Seating discomfort for tractor operators – a critical review

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Abstract

A large number of studies have been conducted and researchers have suggested several criteria for evaluating discomfort and the suitability of a tractor seat in a given working condition. The studies have led to various parameters, viz. the body pressure distributed under and supporting both the buttocks, thighs and the back of an operator, control of posture in static or dynamic condition, ride vibration, exposure time on task and other factors. But in the absence of a more definitive and the most logical criteria particularly from biomechanical viewpoint, the researchers will continue to design conditions and procedures to understand the seat dynamics and evaluate the seating discomfort. Therefore, this paper reviews the research information available in this regard and attempts to set the most appropriate procedure for assessment of seating discomfort during tractor driving.

Relevance to industry

This paper attempts to project the most appropriate method of assessment and selection of tractor seats from engineering and biomechanical view point which could be adopted by the tractor seat manufacturers. It is designed to enhance the feeling of comfort, safety, convenience, and results in higher work output from the operator. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Seating discomfort; Biomechanics; Tractor seat design; Body pressure distribution

1. Introduction

Work tasks on a tractor necessitate a number of actions to be performed by the operator, which puts various demands on the body. Examples of these demands are front steering of tractor, looking backward to observe and control the machine/implement, force required to operate clutch and brake pedals, etc. The task and workplace determine the postures and create a pattern of loading on the structures of the body of the operator. The seat is one component affecting these loads. The tractor seat design can be used as a means to modify loads on body structures to reduce operator’s discomfort. The extended period of sitting include a higher risk of back problem, numbness and discomfort in the buttocks due to surface pressure and discomfort in the legs and feet from pressure under the thighs (Floyd and Roberts, 1958).
The sources of such discomfort are transmission of vehicle vibration to the occupant, body pressure distributed under and supporting both the buttocks, thighs and back of an operator, control of posture either statically or dynamically through differing load paths, clothing and seat covering material, perceptions and interior ergonomic characteristics. These inputs stimulate mechanisms of discomfort that need to be quantified in terms of mechanical requirements for seat design and its behaviour (Viano and Andrzejak, 1992). The biomedical causes of seating discomfort and their inter-relationship are given in Table 1.

Engineering design of seats has procedures to measure only the most basic mechanical aspects such as geometric parameters of seat, choice of suspension system and cushion material used. But, when the occupant sits in a seat, the mechanical parameters interact with the body and initiate physiological processes leading to discomfort. The tractor seat designers have given emphasis on ride vibration and geometric parameters of seat with respect to anthropometric data of users. While, the biomedical causes like pressure distribution at seat-operator interface and body posture are the main factors leading to discomfort to the tractor operator. There is a need to investigate these factors and develop/evolve specific procedures for seat selection and testing in a typical dynamic environment. In view of this requirement, the present paper discusses the aspects of discomfort in the seat-operator interface and presents a critical review of these relevant factors with the following major objectives:

1. The factors affecting seating discomfort.
2. The most appropriate procedure of assessment of operator seat from engineering and biomechanical considerations.

### 2. Biomechanical seating requirements

Biomechanics is defined as an interdisciplinary science (comprising mainly anthropology, mechanics, physiology and engineering) of the mechanical structure and behaviour of biological materials. It concerns primarily the dimensions, composition and mass properties of body segments together, the mobility in the joints, the mechanical relation of the body to force fields, vibration and impacts, the voluntary actions of the body in bringing about controlled movements in applying forces, torque, energy and power to external objects like controls, tool and other equipment.

The forces exerted by arms or legs of a tractor operator must be transmitted through the body and the seat to the ground. The backrest is a channel for such forces on many occasions, otherwise the musculature of the trunk must be tensed to provide a semi-rigid path for the force transmission. The generated muscle tension will increase the load on the spinal column, particularly in the lumbar spine, which is the major channel for load transmission from the upper to the lower part of the body (Corlett, 1989). A backrest can also reduce

