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Ergonomics in Agriculture

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ABSTRACT

Heavy physical work, inadequate working methods, working techniques and tools not only cause unnecessary fatigue and occupational accidents but also leads to low productivity. Some of the crucial factors for poor productivity are like the use of local artisans made tools/equipment; imported tools/ equipment which are not suitable for targeted user's physical capacity; anthropometric data are not taken into considerations for tools/ equipment design. Compared to other industries, ergonomic interventions and solutions have been late coming into agriculture. Application of ergonomic knowledge from various sub-disciplines of ergonomics, e.g., agricultural ergonomics, occupational health and safety, environmental ergonomics and design-ergonomics might be useful for developing sustainable agricultural practices with better productivity and farmer's wellbeing. Humans are variables in their size, shape, characteristics, etc. knowledge of variability in databases helps to provide a baseline, how much adjustability or what range of forces are to be considered to accommodate the intended population of agricultural workers. Body scanning technologies such as 3D anthropometry are maturing but, in developing countries like India, we are still using traditional methods which are time-consuming, and reliability of data is questionable. There is a need to promote inexpensive 3D anthropometry system that would be readily accessible to researchers/ engineers. Therefore database for anthropometry, strength and physical work capacity should streamline on a priority basis.

INTRODUCTION

Agriculture production has experienced a relatively high diffusion of advanced technologies including information systems, automated machinery systems, and even robotic systems that complement or substitute labor tasks. However, as an occupational environment, regardless of these major technological advances, agriculture is regarded as one of the most demanding and hazardous sectors. As a matter of fact, it is ranked second among occupational injuries, fatalities, and illnesses. The host of health problems involves hearing loss, cancers, musculoskeletal disorders (MSDs), and pesticide-caused and respiratory illnesses. The risk factors associated with the musculoskeletal disorders (MSDs) during different agricultural tasks have been extensively like as harvesting of fruit and tree nut crops, climbing ladders meet the burden of bearing heavy loads, repetitive cutting, and excessive reaching. These arduous tasks turn out to cause pain in the whole body, but mostly in the hands, wrists, shoulders, and low back. Prolonged stooping, stresses on the one hand from the tool, and on the other hand from the plant and repetitive gripping are the principal risk factors. Ergonomics in agriculture is a versatile and interdisciplinary topic that involves the identification of the risk factors pertaining to MSDs; the determination of the root causes; as well as the development, implementation, and evaluation of ergonomic interventions. The most widespread and alarming non-lethal disease among farmers is considered to be the MSDs. Fathallah, F.A. Appl. Erg. 2010. Manual operations such as harvesting and pruning are very common, in particular in developing countries. These tasks involve working in awkward postures, prolonged and repetitive trunk bending, kneeling, heavy carrying and lifting, which constitute the main risk factors for the pathogenesis of MSDs. Manual operations such as harvesting and pruning involve working in awkward postures, prolonged and repetitive trunk bending, kneeling, heavy carrying and lifting, which constitute the main risk factors for the pathogenesis of MSDs. Benos.L. *et.al.* Appl. Sci. 2020. Working in a stooped posture is an important risk factor for low back disorders (LBDs) that requires special focus. Spinal flexion increases the loading on the passive tissues of the lumbar spine compared to neutral postures, yet sustained or repeated flexion reduces the load bearing capability of these tissues.

Present status of ergonomics in Indian agriculture

Anthropometric and biomechanical characteristics of the users are essential for designing tools and equipment for enhancing their comfort, safety and productivity. On the other hand, the use of poorly designed tools and equipment fails to account for the anthropometric and biomechanical characteristics of its users and has a negative influence on human health. Across India, the anthropometric and biomechanical database of agricultural workers has been compiled and utilized by various researchers to design, development, design modification of various tools and equipment; while anthropometric database and muscular strength database are limited for Northeast India. Moreover, tools/equipment designed specifically for the population of one region could not be used for the people in other regions without modification or redesign to consider differences in their characteristics. Furthermore, it has been observed that minimal work has been done for tools and equipment used in this region. Indeed, it has also been shown in different circumstances that although farmers are rational and intelligent enough, technological stagnation or slow improvements may still withstand them.

