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# H-point simulation in musculoskeletal models of seating.

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**Abstract**

This paper investigates the opportunity to simulate soft surfaces in rigid body inverse dynamics musculoskeletal models. More precisely, the paper addresses the change of H-point location in response to the forces produced by the body against the environment, such as pedal forces or steering forces. This situation cannot be handled by basic inverse dynamics, because the elastic deformations contribute to the movement but are unknown when the simulation begins.

We demonstrate how a new inverse dynamics analysis method called force-dependent kinematics (FDK) can be used to simulate the body's movement in a cushioned seat. In other words, the method allows some motions to be output rather than input in the inverse dynamics simulation.

The paper briefly introduces the basis of the method, presents a seated human model and shows sample simulation results for the case of emergency braking.

It is concluded that H-point and seated body-seat posture can be simulated given information about the nonlinear compliance, i.e. force-deformation curves of the seat cushions and the soft tissues in contact with the seat. The latter information can be obtained either experimentally or by advanced finite element simulation.

*Keywords: Force-dependent Kinematics, Musculoskeletal modeling, Seating, Ergonomics, H-point location.*

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## 1. Introduction

Computational models have had a profound influence on the design of industrial products. In the automotive field, simulations within structural performance, aerodynamics and NVH response have drastically improved vehicle performance. In the vehicle occupant field, simulations of structural crash worthiness and passive behavior of the human body (van Lopik and Acar, 2007) in conjunction with airbags, seatbelts and hard obstacles have contributed to the vast improvement of occupants' safety within the past decades.

While modeling of such passive responses has made much progress, voluntary human performance remains a modeling challenge in many aspects. Musculoskeletal models are emerging and have gained impact in recent years (Damsgaard et al., 2006, Delp et al., 2007, Erdemir et al., 2007, Pandy, 2001). These models are based on rigid body mechanics in conjunction with optimization procedures to predict muscle actions. While these systems can predict voluntary muscle actions with considerable accuracy, their internal workings make it difficult for them to cooperate with passive simulation techniques. More precisely, systems based on inverse dynamics require kinematic information including posture as input. When the body is placed on an elastic foundation, such as a car seat, and exerts muscle-driven forces against the environment, such as pedal or steering wheel actions, the deformation of the seat will depend on the muscular actions. This means that the posture is unknown until the analysis has been performed, so inclusion of elastic elements such as soft tissue or elastic supports in this type of model is challenging.

One important example of this shortcoming is not accounting for the body sinking into a car seat depending on the posture and activities of the driver. The deformation of the seat influences the H-point (middle point between the hip joint centers) location and orientation in the seat, and this in turn influences the entire ergonomics of the situation. It is, therefore, important to be able to include this effect into musculoskeletal models. This is a pilot study to investigate the feasibility of analyzing H-point location as a function of driving activity. We shall use the example of emergency braking to illustrate the technique.

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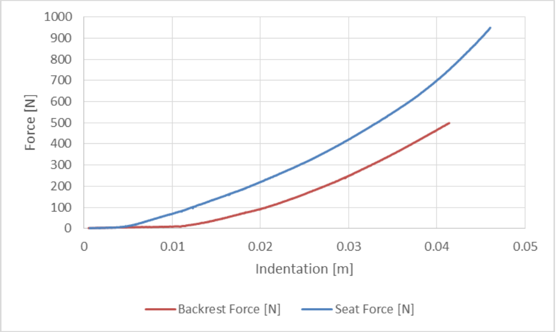

Figure 1. Experimental indentation/force curves for the seat and backrest, respectively. Only the ascending parts of the curves are included.

## 2. Materials and Methods

Data for nonlinear seat elasticity were obtained from experiments with seat indenters performed at Ford-Werke GmbH, Cologne, Germany. Each indenter replicates roughly the body shape in contact with the seat pan and backrest respectively and therefore collects the total resistance force of these elements. Seats are visco elastic; loading and unloading produce different curves. Curves interpolating the ascending part of the experimental data for the seat and backrest respectively were generated. The two curves are shown in Fig. 1.