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**Table 1**

<table>
<thead>
<tr>
<th>Human experience</th>
<th>Biomechanical causes</th>
<th>Engineering causes</th>
<th>Seat/environment Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>Circulation occlusion</td>
<td>Pressure</td>
<td>Cushion stiffness</td>
</tr>
<tr>
<td>Pain</td>
<td>Ischemia</td>
<td>Pressure</td>
<td>Cushion stiffness</td>
</tr>
<tr>
<td>Pain</td>
<td>Nerve occlusion</td>
<td>Pressure</td>
<td>Seat contour</td>
</tr>
<tr>
<td>Discomfort</td>
<td>—</td>
<td>Vibration</td>
<td>Vehicle ride</td>
</tr>
<tr>
<td>Perspiration</td>
<td>Heat</td>
<td>Material breathability</td>
<td>Vinyl upholstery</td>
</tr>
<tr>
<td>Perception</td>
<td>Visual/auditory tactile</td>
<td>Design/vibration</td>
<td>Vehicle cost</td>
</tr>
</tbody>
</table>
loads on the lumbar spine by transmitting part of the gravity forces due to the head, arms and upper trunk (Corlett and Eklund, 1984). The comfort of a seat depends, in a dynamic sense, on the extent to which it permits muscular relaxation while stabilising the open-chain system of body links. A decrease in the muscle activity in the shoulder and neck region was found when the tractor seat was swivelled up to 20° from the normal forward facing position. The swivelling seat was found beneficial to the driver, particularly for tasks requiring mainly rearward visual monitoring (Bottoms and Barber, 1978).

Donati et al. (1984) designed a mock tractor of a typical medium-sized tractor set on a rig to simulate the work place and reproduce the visibility conditions of this class of tractor. They developed a combined steering and vigilance task to simulate tractor operations. It was concluded that the tractor operator’s posture is important particularly while assessing the height of backrest. The height of the backrest has to be high enough to offer correct support to the operator’s back yet sufficiently low to enable him to control a rearward implement. However, in other vehicles such as car the opinion is different. In cars, the driver’s posture is more relaxed with larger seats having better body contact as compared to that for a tractor driver. The tractor operator on the other hand, requires looking back to monitor the operation, steer the vehicle, operate different levers, viz. clutch, brake, gear and throttle and hence they require force, skill, alertness and associated body postures.

The International Standard (ISO 4253, 1993) and Indian Standard (IS 12343, 1988) lay down dimensions for the operator’s seat and location of specific control relative to the seat index point (SIP) within the seating accommodation on agricultural tractor with a track width greater than 1150 mm. The seat index point (SIP) as per ISO 5353 (1984) is the interaction on the central vertical plane passing through the seat centreline of the theoretical pivot axis between a human torso and thighs (Fig. 1). The controls included are the steering wheel, clutch pedal, brake pedal and throttle pedal.

Ng et al. (1995) used a questionnaire to 20 healthy subjects to determine the important features of a car seat. They mounted the test seat on a seat buck, which simulated the driver’s side of a car. They concluded that 70% of the car drivers felt that lumbar support and seat pan tilt are very important while only 35% felt the height of the seat pan (from floor) is very important. Subjects indicated that their perception of seat comfort was influenced most by thigh support (75%), thoracic support (70%) and lumbar support (65%). This study was conducted under static condition. However, the subject’s weight distribution on the seat pan and backrest varies between static and dynamic conditions. Therefore, the subject’s perception of seat comfort must be evaluated under dynamic condition.

Table 2 gives important seat features and attributes related to tractor operator comfort. The seat cushion supports 60–75% of the body’s static mass depending on body shape and size and its posture in the seat. Dynamically, the seat cushion is compressed with much higher forces than the seat back due to greater vertical accelerations compared to fore-aft or lateral accelerations in normal driving. Sometimes, vertical acceleration forces while riding may allow the seat cushion to momentarily
support more than 300% of the total static mass (Pywell, 1993).

2.1. Physiological aspects

Fig. 2 gives a simplified model of a comfortable seat design approach based on biomechanical requirements. As depicted, research is presently limited in its understanding of physiological parameters relevant to positive state of comfort and of moderate levels of discomfort. Discomfort is a subjective experience, which can result from a combination of physiological and psychological processes, time on task and muscle fatigue. Discomfort in a seated posture is experienced when pressure on soft tissues results in a shortage of oxygen and a build up of carbon-dioxide and waste products such as lactic acid. Estimation of such discomfort requires physiological measurements because it appears to provide an objective corollary of subjective experience (Lueder, 1983).

