Preface

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Biographical notes: Gunther Paul studied Engineering and Ergonomics at TU Darmstadt in Germany, where he received his Master in Mechatronics and PhD in Ergonomics. After working at TU Darmstadt, he joined Ford and remained in product development, IT and manufacturing engineering functions in the automotive industry in Europe until 2009; when he moved to Australia and established the Ergolab research group at the University of South Australia. He is now reading OHS and Ergonomics at Queensland University of Technology, co-chairing the IEA technical committee for human simulation and virtual environments, and researching comfort-related, biomechanical DHM for product design and musculoskeletal workload assessment.

Matthew P. Reed is Research Associate Professor and Head of the Biosciences Group of the University of Michigan Transportation Research Institute and directs the Human Motion Simulation Laboratory in the Center for Ergonomics. He holds a Doctorate in Industrial and Operations Engineering from the University of Michigan. He is the author of more than 150 technical papers on anthropometry, digital human modelling, vehicle ergonomics,

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vehicle occupant crash protection, and related design tools. He is a Fellow of SAE International and has received numerous awards from SAE for contributions to the automotive engineering literature.

Xuguang Wang is a Senior Researcher at the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR, formerly, INRETS). After a PhD in Solid Mechanics, he joined INRETS in 1991, ever since working on digital human modelling for ergonomic simulation. He was involved in several European and industrial projects in collaboration with car manufacturers. He was the scientific coordinator of the project DHErgo (Digital Humans for Ergonomic design of products, 2008–2011), aiming to develop dynamic and musculoskeletal human models for ergonomic design of products. His current research concerns human motion control and simulation, and discomfort modelling for workplace design such as vehicle interior design.

The automotive industry has been the focus of digital human modelling (DHM) research and application for many years. In the highly competitive marketplace for personal transportation, the desire to improve the customer's experience has driven extensive research in both the physical and cognitive interaction between the vehicle and its occupants. Human models provide vehicle designers with tools to view and analyse product interactions before the first prototypes are built, potentially improving the design while reducing cost and development time. The focus of DHM research and applications began with prediction and representation of static postures for purposes of driver workstation layout, including assessments of seat adjustment ranges and exterior vision. Now DHMs are used for seat design and assessment of driver reach and ingress/egress. DHMs and related simulation tools are expanding into the cognitive domain, with computational models of perception and motion, and into the dynamic domain with models of physical responses to ride and vibration. Moreover, DHMs are now widely used to analyse the ergonomics of vehicle assembly tasks. In this case, the analysis aims to determine whether workers can be expected to complete the tasks safely and with good quality. This preface provides a review of the literature to provide context for the nine new papers presented in this special issue.

Seating comfort exhibits an important competition factor for most car manufacturers. In automotive engineering practice however, design and development of new and comfortable car seats is mostly based on "empiricism, legacy knowledge and extensive, time-consuming and costly prototyping and experimental/field testing" [Grujicic et al., (2009), p.4273]. It is outdated (Kolich et al., 2004) and driven by qualitative design targets, such as to avoid restrictions of mobility and postural fixity, which are considered a risk factor for spinal disorders. Nevertheless, even a qualitative goal can be hardly reached without quantitative data that supports design. Given that small movement mobility constitutes an important aspect of sitting comfort, with an impact on safety and workload (Fleischer et al., 1987), knowledge of human body shape is required to implement the rule in a seat design. Mergl et al. (2004) pointed out the shortened development cycle of car seats, while demand for more comfortable seats increases at the same time, and recommended the use of numerical models of body/seat interaction to satisfy this trade-off. The virtual investigation of static and dynamic effects on seating comfort yet requires an appropriate seat model considering static and dynamic properties of the structure, the foam and the trim beyond the application of an adequate human

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model (Siefert et al., 2008). The effort is justified though, because the contact interaction between human and seat is an important factor in the comfort sensation of subjects (Verver et al., 2004). In a comprehensive seat comfort model, Paul and Ackermann (2007) described comfort as a state determined by affective-motivational factors and cognitive-hygiene factors, which can each be subjective or objective. Cognitive-objective factors are for instance vibration, pressure and thermal comfort, while tactile comfort represents a cognitive-subjective factor, and posture or design constitute affective-objective factors.

The H-Point (Society of Automotive Engineers, 2009) is a key design determinate used by car and car seat manufacturers. Given that modern car seats are typically fullfoam seats, the H-Point location is primarily dependent on the highly non-linear and viscoelastic, quasi-static behaviour of foam, which is significantly different from its dynamic behaviour. Interfacial forces, including frictional forces and tangential shear forces between occupant and seat play an essential role in determining the static settling point in the system and thus the H-Point (Ippili et al., 2003). While the H-Point is currently modelled under symmetric conditions (Society of Automotive Engineers, 2008; van Hoof et al., 2004), Kyung and Nussbaum (2009) reported that driving postures (joint angles) were found to be bilaterally asymmetric and that therefore, driving postures of DHM should be described and positioned asymmetrically. They also found that seat design differences within vehicle classes did not have a substantial effect, while eye point determined driving posture. This coincides with the occupant posture cascade prediction model (CPM) approach, which combines multiple independent predictions of key postural degrees of freedom with inverse kinematics guided by data-based heuristics (Reed et al., 1999). It claims to produce accurate posture predictions for a wide range of passenger car interior geometries, although inputs to the model only include vehicle package dimensions, seat height, track angle, cushion angle and occupant anthropometry - and no seat material properties. This is somehow supported by findings from Yamazaki (1992), who when comparing a soft cushion seat (13.6 N/mm spring constant) with a standard seat (15.3 N/mm spring constant), found large variations in postures and deformations regardless of the cushions. Those differences were manifested in pelvis angle and thigh inclination, contact shapes, position of the inflection point along the surface curve, and absolute deformation. However, the feeling of seat hardness correlated with anthropometric variables and maximum vertical cushion compression, and it was concluded that seat comfort is influenced by the pressure and shape of the contact surface between occupant and seat, depending on the elasticity of body tissues and seat cushion. Correlation between body mass or hip circumference and seat contact area or seat pressure were also reported by Paul et al. (2012), who equally found that leg take-off point needs to be considered a function of seat design in terms of geometry, functional angles, surface shape and foam formulation, rather than anthropometry.