For the purpose of modeling, the seat and backrest stiffnesses were distributed evenly to six support points on each of the two parts, seat pan and backrest, onto which the human body had the opportunity to rest. A better model can be obtained with localized hardness measurements. Please notice that only the foam and spring compliance was included, while the deformation of soft body tissue was disregarded. Only the perpendicular stiffness components were included. A more accurate stiffness representation can be obtained by means of detailed finite element models of the body and seat (Siefert, Pankoke, & Wölfel, 2008), or by advanced system identification, for instance using a motion capture experiment. Improved stiffness data will influence the result but make no difference to the working principle of the musculoekeletal simulation method that is the object of investigation in this paper.

The AnyBody Modeling System (Damsgaard et al., 2006) (AnyBody Technology, Aalborg, Denmark) was used for this investigation. A model of a seated car driver was developed, including the seat stiffnesses mentioned above. The model, comprising roughly 1000 muscles, is shown in Fig. 2.

In addition to being placed in the seat, the model is supported by two hands holding the steering wheel, the left heel resting on the floor and the right foot pushing the brake pedal by a force growing linearly from zero to 200 N. The model is depicted in Fig. 2 and Fig. 3 shows the application of the pedal force.

To address the problem of the elastic support of the body by the seat, a new musculoskeletal analysis method named Force-Dependent Kinematics (FDK) (Andersen et al., 2011) was employed. The differences between FDK and the conventional inverse dynamics analysis method are the following:

- Inverse dynamics requires all motions to be prescribed as input to the analysis, but FDK allows some degrees-of-freedom to remain kinematically undetermined at the onset of the analysis.
- Undetermined degrees-of-freedom must be balanced by elastic elements and, as a result of the analysis, the elastic deformation is determined, thus providing the lacking kinematic information. FDK assumes static equilibrium in the specified FDK degrees-of-freedom.

FDK degrees-of-freedom for this model are the horizontal and vertical locations of the H-point. These two degrees-of-freedom are supported by the elastic functions of Fig. 1, such that the body’s impression into the seat and backrest are depending on posture, gravity and the executed task, e.g. applied brake pedal force, in addition to locations of boundary conditions such as the steering wheel position. Please notice that, due to the kinematic constraints of the model, most other degrees-of-freedom depend on the resulting pelvis location, for instance the knee, hip and elbow flexion.

Figure 2 The musculoskeletal model.

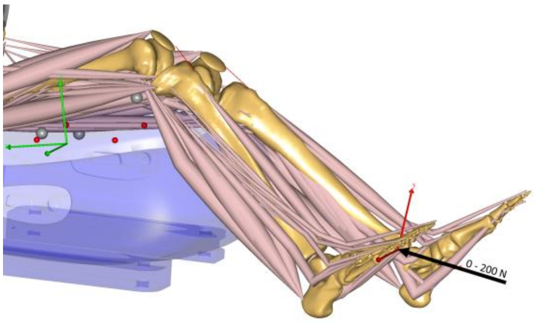

Figure 3. Brake pedal force.

Everything else about the analysis is the same, so the musculoskeletal model will provide information about muscle actions, joint reaction forces and other physiological parameters of the working human body.

## 3. Results

Fig. 4 illustrates the simulated motion of the model resulting from the increasing brake pedal force and the elastic deformation of the seat components. The pelvis moves primarily backwards into the backrest but also upwards due to the vertical component of the brake pedal force. Please notice the change of arm and leg joint angles resulting from the movement.

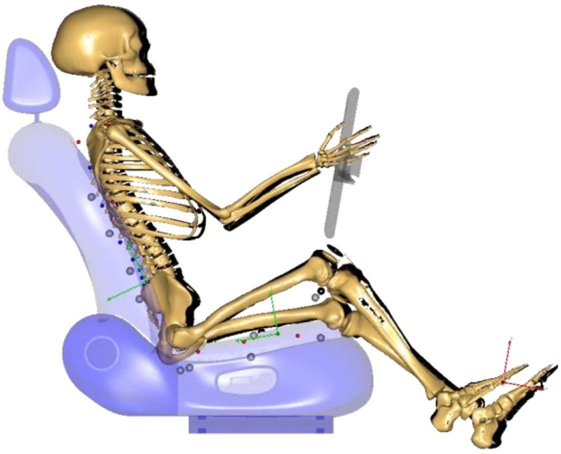

Figure 4. Overlayed image of initial (pedal force = 0 N, color black) and final (pedal force = 200 N, color yellow) postures. The muscles have been graphically removed from the figure in the interest of legibility.