Schmidtke (cited in Rohmert and Luczac, 1978) has classified the phases of physical fatigue that appears to parallel sequential phases of discomfort. In the first phase, task-specific physiological disturbances can be detected, such as muscle activity (electromyograms), generally appearing prior to one's cognition. In the second phase, disturbances reach a level at which operator perceives them. This indicates a reaction of arousal and activation (i.e. heart rate, arrhythmia, and EMG of trunk muscles not specifically related to task).

In a seated posture, the mass of the head, torso, arms, hands, and any mass suspended in hands are supported down the spinal column (Fig. 3). The figure indicated a series of individual vertebrae interlaced with compliant disks, able to withstand compressive forces acting axially through the

Table 2
Important seat features and attributes for tractor operator

<table>
<thead>
<tr>
<th>No.</th>
<th>Seat attributes</th>
<th>Seat features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lumbar support</td>
<td>Lumbar support</td>
</tr>
<tr>
<td>2.</td>
<td>Seat back firmness</td>
<td>Seat back tilt</td>
</tr>
<tr>
<td>3.</td>
<td>Seat cushion firmness</td>
<td>Cushion stiffness</td>
</tr>
<tr>
<td>4.</td>
<td>Thoracic support</td>
<td>Seat back tilt</td>
</tr>
<tr>
<td>5.</td>
<td>Seat back size</td>
<td>Seat dimensions</td>
</tr>
<tr>
<td>6.</td>
<td>Buttock support</td>
<td>Seat cushion material</td>
</tr>
<tr>
<td>7.</td>
<td>Seat back lateral support</td>
<td>Seat backrest</td>
</tr>
<tr>
<td>8.</td>
<td>Thigh support</td>
<td>Seat pan tilt</td>
</tr>
<tr>
<td>9.</td>
<td>Physical appearance of the seat</td>
<td>Aesthetics</td>
</tr>
<tr>
<td>10.</td>
<td>Seat cushion size</td>
<td>Seat dimensions</td>
</tr>
<tr>
<td>11.</td>
<td>Colour of the seat</td>
<td>Aesthetics</td>
</tr>
</tbody>
</table>
column. The muscles, acting in tension, apply compressive loads between the ends of skeletal members to apply rotational force at the pivots. In a dynamic condition, the spinal column acts like a shock absorber or an energy absorber and transmits vertical forces. The energy transmission and isolation paths affect the operator comfort. The spinal column loads the iliac spine (pelvis) and the gluteus maximus (buttock) region. The spinal column vertical forces are applied in shear and compression through ligaments to the pelvis. The pelvis, in a seated position, distributes these forces through the buttock muscle via surface area around the lower pelvic bone surface. The forces are further distributed outward through the buttock to the buttock-seat interface where the compressive forces are opposed by the cushion surface stiffness and shape. The buttock muscle area directly beneath the ischial tuberosity is in compression across the muscle. The compression forces on the buttock and surrounding muscle compromise their ability to exchange nutritional input and metabolic by-products with the circulatory system, resulting in lactic acid accumulation, influencing neural stimulus of fatigue and pain. The muscle size and mass are determinant of the forces the muscle can comprehend. The buttock muscle is larger and thicker than surrounding muscle. Therefore, this can better able to withstand compressive forces during sitting. The interface of the gluteal and posterior femur muscles with a vehicle seat cushion may determine the muscle’s ability to maintain efficacy with minimum pain or discomfort. The shape and compliance of the seat cushion may affect the occupant’s ability to withstand the vertical forces between the body and the seat (Pywell, 1993).

2.2. Engineering aspects of seating discomfort

The biomechanical and engineering factors like ride vibration, pressure distribution at the seat–operator interface and the body posture play an important role in a tractor seat-design. A well-designed seat should be able to accommodate all sizes and shapes of users and should provide adequate body support. When the body is not well supported, several muscle groups act together to restore stability, contributing to static loading resulting in discomfort to the occupant (Gross et al., 1992).