Application of practical knowledge from various disciplines of ergonomics like agricultural ergonomics, occupational health and safety, environmental ergonomics and design ergonomics may be useful for developing sustainable agricultural practices leading to a better productivity and uplifted farmers' well-being. Anthropometric and biomechanical database along with information regarding the cause and prevention of injury/accidents are essential requirements for the design and development of appropriate tools/equipment. The ergonomic design of products adapted to the user population puts particular emphasis on an ergonomic approach that is anthropometric as well as the biomechanical database. It is true that the user-centered design of tools and equipment takes into account not only the physical human body dimensions but also strength capabilities of intended users. Patel T (2020) J Ergonomics. The efficiency of the man machine system depends on the human operator, the tool, and the task. Therefore, understanding of the relationship between the capabilities of human worker and the force requirement for operating tools and equipment is of fundamental importance to ergonomic research and practice. A large amount of strength required to perform a task or failure to include variability in its range can produce degraded results which can affect the musculoskeletal system by physical overloading which causes discomfort, fatigue, pain, injury and illness to workers. Isometric muscular strength is considered as one of the most crucial factors for the design and development of various tools and equipment in agricultural activities. Isometric muscular strength data of Indian farm workers have been measured and utilized. Adjusted or normalized strength data from other countries or other regions of India could not be utilized for designing of tools and equipment for Indian people since the capability to exert maximum force to do the task depends on a person's race, body weight and lifestyle.

Effective ergonomic interventions must be developed and implemented to reduce musculoskeletal disorders among farmers. Ergonomics or human engineering deals with the aspect of the man-machine system which means engineering the product or machine to fit the operator. In agricultural machinery, application of ergonomics is important as the operator has to operate the machine in the field. In the present era of user-centeredness and market competition, ergonomic considerations are a must for agricultural equipment design as the users are no more bound to cope with whatever design imposed on them. Wolfgang. L. ILO's encyclopedia 1983. The objective of ergonomics is not only to improve work performance but also to improve human comfort as well as safety. The important term is Anthropometry is the technology of measuring various human physical traits, such as body dimensions of workers and their strength and engineering anthropometry is an effort to apply such data to equipment and workplace design to enhance the efficiency, safety and comfort of the operator.

Database for Indian Agricultural Workers for various Equipment

1. Design of Handle Height for Manually Operated Equipment:

The 5th, 95th and 50th percentile values of Metacarpal III height of male and female Indian agricultural workers have been found to be 680, 740 and 675 mm; 572, 686 and 629 mm respectively. Furthermore, the 5th, 95th and 50th percentile values of elbow grip length of male and female Indian agricultural workers to be 290, 360 and 325 mm; 220, 320 and 267 mm respectively. For maximum work efficiency, it is suggested that the elbow flexion angle should be in the range of 85 – 110º (Grandjean, 1988). Tewari (1985) showed that for the push and pull operation of a machine the elbow flexion angle would be 90º. Considering the elbow flexion angle as 100º, and 5th and 95th percentile value of elbow height and elbow grip length from the anthropometric data one can easily find out the optimum length of the handle from the geometry adopted by the operator. The optimum holding height for male and female population ranges from 630 to 677 mm and 534 to 630 mm respectively.

2. Strap Design for a Knapsack Sprayer:

The anthropometric values of scapula to waist back length and waist circumference determine the design of the strap. The 5th, 95th and 50th percentile values of scapula to waist back length of male and female Indian agricultural workers have been found to be 420, 630 and 508 mm; 337, 580 and 439 mm respectively. Therefore, the optimum value of the strap length could be taken as the mean value for the male and females and it should be adjustable for 5th and 95th percentile values of the operator. The value of strap length for males should be 508 mm and adjustable within 420 and 630 mm. The value of strap length for females may be 439 mm and adjustable within 337 and 580 mm. The 5th, 95th and 50th percentile values of waist circumference of male and female Indian agricultural workers have been found to be 650, 927 and 760 mm; 610, 875 and 726 mm respectively. The optimum value of the waist belt length should be the 50th percentile value of waist circumference for the male and females and it should be adjustable within 5th and 95th percentile value. Therefore, the value of waist belt length for males may be taken as 760 mm and adjustable within 650 and 927 mm. The value of waist belt length for females should be 726 mm and adjustable within 610 and 875 mm.

3. Design of Feeding Chute of a Thresher:

The 5th, 95th and 50th percentile values of height of male and female have been found to be 940, 1022 and 942 mm; 830, 970 and 894 mm respectively. The maximum permissible height for the feeding chute should be decided from height (Kumar et al., 2002). Considering this the feeding chute of a thresher should be 940 and 830 for male and female respectively, being the 5th percentile value of height.

4. Load Carrying:

The 5th, 95th and 50th percentile values of weight of male and female Indian agricultural workers have been found to be 50, 65 and 51.4 kg; 34, 55 and 42.8 kg respectively. For continuous load carrying, it has recommended 40% body weight as permissible limit. Since, the agricultural workers of lowest body weight should able to carry the load, the maximum permissible limit for male and female Indian workers would be 20 and 13.6 kg.

5. Layout of Tractor Workplace Design:

The design of tractor operator's work place includes the following considerations:

(1) Access to work place
(2) Work place dimensions
(3) Seat design and its adjustments
(4) Control locations and actuating forces.

