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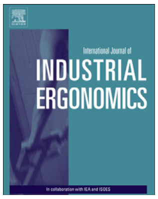

Biomechanical model to predict loads on lumbar vertebra of a tractor operator

C.R. Mehta [a], [*], V.K. Tewari [b]

[a] AICRP on Farm Implements and Machinery, Central Institute of Agricultural Engineering, Nabi-bagh, Bhopal 462 038, India
[b] Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur 721 302, India

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ABSTRACT

A biomechanical model is important for prediction of loads likely to arise in specific body parts under various conditions. The biomechanical model was developed to predict compressive and shear loads at L4/L5 (lumbar vertebra) of a tractor operator seating on seats with selected seat pan and backrest cushion materials. A computer program was written to solve the model for various inputs viz. stature and weight of the tractor operators, choice of operating conditions, and reaction forces from seat pan and backrest cushions. It was observed that maximum compressive and shear forces ranged 943–1367 N and 422–991 N, respectively at L4/L5 of tractor operators steering the tractor with leg and hand control actions and occasionally viewing the implement at back. The compressive forces were maximum (1202–1367 N) with coir based composite seat backrest cushion materials (thickness of 80 mm, density of 47.19 kg/m^3) and were minimum (943–1108 N) with high density polyurethane foam (thickness of 44 mm, density of 19.09 kg/m^3) for the seats.

Relevance to industry: The biomechanical model of a tractor operator is important for theoretical understanding the problem of sitting and is also valuable in prediction of compressive and shear loads at L4/L5 of operator under various operating conditions. It will help in design of tractor seat for operator's comfort.

1. Introduction

The nature of tasks on a tractor necessitates a number of actions to be performed by the operator, which puts varying physiological demands on the body. Examples of these tasks are steering of tractor, looking backward to observe and control the machine/implement, and force required to operate clutch, brake, and hydraulic control lever. The task and workplace determine the postures and create a pattern of loading on the structures of the body of the individual. The seat is one component affecting these loads. Tractor seat design can be used as a means to modify loads on the body structures to reduce operator's discomfort. The load on the spine and its distribution in time, as well as muscle activity resulting from postural and external loading, are important determinants of discomfort and pain in the back (Eklund et al., 1983). Knowledge of these loads is important for the design of tractor seat and for the evaluation of work tasks as well as for estimation of postural loads.

Pheasant and Harris (1982) studied the biomechanical factors, which influenced human strength in the operation of a tractor pedal. The variables investigated were horizontal distance in front of the seat reference point (SRP), vertical distance above and below SRP, lateral distance from the midline, direction of thrust and use of steering wheel for 'bracing'. They represented seat–man–pedal assembly by a kinetic chain of four linkages.

Eklund et al. (1983) described a method for calculating biomechanical load on the spine (at L3) and back muscles for a seated task. This method utilised a small computer online to a force platform and the results were obtained within a few seconds. It dealt with vertical forces arising from support of the hands and arms, weight lifting and vertical acceleration as well as trunk movements but did not deal with horizontally imposed forces.

Corlett and Eklund (1984) discussed loading on the spine and active muscles of the back during upright sitting. It was shown that the backrest was located at the lumbar spine area so that the centre of gravity (CG) of the super-incumbent body parts could be positioned above the vertebrae, permitting the gravity load to be

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* Corresponding author. Tel.: +91 755 2521163; fax: +91 755 2734016.
E-mail addresses: crmehta@ciae.res.in, crmehta65@yahoo.co.in (C.R. Mehta), prof.vktewari@gmail.com (V.K. Tewari).

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Nomenclature

Gravitational forces

W	gravitational force on the whole body
W_f	gravitational force on the forearms and hands
W_u	gravitational force on the upper arms
W_{sh}	gravitational force on the shanks and feet
W_t	gravitational force on the thighs
W_b	gravitational force on head, neck and trunk
W_{bu}	gravitational force on the trunk, neck and head above the chosen plane
W_{bl}	gravitational force on the trunk below the chosen plane