2.2.1. Pressure distribution

Pressure distribution at the seat–operator interface is the main factor for seating discomfort evaluation. Usually, a sitting person unconsciously adjusts his body position when he feels discomfort. There is an inverse relationship between the tolerable pressure levels and the time duration of the pressure. This time pressure relationship depends on many factors such as general health of the patient, the diet, seat pan and backrest cushion type etc. If pressure is relieved intermittently, higher pressure can be tolerated for the same time period or a longer duration of a specific pressure. A good cushion distributes the pressure more uniformly over the skin area. Thus, it decreases the incidence of pressure sores and lengthens the tolerable time period in a given body position (Chow and Odell, 1978). Sanders and McCormick (1993) suggested that the weight should be distributed rather evenly throughout the buttock area, but minimised under the thighs. The study conducted by Ng et al. (1995) showed that the pressure distribution was uneven across the thighs and buttocks, with most of the load concentrated in the buttock region. There was good pressure distribution in the lumbar and thoracic regions. Consistent with the subjective responses, loads on the thoracic and lumbar bolster regions were low, which indicates that more support should be provided in these areas.

Tractor seat design with raising the front portion of the tractor seat cushion using low density foam material and padding the remaining portion with a minimum thickness of foam avoided equal pressure weight distribution over the buttocks and minimised the scrubbing motion of the body relative to the stabilising backrest (Morrison and Harrington, 1962).

However, the seat pan cushion for tractor seat should neither be too soft nor too hard on the outlying portions of the buttocks to maintain blood circulation to prevent muscular fatigue and discomfort during long period of sitting of the operator. The most of the body weight during sitting must be supported at the ischial tuberosities and diminish towards surrounding areas. This can be
accomplished by proper selection of seat cushion material and proper seat height above the footrest.

2.2.2. Body posture

The agricultural tractor driving requires the operators to maintain a stable posture despite dynamic conditions so as to perform the driving task even while looking backwards to observe and control the machine attached to the rear of the tractor. These requirements may involve a large number of turning movements from looking ahead to behind and vice versa resulting into a poor posture (Donati et al., 1984). Barber (1979) reported 11, 17 and 15 turns/min. for the ploughing, forage harvesting and baling operations, respectively. These operations forced drivers to spend a large proportion of their time looking backwards resulting in spine loading. If the spine is subjected to postural stress for long enough, it stiffens as well as shortens. Due to this disturbance to the spine joint, a change in the pattern of activity in proprio-ceptive and kines-thetic neurons takes place (Troup, 1978). The perceived postural load could be assessed in terms of frequency and/or duration of awkward posture at work. Study by Bovenzi and Betta (1994) indicated a linear trend of increasing prevalence of low back pain (LBP) with increasing perceived postural load in tractor drivers. The drivers with excessive exposure to whole body vibration (WBV) and postural stress had more than three-fold increased risks for chronic LBP compared with the unexposed subjects.

In view of this, the swiveling of tractor seat, optimum location of controls and the operator’s work place design are advantageous. A tractor seat with a swivel up to 20° from the normal forward facing position resulted in a decrease in muscle activity in the shoulder and neck regions and increase in rearward visual monitoring (Bottoms and Barber, 1978). The use of mirrors has also improved the working posture. However, this was not effective for controlling implements located outside the cab. Further, the use of these mirrors required a certain learning effort from the drivers, which goes against their habit of direct viewing of implements (Sjoflot, 1980). Rajvir (1995) reported operators frequency of operation per hour of clutch pedal, brake pedal, draft control lever and viewing rearward of 44, 112, 90 and 169, respectively, during field study. The tractor configuration having steering column angle with respect to horizontal 70°; pedal locations from seat reference point (SRP) – clutch 590 mm, brake 620 mm and draft control lever 295 mm was the best for Indian operators. The most efficient location of controls resulted in steering column angle of 64.8° with horizontal, foot pedals (clutch and brake) distance of 627 mm from SRP and the draft control lever distance of 167 mm from SRP for Indian operators based on minimum energy expenditure rate (EER) and rated perceived exertion (RPE) scores. The seat reference point as per IS: 12343 (1988) is the point in the central longitudinal plane of the seat where the tangential plane of the lower backrest and a horizontal plane intersect. The horizontal plane cuts the lower surface of the seat-pan board 150 mm in front of the plane parallel to the rear face of the lower backrest board (Fig. 1).