The operator work place of a machine is designed relative to seat index point (SIP) and seat reference point (SRP). The seat index point (SIP) as per ISO 5353: 1995 is the interaction on the central vertical plane passing through the seat centre-line of the theoretical pivot axis between a human torso and thighs. The seat reference point as per IS 11806: 1995 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 SIP is located 90 mm above and 140 mm in front of SRP.

6. Access to workplace:

Easy access to driver's seat on a tractor is very important, as the driver has to climb on or off frequently. It is therefore, necessary to provide a path for easy mounting and dismounting from the tractor between the engine and rear fender. Major parameters in access to workplace include.

(i) Steps - height, arrangement and size

(ii) Hand holds - type, arrangement and size
(iii) Doors (in case of cabs) - size, shape and hinging

7. Work place dimensions

The design of agricultural equipment or a tractor requires anthropometric data of user population for enhancing operator's comfort, safety and efficiency. The selected anthropometric and strength data of Indian agricultural workers. The International Standard (ISO 4253, 1993) and Indian Standard (IS 12343, 1998) lay down range of dimensions for the operator's seat and location of specific controls relative to the seat index point (SIP) within the seating accommodation on agricultural tractor with a track width greater than 1150 mm. The controls included are the steering wheel, clutch pedal, brake pedal and throttle pedal. However, these standards do not specify location of hydraulic control lever relative to the SIP within the seating accommodation. The position of steering wheel relative to SIP is mainly dependent on the angle of the upper arms to the torso and the angle between the upper and lower arms. It must be 425 - 525 mm forward and 175 - 385 mm above the SIP. The choice of steering column angle α is affected by the seating position, steering wheel diameter and the force required to turn the steering wheel. The steering column angle (α) shall be in the range of 0 - 40° (IS 12343: 1998). For steering effort requirements refer to ISO 10998: 1995. A good seat should enable the user to change posture at intervals so that different groups of muscles can be called into play. The most critical dimensions in the design of tractor seat based on available limited anthropometric data of Indian population are:

8. Seat height:

It is measured from footrest to front of the seat surface. In general, the seat height should be lower than the distance from footrest to the underside of the thigh when the 5th percentile person is seated (*i.e.* popliteal height) to reduce excessive pressure. The popliteal height of 5th percentile Indian tractor driver is around 400 mm. The Indian Standard IS 12343: 1998 recommends a maximum seat height of 540 mm

9. Seat length:

The horizontal distance parallel to the longitudinal plane of the tractor measured from the front edge of the seat cushion to the transverse plane containing the seat reference point (SRP) or 140 mm to the rear of the transverse plane containing seat index point (SIP) (ISO 4253: 1993). Seat length should be about three-quarters of the thigh length, keeping in view that there should be enough clearance between back of the lower leg and front edge of the seat for the 5th percentile operator. The Indian Standard recommends a seat length of 400 ± 50 mm (IS 12343: 1998).

10. Seat pan width:

It is the horizontal distance between the outside edges of the seat surface measured in a plane perpendicular to the medium plane of the seat or the width measured along a horizontal transverse line passing through the seat index point (IS 12343:1998). In order to assure driver's comfort and convenient posture change, the seat width should be wider than buttock width of 95th percentile operator (Shao and Zhou, 1990). It should not be less than 450 mm (IS 12343: 1998).

11. Seat backrest height and width:

The function of a seat backrest is to maintain a relaxed (*i.e.* non-fatiguing) spinal posture. The proposed dimensions of the backrest relate quite simply, to the distance from the upper lumbar region to the underside of the buttocks and to the shoulder width. The shoulder width of 95th percentile population is selected for the seat width (Mehta, 2000). The backrest height is measured above the compressed seat, if padding is present. Many researchers suggested that backrest should have an open area of height of at least 125 - 200 mm to accommodate sacrum and fleshy parts of buttocks just above the seat pan and to allow the lumbar region to fit firmly into the backrest. Therefore, the tractor seat backrest should support the lumbar region only. For effective lumbar support, this height should be independently adjustable.

12. Backrest inclination:

The inclination of the backrest to the seat pan serves two purposes. First, it prevents the operator from slipping forward, and second, it causes him to lean against the backrest with the lower (lumbar) part of his back and sacrum supported. In order that the trunk-thigh angle is in comfort range when sitting, this slope angle should be in the range of 95 to 105º from the horizontal (IS 12343: 1998).

13. Seat pan tilt:

It refers to the angle of the seat pan to the horizontal. A seat pan that is tilted backwards will produce two effects. First, by the force of gravity the sitter's back is moved towards the backrest, so supporting the back muscles. Secondly, a slight inclination of the seat pan at the front helps to prevent the gradual slippage out of the seat. The Indian Standard IS 12343:1998 recommends a tilt of 3 to 12º backward for the seat pan.