For seat safety, the seatback is significantly more important than the seat cushion, as it needs to support about 70% of the load in a crash (Viano, 2003). The aim of seat safety design, particularly for low-speed rear crashes, should therefore be to reduce the product of seat frame rotation stiffness at the recliner and seatback stiffness, as stiff seats develop proportionately higher loads on the occupant, and therefore require more structure to sustain the forces. This leads to heavier and more costly designs and degraded safety performance. Apart from head restraint position and potential intrusion of anti-submarining components, the safety design target has no impact on seat comfort.

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When investigating seat comfort with a focus on ride comfort, typically in a frequency range of 0–30 Hz, acceleration is mostly measured on the seat cushion acting along a vertical axis representing the subject spine, and on the seatback for a longitudinal axis acting normal to the subject trunk or shoulders. For predicting ride comfort, the human can then be represented using either physical or analytical models. The active, three-dimensional physical vibration dummy MEMOSIK V (Mozaffarin et al., 2008) simulates the human dynamic behaviour by reproducing an equivalent dynamic mass in the fore-and-aft, the lateral and the vertical direction, considering seat cushion and seatback. The tool can be configured for mass percentiles F05, M50 and M95 and allows posture variation for the complete design range of passenger car and commercial vehicle seats. Rating human vibration exposure according to ISO 2631-1, it was developed using three different road excitation classes according to low, middle and high intensity in the frequency range from 0.5 up to 35 Hz. The dummy spine is equipped with adaptive torsion stiffness and serves for the simulation of the rolling characteristics of the human on the backrest. In an analytical approach, ride comfort can be predicted in lumped parameter models, as for example (Pennati et al., 2009) who developed a seat cushion model with two parallel spring-dampers, representing interface stiffness and damping between gluteus, femur and seat. Dynamic lumped parameter models sometimes neglect that cushion stiffness as a static seat factor determines how vibration influences overall seat comfort: cushions with lower stiffness are more comfortable and more sensitive to changes in vibration magnitude than cushions of higher stiffness, and perception of overall seat comfort depends on both static and dynamic factors, with cushion stiffness being a dominant factor for low vibration magnitude. Ebe and Griffin (2000a) thus predicted overall seat comfort in a linear model, including Young's modulus when loaded to 490 N and vibration dose value (VDV), following Steven's psychophysical law. The highest subjective comfort was found at a modulus of 16.6 N/mm (Ebe and Griffin, 2000b). Nonetheless this study provided only limited information about foam physical properties, and particularly sub-frame properties were not included in the model, which limits the use to rigid frame/pan seats. van Niekerk et al. (2003), using white noise excitation, also found a very good correlation between subjective ratings and SEAT values when both the subjective ratings and transmissibility were averaged over subjects. On the other hand, they pointed out that neither accelerometer location nor posture is standardised for the type of measurement. Equivalent results were confirmed under similar conditions for the VDV ride comfort evaluation tool developed by Pennati et al. (2009), although other than SAE J1013 accelerometers were used.

Patten and Pang (1998) mimed properties exhibited in open cell foams by using non-linear stiffness and damping effects in their vertical vibration seat cushion model. They reported conforming results between a simulation using the cushion model with an ISO 5982 vibration model of a seated human, and experimental data. Humans express significant discomfort when submitted to vertical vibration at about 5.8 Hz when sitting, as this frequency corresponds to a spinal resonance. In ride comfort measurements which assume an upright posture, approximately 70 percent of the human mass is supported by the seat, with the remainder supported by the feet interface with the floor pan. Vibrations are transmitted to the human body as a 'nimbling' (sic) sensation (from Japanese 'hyoko', a better translation would be 'poking') by vertical motion of the occupant in the 2–4 Hz range; as 'pressure on the stomach' in the 4–8 Hz range; and 'rugged, 'trembling' and 'tingling' sensations on the thighs above 8 Hz. For this reason seat pad materials need high vibration absorbance in the entire frequency range (Murata et al., 2002). When

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comparing a high-resilience with a low-resilience foam seat pad with otherwise identical properties (mould, hardness), the high-resilience type resin shifts the resonance point to a lower frequency and thus reduces vibration transmissibility at higher frequencies, while low-resilience foam lowers transmissibility in the lower frequency range. With their development based on a high-resilient foam, transmissibility at the resonance point around 2–4 Hz was increased, and as a countermeasure, the airflow rate of the polyurethane foam was suppressed using a high-activity polyol in order to increase the air damping effect of the system and absorb vibration in the low-frequency range. This foam exhibited superior ride comfort.

In this special issue, nine papers are selected covering a variety of DHM and their applications in the automotive industry:

- *Seat design and comfort assessment* (three papers by Paul et al., Reynolds and Siefert and Pankoke).
- *Driving posture investigation and prediction* (two papers by Bulle et al. and Gragg et al.).
- Interior design of a new concept car (by Kremser et al.).
- Effects of vibration on seated reach performance (by Kim and Martin).
- Ergonomic assessment of automotive assembly tasks (by Schaub et al.).
- *Human shape simulation under motion* (by Cheng et al.). Although this paper is not directly related to an automotive study, DHM capable of predicting dynamic shape have a great potential for assessing space requirement of a car interior (i.e., the vehicle package) or the workplace.

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