3. Models for seating discomfort

Many researchers assume that comfort and discomfort are two opposites on a continuous scale, ranging from extreme comfort through a neutral state to extreme discomfort (e.g. Shackel et al., 1969). Hertzberg (cited in Lueder, 1983) “first operationally defined comfort as “the absence of discomfort”. Many research studies indicate that discomfort is primarily associated with physiological and biomechanical factors and that comfort is primarily associated with aesthetics. Fig. 4 shows a hypothetical model for perception of sitting discomfort and comfort. The transition from discomfort to comfort and vice versa is possible in the intersection of the axes. Hence, if discomfort is increased, such as with increase time on task and fatigue, comfort will decrease. Although good biomechanics will not increase the level of comfort, it is likely that poor biomechanics may turn comfort into discomfort (Zhang et al., 1996). Hence, comfort can be defined as the sense of well being, plushness of the seat and discomfort as poor biomechanics, fatigue and restlessness. Thus, one cannot provide comfort in a seat design; one can only eliminate sources of discomfort. Seats may be described as being either ‘comfortable’ or ‘uncomfortable’. 
Jacobson et al. (1978) developed mathematical models for predicting human comfort responses to environmental variables for diverse vehicles. They also developed a composite model for ground based vehicles and is given by

\[ C = 1.42 + 0.69R + 0.04(\text{Noise} - 60) \]

where \( R \) is r.m.s. roll rate in deg \( \cdot \) s\(^{-1} \) and \( C \) is the comfort level.

It has a multiple correlation of 0.65, thus accounting for 42% of the variance in mean comfort levels. This model did not predict comfort for existent vehicles but rather to do so for non-existent ones.

Leatherwood et al. (1980) developed an empirical model for the prediction of passenger ride discomfort in the presence of complex noise and vibration inputs. The three basic elements of the empirical model were estimation of discomfort due to sinusoidal and/or random vibrations within single axis, empirical estimation of discomfort due to vibration in combined axis and application of empirically determined corrections for the effect of interior noise and duration of vibration (Fig. 5). The output of the model, discomfort estimate was in the form of a single descriptor (DISC level). This model was based upon the empirically derived psychological functions relating human discomfort response to the level of the physical stimuli that produce the response.

The tractor operator comfort is dependent on vehicle design, the way the vehicle is operated and the expectations and sensations of drivers. Seat is one of the most important components, which influence the comfort of a tractor operator (Stikelather, 1991). Because, it provides the interface between a mechanical system, the tractor, and the delicate and sensitive human biological system, the operator. Therefore, there is a need to develop a model or method of predicting operator perception of vehicle comfort for an efficient and successful tractor seat design. The seat design process should consider the relative and combined effects of different causes of discomfort and consider whether customer opinion of good comfort can be achieved without unnecessary reductions in stimuli commonly associated with discomfort.

4. Ride vibration discomfort

Comfort in vehicles requires the absence of unpleasant intrusions. Vibration can be a principal cause of discomfort in tractors. The vibration characteristics which mostly influence response are the
direction of the vibration, the point at which it comes into contact with the body, the vibration frequency, its magnitude and duration (Griffin, 1986). The low-frequency vibration produced by an agricultural tractor can be extremely severe, depending upon the terrain the tractor is crossing and the speed of travel. In order to reduce the health risks to the driver and discomfort experienced and to enable the driver to work more quickly, it is important to isolate the driver from the vibration as much as possible (Fairley, 1995).

Bovenzi and Betta (1994) investigated the occurrence of low back pain in a population of 1155 tractor drivers exposed to whole-body vibration (WBV) and postural stress. They concluded that low back disorders in tractor drivers were significantly associated with both vibration dose and postural load. The exposure level for WBV recommended by a proposal of European Directive on Physical Agents seem to be more adequate to prevent long-term health effects on the lower back than the exposure limits suggested by the ISO 2631/1 (1985).

Fairley (1995) conducted a field study to predict the discomfort caused by tractor vibration from objective measurements of vibration in the cabin. Eleven professional drivers judged the vibration discomfort produced by four different tractors on 16 different test runs. For each of 704 tests carried out, the discomfort caused by the vibration was predicted from the measured vibration in the cabin using a total of 20 different procedures. On the basis of correlation between the subjective judgements and predicted values, it was concluded that the best procedure for predicting the vibration discomfort in an agricultural tractor is that recommended by ISO 2631 (1978) using the frequency weighted r.m.s. values of vibration (0.5–20 Hz) measured on the seat pan in the three orthogonal directions, and taking the square-root-of-the-sum of the squares of the values in order to combine the directions as recommended in amendment 1 to ISO 2631 (1985).

