Results

3.1. Effects of the discomfort indicators

A linear regression was performed on the CP50 ratings to investigate the effect of the discomfort indicators on the global discomfort:

$$Discomfort = k_1 * IndStart + k_2 * IndEnd + k_3 * IndJT + k_4 * IndHeel$$

Fout! Verwijzingsbron niet gevonden. shows that the proposed discomfort indicators, except the one related to the ankle angle at the end of depression (IndEnd), were significantly correlated to the discomfort ratings and thus could explain the global discomfort rating.

Table 1
Results of the linear regression on CP50 ratings

Indicator	k_i	Standard Error	P-Value
IndStart	6.45	1.55	0.0000
IndEnd	1.44	1.73	0.4069
IndJT	7.30	3.50	0.0384
IndHeel	7.04	2.93	0.0170

However, the resulting discomfort predictive model has a low R^2 score, i.e. 11.4%.

3.2. Discomfort function behaviour

The behaviour of the predictive model was analyzed in order to estimate if even with a low R^2 score, it was able to differentiate the configurations and the type of configuration as it was observed with the experimental data.

The ratings of the predictive model, as the ones from CP50, were analyzed according to two independent variables:

- Configuration (Config or C), 6 existing pedal configurations
- Type of configuration (ConfigType or T), i.e. imposed or less constrained

An ANOVA showed strong effects of both variables on either the predicted or the CP50 ratings.

For ratings, the less constrained configurations were better rated than the imposed ones. Fig. 4 shows the mean scores for the indicator-based discomfort model.

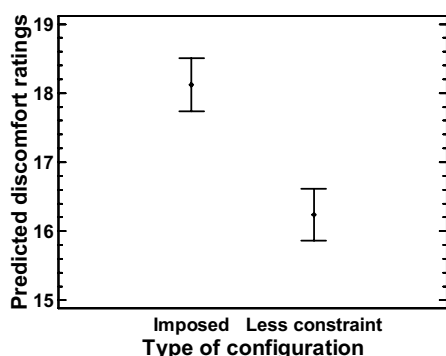


Fig. 4: Predicted discomfort ratings in terms of type of configuration

Moreover, the same classification of the pedal configuration in terms of discomfort ratings could be observed (Fig. 5). C3 was the less uncomfortable configuration. C4 and C6 had the worst mean discomfort ratings. C1, C2 and C5 had average scores. It can also be noticed that the predicted ratings were less dispersed.

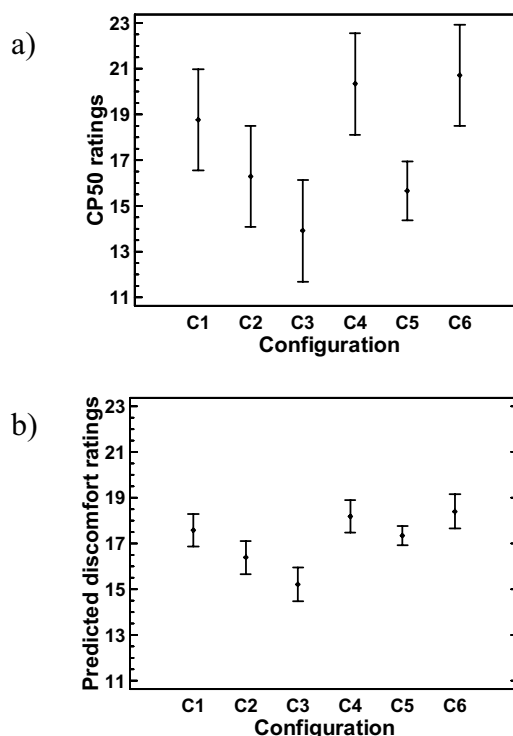


Fig. 5: Discomfort ratings in terms of configuration, a) from CP50 rating scale (experimental data), b) from indicator-based discomfort model.

4. Discussion and conclusion

In this work, we have applied the concept of less constrained motion to define pedal clutching motion discomfort assessment indicators.

Globally, the proposed global discomfort indicators matched the effects of the configuration and the type of configuration observed on the CP50 scores. Low R^2 coefficient of the discomfort predictive model might be partly explained by low reproducibility in discomfort rating [10] and by the fact that the tested pedal configurations were very close to one another.

It should also be pointed out that people did not use the same interval of the CP50 scale to estimate discomfort perception. The discomfort model presented here was developed to match a global behaviour. It did not take into account any subject specific discomfort threshold.

Compared to existing ergonomic assessment methods, the proposed discomfort indicator succeeded in differentiating the tested configurations in agreement

with experimental observation, even with the restricted variability of the pedal design parameters.

The motion related discomfort modelling approach applied in this study may be useful for a design engineer to judge whether the designed product will be appreciated in terms of ease-of-use and comfort.

In this study, the global discomfort predictive model was defined using a linear regression on experimental data. However the weighting coefficients could also be estimated by an ergonomic expert. The main contribution of the method is to propose objective discomfort indicators based on biomechanics analysis. But the way to use these indicators may require some expertise.

The approach is meant to be generic by definition, it would be interesting to test it with other case studies like, for example, an upper limb task motion. One drawback, as for all data-based methods, is that new experiment has to be performed for a new task-related design problem, which is a time consuming process.

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