The movement of the H-point can be studied in details in Fig. 5. The pelvis is initially mainly pushed backwards in the seat but subsequently elevates too.

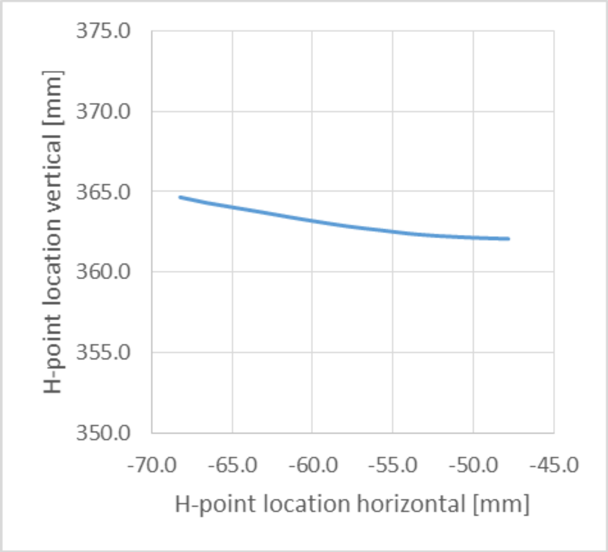

Figure 5. H-point movement in the xy coordinate system of Fig. 4. The movement starts from the lower, right end of the curve.

## 4. Discussion

The investigation reported in this paper is merely a pilot study and requires significant tuning before practical use. However, the principle opens new applications of musculoskeletal analysis in which different seats' ability to accommodate pedal and handle operation of different people can be investigated.

The ability of the FDK analysis to predict kinematics and kinetics simultaneously comes at the cost of significantly higher computation time compared to a normal inverse dynamics analysis with kinematics as input. The present analysis comprising more than 1000 independently activated muscles requires about three hours computation time on a laptop computer with Intel I7 processor. The same model with the same muscle configuration on the same computer can be analyzed in a few minutes with a conventional inverse dynamics analysis that does not predict H point displacement. It is possible to run a simplified version of the model in which the anatomical muscles have been replaced by joint motors with realistic anatomical strength, thus reducing the number of unknown forces in the model drastically. In this case, the prediction of the H-point displacement is much the same as in the complex model, while the analysis time is reduced to minutes. Thus, the simplified model may be used as a surrogate for the more complex model during *in-silico* design experiments.

This model did not take the deformation of the soft tissues into account. This might be accomplished in the future by including the elastic properties of these tissues in the model. However, the stiffness of muscle tissue depends much on the muscle activation. Hence, in a scenario where the soft tissue effect is included in the model and the stiffness of the tissue is linked to the muscle activation, the H-point simulation may differ between a muscle-equipped model and a model based on joint motors only, especially for high-activation tasks such as emergency braking involving the buttock muscles.

The practical work with the model has revealed that seat stiffness modeling must be performed with the needs and internal workings of the numerical algorithms in mind. For instance, the interpolated stiffnesses of Fig. 1 are measured within reasonable practical force and deformation limits, and the results of the analysis are of course within these limits. However, intermediate results during the numerical iterations may exceed the limits, so it is necessary to define functions that provide force/deformation data to accommodate intermediate results outside the normal limits during the algorithm's iteration.

Experiments with more degrees-of-freedom included in the FDK analysis should be conducted. The method in principle allows for some of the anatomical joint angles, for instance the lumbar lordosis, be determined by FDK. This would open the possibility to simulate, for instance, the effect of lumbar support in the backrest.

## 5. Conclusion

Force-dependent kinematics was originally developed to allow analysis of non-conforming anatomical joints. However, the technology also allows for analysis of elastic elements in industrial products and their possible influence on the ergonomics of these products. This significantly enhances the applicability of musculoskeletal simulation for ergonomic design purposes.

The purpose of this paper is merely to present the method. Experimental validation of this type of analysis is ongoing and imperative before practical use.

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