Lines et al. (1995) measured whole-body vibration on tractors and other agricultural vehicles during a wide range of normal field operations. It was concluded that a majority of tasks exceeded the level of ISO 8-h exposure limit. They found that tractor drivers regularly exceeded the vibration limit given by the proposed EC Directive on Physical Agents. They recommended that the assessment of tractor vibration should be based on BS 6841 using the root mean quad (r.m.q.) method. The assessment of tractor vibration using ISO 2631 may under-estimate vibration severity.

In view of above studies, it is found that researcher opinions are divided on the use of standards for ride vibration evaluation on a tractor under dynamic conditions. But, it was observed that the tractor operator should not be exposed to more than 2.5 h continuously to cause severe discomfort, pain and injury. The ISO 2631/1 and BS 6841 may be used for evaluation of vibration exposure time and vibration dose value, respectively.

5. Discomfort assessment

The assessment of seating discomfort during tractor driving may be approached by objective measurement as well as subjective assessment.

5.1. Objective techniques

5.1.1. Physiological method

The most widely used forms of physiological comfort have been EMGs of large muscle groups relevant to the task. EMGs have also been used to evaluate seat design and posture. The surface electrodes that are able to sum over larger areas are located remotely and measured muscle activity of indeterminate volumes. In another approach, the comparison of relative stresses acting on the spine is done. The x-rays are also used to examine deviations from the normal spinal curvature with different sitting positions. A needle-shaped pressure transducer was developed to measure spinal pressure by inserting it into the intervertebral disc (Lueder, 1983).

A dual mode bicycle ergometer is used for hand and leg load. The hand posture is a simulation of driver’s posture in tractor-driving task. The sitting-resting heart rate (HR) and oxygen consumption rate (OCR) are recorded using telemetry system and oxylog respectively before the start of the experiment. Each work bout is performed for
6 min. The signal of HR (beats per min.) are recorded from chart paper of cardiomin and OCR (l per min.) are recorded on the oxylog. Energy expenditure rates are calculated with the calorific equivalent to oxygen at a respiratory quotient (RQ) equal to 0.8 (Rajvir, 1995).

5.1.2. Seat pressure

Several researchers have measured the pressure at the human-seat interface using electronic sensors (capacitive, resistive, strain gauge), pneumatic and elektro-pneumatic. However, the visco-elastic behaviour at the interface is completely altered by the sensors used. Furthermore, many of these sensors cannot be used under dynamic loading conditions (Prasad et al., 1995).

To overcome these problems, Ng et al. (1995) used flexible pressure mats made of force-sensing resistors to measure seat pressure. These pressure mats were configured over the seat pan and seat backrest and do not affect seat geometry. The seat pan mat was designed to cover an area of approximately (407 mm × 407 mm), which included 225 pressure points arranged into a 15 × 15 matrix. The seat backrest mat measured (356 × 533 mm) and also consisted of 225 pressure sensors arranged into a 15 × 15 matrix. At zero or very low pressures, the sensors performed as an open circuit. After the pressure had reached a low threshold, increasing the force rapidly reduced electrical resistance. Data were collected from the seat pan and seat backrest pressure mats simultaneously with the subject seated at his preferred setting. During data collection, the subject assumed a driving posture with both hands gripping the steering wheel, the right foot on the accelerator pedal and the left foot on the 'dead' pedal. Seat pressure data for the seat pan and seat backrest for each subject were obtained and averages of seat pressures were divided into 12 regions for analysis. This pressure measuring technique is fast, dynamic and allows real time viewing of the pressure data. But, the instrumentation is neither economically viable nor readily available.

There is a need in the tractor industry to derive objective measures of seat comfort/discomfort assessment. The method of interface pressure measurement would provide designers with rapid, easily quantifiable data, which would indicate areas of seat which were contributing to seat comfort/discomfort at an early stage in the design process. It will also help in the selection of cushion materials for the tractor seat pan and seat backrest.