Supporting forces

F_t	reaction force on the seat pan
F_b	reaction force on the seat backrest

External forces

F_s	reaction force on the steering wheel
F_p	reaction force on the clutch or brake pedals
F_h	reaction force on the hydraulic control lever
M_n	moment around disc L4/L5 of twisting torque at neck
M_s	moment around disc L4/L5 of twisting torque at steering wheel
C_u	compressive force in the plane for upper body stability
C_l	compressive force in the plane for lower body stability
S_u	shear force in the plane for upper body stability
S_l	shear force in the plane for lower body stability
M_{L4}	moment around disc L4 in the sagittal plane

Inclinations

α	inclination of the shank with the horizontal
β	inclination of the thigh with the horizontal
γ	inclination of the torso with the horizontal
Y	inclination of reaction force on steering wheel with the horizontal
Φ	inclination of the feet with the horizontal
Y_u	inclination of upper arms with the horizontal
Y_f	inclination of lower arms with the horizontal
Y_h	inclination of hydraulic control lever with the horizontal
Y_n	inclination of upper arms with the vertical

Distances

d_{ih}	lever arm in horizontal direction between force F_i/W_i and point of moment calculation
d_{iv}	lever arm in vertical direction between force F_i/W_i and point of moment calculation
i	u, f, s, b, t, sh, p, h and cg

transmitted to the seat without counteracting torque which muscles would have to provide.

Viano and Andrzejak (1992) reviewed issues relating to seats including design for comfort, mechanics of discomfort, and low back pain. They focussed on the interface between seating technology and occupant comfort and found that seating features and riding comfort required more specific information on the biomechanics of discomfort by pressure distribution, body support, ride vibration, material breathability, and other factors. These inputs stimulated mechanisms of discomfort that need to be quantified in terms of mechanical requirements for seat design and function. They concluded that the new seat requirements need to be based on biomedical science and should include the needs of customers.

Hubbard et al. (1993) described a group of computer models and a drawing template that represented the geometry and movements of people of different sizes for design of automobile seating. These models included a two-dimensional articulated drafting template and a three-dimensional computer model of the skeletal system with soft tissue thickness. They represented the external body contours on the back of the torso, model of forces and moments between body segments based on seated posture, body segment masses, and seat surface forces. The developed models and template provided biomechanical information that assisted designers in creating seats that fitted and moved with people. It was observed that the geometric characteristics of people and their geometric interactions with seats were directly related to the physiological features of the seating comfort.

Oberg (1993) suggested a biomechanical model of the lumbar spine load due to twisted trunk postures during tractor ploughing. Video recording of tractor driver's work in a transversal plane was done to quantify head and trunk twisting angles and its duration's. A laboratory mock up of the interior of the tractor cabin was set up to reproduce and to measure these working postures using a three dimensional Mac Reflex position and motion analysis system. It was observed that the lumbar thoracic spine was kept twisted 37° during a whole furrow and head was twisted in relation to the shoulder further 90° to the right during 90% of the total duration and 20° to the left during 10% of the duration.

Boden and Oberg (1995, 1997) observed that the exerted torque from passive tissues at different twisting angles in sitting position for tractor drivers changed as the passive tissues were resisting or assisting the twisting action. They concluded that up to 20° rotation, the trunk twisting stiffness was approximately 0.1 N m/degree and after 40° rotation, the corresponding value was 0.4 N m/degree.

Hansson and Öberg (1996) described a method for analysis of static biomechanical load of an agricultural tractor driver when manoeuvring the controls inside the cab. The measurement procedure was standardized and the transfer of data from the opto-electronic measurements to the biomechanical model was computerized, which increased the accuracy and made it possible to analyse measurements of time series within a reasonable time. However, since the method was based on calculation of static load, it was mainly suited for analysis of static working tasks or tasks including only slow movements.

Srdjevic and Cveticanin (2004) proposed a method for identifying principal parameters of the n-DOF (n degrees-of-freedom) biomechanical model of a seated human driver. The model was considered as a structure represented by masses of human body segments, mechanical springs and dampers, and also as a biomechanical system with dynamic performances described in terms of response functions in the frequency domain, such as the driving-point mechanical impedance, and seat-to-head transmissibility function. The problem addressed was to identify the structural components that provided the best dynamic model performance for the driver-seat system. The proposed method was comprehensive in approach and efficient in application.

In order to assess the tolerability of a given posture, measurement of lumbar stresses is important. The stresses are generally expressed in terms of forces and moments acting on a given articulation of the lumbar spine and in particular on its