5.1.3. Ride vibration assessment

The SAE J 1384 (1993) establishes a method for testing of seats of agricultural tractors. The standard describes a procedure utilizing human subjects (operators) for measuring and evaluating seat performance in the laboratory as a function of machine type and operator weight. The method measures the frequency weighted root-mean-square vertical acceleration transmitted to the operator at the seat/buttock interface (whole body vibration) during simulated machine vibration on a vibration test stand or ride simulator. The test shall be carried out with two test persons: one with a total mass of 55 kg (−0%, +10%) of which not more than 5 kg may be carried in a weighing belt around the waist, the other with a total mass of 98 kg (−0%, +10%) of which not more than 8 kg may be carried in the belt.

The International Standard ISO 2631 (1974, 1978) originally recommended that the discomfort caused by whole-body vibration should be evaluated on the basis of simply the worst frequency component of the frequency weighted vibration measured on the seat pan in the most uncomfortable direction. This was changed by amendment 1 to ISO 2631 (1985) which recommends taking the square root of the sum of squares of the frequency weighted r.m.s. values of the vibration measured on the seat pan in the three orthogonal directions.

The realization of the limitations of the International Standard, and the importance of vibration input other than at the seat pan in some situations, led to the development of methodology used in the British Standard BS 6841 (1987), which sums multi-axis vibration measurements on the foot rest, the seat pan and the backrest in order to predict the overall vibration discomfort. The standard also includes the option of using root-mean-quad (r.m.q.) values instead of root-mean-square (r.m.s.) values for analyzing impulsive vibration, or of using vibration dose values for intermittent or time-varying exposures.
5.2. Subjective assessment

The use of subjective responses regarding comfort frequently entails four assumptions described by Branton (1969), two of them are particularly relevant. It is assumed, first, that the respondents are aware of their feelings of comfort and, second, that feeling of comfort can be verbalized. The techniques of assessment chosen will depend, upon whether discomfort of the whole of the system (tractor itself) is to be investigated or whether specific aspects of the operator’s environment are to be considered. The normal technique of assessing the overall discomfort of an existing system is by using questionnaires. In order to produce valid and reliable responses, the questions asked must be unambiguous, to the point and must be able to be understood by most people of all age groups and intellectual levels. The techniques used to rank and rate subjective discomfort are given below.

5.2.1. A pair comparison technique

This psychological scaling method is used to determine subjects preferred and least preferred seats for the trials.

In this technique, all seats to be evaluated are presented to the subject in all possible pairs. It is then required to judge whether one of the pair is of a greater quantity than the other along a predefined dimension. The subject’s response, therefore, is essentially a comparative judgement. A matrix of the proportion of times one seat is preferred over another, from which a ranking (and thus determine the relative importance of) of the seats was calculated (Oborne, 1978).

5.2.2. Rating scales

First, the subject is required to rate comfort for various features of the seat pan and seat backrest on a scale of 1 to 10, with 1 representing ‘very poor’ and 10 representing ‘very good’. The second has a scale of +10 to −10 representing each extreme condition of the factor, with the midpoint 0 representing ‘just right’. For example, for seat cushion firmness, −10 corresponds to ‘too firm’ and +10 correspond to ‘too soft’. These comfort ratings were based on a continuous interval with a normal distribution (Ng et al., 1995). Another method using general comfort rating consists of a 16 cm horizontal line that is marked ‘little discomfort’ at one end and ‘much discomfort’ at the other end. The driver has to put a cross on the horizontal line at the end of the test run in relation to his feeling of overall vibration discomfort magnitude (Fairley, 1995).

The category partitioning scale (CP-50) (Shen and Parsons, 1997) shown in Fig. 6 can be used for rating seated pressure intensity and perceived discomfort. In this method, the subjects will be asked to rate the pressure stimuli by selecting numbers from the two scales subdivided into five categories.

<table>
<thead>
<tr>
<th>Pressure Level</th>
<th>Comfort Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pressure / No discomfort</td>
<td>0</td>
</tr>
<tr>
<td>Very low pressure / Slight discomfort</td>
<td>5</td>
</tr>
<tr>
<td>Low pressure / Slight discomfort</td>
<td>15</td>
</tr>
<tr>
<td>Medium pressure / Discomfort</td>
<td>25</td>
</tr>
<tr>
<td>High pressure / Severe discomfort</td>
<td>35</td>
</tr>
<tr>
<td>Very high pressure / Severe discomfort</td>
<td>45</td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6. Category Partitioning Scale (CP-50) for rating pressure intensity and perceived discomfort (Shen and Parsons, 1997).
Firstly, he will be asked to determine the category into which the pressure intensity or discomfort levels falls. Then, he may “fine tune” his judgement using the numbers within the category.

Sometimes, a body area chart discomfort checklist (Fig. 7) is used. In this the subject is asked to identify body areas experiencing discomfort and to rate this discomfort on a 10 cm long unmarked visual analogue scale with ‘no pain or discomfort’ on one end and ‘agony’ on the other end. The subject is also asked to indicate what type of sensation is contributing to the discomfort. Two discomfort checklists are to be filled out, one at the start of the test and the second after a long period in the seat (Lusted et al., 1994). The ratings are then compared to estimate the level of discomfort.

The various features of the tractor seat pan and seat backrest must be rated first on a scale of 1 to 10 and second on a scale of —10 to 10. The category partitioning scale (CP-50) may be used for rating seated pressure intensity and perceived discomfort. The body area chart discomfort checklist may be used to rate this discomfort under dynamic condition to identify body area experiencing discomfort.

5.3. Posture analysis

Two methods are commonly used for assessment of postural discomfort at work. These are body mapping (Corlett et al., 1976) and rating the frequency of each posture (Bovenzi et al., 1994).

5.3.1. Body mapping

In this method, the perceived discomfort is referred to a part of the body (Fig. 8). The subject is
Fig. 8. Body map and scales for discomfort assessment (Corlett et al., 1986).

asked if he or she experiences discomfort from any part of the body. If so, the subject is asked to mention all body parts with discomfort, starting with the worst, the second worst and so on until all parts have been mentioned. The subject is also asked to assess total discomfort, and discomfort from the worst on a particular body part, using a "five or seven point scale. The scales are graded from 'no discomfort' at all to 'maximal discomfort' (Corlett et al., 1986).

5.3.2. Rating the frequency of each posture

The awkward posture at work (prolonged sitting, twisting, bending forward and lifting) is assumed by rating the frequency and/or duration of each posture on a five-item index scale assigning a value from 0 ('never') to 4 ('very often'). A mean value of the postural indices during a typical workday is calculated for each subject and a new measure of perceived postural load is constructed by categorizing the average postural load into four grades:

- Mild: 0–0.99
- Moderate: 1–1.99
- Hard: 2–2.99
- Very hard: 3–4

6. Concluding remarks

Discomfort is the subjective experience, which can result from a combination of physiological and psychological processes, total time spent on task and body posture assessed for task related muscle fatigue. Several mathematical models have been developed for the prediction of the passenger ride discomfort in the presence of complex noise and vibration inputs. However, there is no exclusive model available for tractor operator's comfort in a static-cum-dynamic condition particularly with regard to the type and property of the cushion materials used. Hence, a comprehensive and practical method for the assessment of the relative performance of tractor seat pan and seat backrest cushion material is needed with a view to reduce tissue stress and stress gradient.

It is felt that to improve operator's comfort on a tractor seat during dynamic condition, there is a need to have more specific information on biomechanics of discomfort by seat pressure distribution, body support, ride vibration, body posture, and cushion materials used. The assessment and evaluation of seating discomfort should be approached by way of objective as well as subjective assessment.

The objective assessment of tractor seat should be approached by the measurement of pressure and ride vibration at the seat–operator interface. The subjective assessment must be done by rating the different features of seat and seat pan backrest on scales of 1 to 10 and 0 to 10 and rating the complete seat on unmarked scale. The work related body area chart discomfort checklist must be used to identify body areas experiencing discomfort and rate it on a scale. The postural discomfort must be approached by rating the frequency and/or duration of each posture on a five item index scale assigning a value from 0 (never) to 4 (very often).
The different researchers have different view regarding the overall (the best) procedure for predicting the vibration discomfort in an agricultural tractor. However, the ISO 2631/1 and BS 6841 appear reasonable comprehensive criteria for evaluation of tractor ride vibration. The crest factor must be given due importance for calculating vibration dose value.

References


Purcell, W.F.H., 1980. The human factor in farm and industrial equipment design. Lecture series no 6 by the Power and Machinery Division Tractor Committee (PM-47), American Society of Agricultural Engineers, St. Joseph, MI, USA.