14. Seat pan concavity:

Tewari and Prasad (2000) recommended that the tractor seat pan should have a radius of curvature of 750 mm for Indian operators for better contact and more uniform pressure distribution at seat-operator interface

15. Seat backrest concavity:

The Tractor seat backrests with a radius of curvature of 300 mm are recommended by Tewari and Prasad (2000) for Indian tractor operators for better contact between back of the body and backrest.

16. Seat suspension and damping:

Suspension seats have the cushions in seat pan and seat backrest mounted to a resilient spring, damper and linkage mechanism called seat suspension. The purpose of the seat suspension is to reduce the level of tractor vibration transmitted to the operator, especially in the low frequency range (2 - 6 Hz). Besides the spring and damper, a seat suspension requires a linkage mechanism to stabilise, guide, and constrain the suspended mass (cushion plus operator). This linkage mechanism permits the suspended mass to move with respect to the seat base in the desired direction, usually the vertical axis. Therefore, the four bar linkage type suspension mechanism is generally selected for the tractor seat.

17. Seat cushion:

The seat surface should be cushioned (25 – 50 mm of compression is sufficient). The tractor seat with synthetic rubber foam cushion materials (thickness = 101.43 mm and ρ = 69.72 kg m^{-3}) and composite (layers of coir and medium density foam) seat backrest cushion material (thickness = 79.00 mm and ρ = 47.19 kg m^{-3}) was found to be the most comfortable for Indian operators (Mehta, 2000).

18. Control location and actuating forces:

Controls are the normal way in which an operator conveys his instructions to a machine. The factors affecting the selection of individual controls, the consideration involved in the arrangement of controls within the workspace area and the detailed design recommendations are as follows:

19. Selection of individual controls:

Main considerations in the selection of individual controls for a workplace are purpose of the control, operator's requirements and workplace requirements. (Matthews and Knight, 1971).

20. Location of controls:

For deciding the location of controls, the concept of optimum dimensions and limiting dimensions is used. The optimum dimensions define the most desirable space for location of controls both in neutral position and when displaced in any direction. The limiting dimensions define the acceptable but not necessarily the most desirable space for the location of controls. If controls are placed outside this space they are either too close or too far from the operator. The dimensions usually chosen to define the boundaries of these spaces are generally estimated to cater to 90% of the operator's population *i.e.* from 5 - 95th percentile. The control should be easily accessible from the operator's seat. Overlapping control zone locations are permissible to provide independent and simultaneous control action. It is recommended that frequently and infrequently operated controls including their displacement should be located within the zone of comfort and within the zone of reach, respectively.

21. Hand controls

Hand controls should be used in preference to foot controls where accuracy and speed of control positioning are important and continuous or prolonged application of moderate or large forces (90 N or more) are not necessary. The controls should not be placed such that the operation requires awkward or uncomfortable positions like stooping, kneeling or crouching unless absolutely unavoidable. One hand controls are preferable to those operated with both hands, for precision and speed, except that large-diameter control wheels with reciprocal-rotary motion (steering wheels) are best operated with two hands. Controls for two-hand operation should be used where larger forces are required. The preferred hand should be used where speed, accuracy or strength of the control movement are important. The design should therefore, plan for right-handed operation of more important controls. For seated operators, pull forces are the strongest when the controls are at or near the full extension of the elbow and push forces are the greatest at an elbow angle of 150 - 160^{0}. While the speed and accuracy of visually controlled movements are the greatest when the controls are close to the operator (175 mm from the body), they become progressively worse as distance increases. Ideally the optimum vertical location of controls for the standing operator should lie between the shoulder level and the elbow level with the arms at the side of the body. If this area were optimized for both tall and short operators (lower limit at the elbow height of tall operators and upper limit at the shoulder height of small operator), the residual area would be too small to be of practical value. The best alternate is to use the dimensions of the average (50^{th} percentile) operator; the limits of this area will be within fairly easy operating range of all operators and will be near-optimum for most men (the middle 60 - 75% of the population).

22. Foot controls:

Foot controls should be used in preference to hand controls where there is a continuous control task, continuous or intermittent application of moderate to large forces, and hands are in danger of being overburdened with control tasks. Pedals may be divided into two groups *i.e.* those designed for use when the force is above 40 to 80 N which is obtained by movement of the leg (*e.g.* brake pedals) and those where force is small (about 40 N or less) and continuous operation is required which is obtained mainly from the ankle (*e.g.* an accelerator pedal). For all but light pedal pressures (less than 40 - 80 N) the foot should be applied to the pedal so that the long axis of the tibia (lower leg) is immediately over, and in line with, the axis of pivot of the pedal. The long axes of the foot and lower leg should form a 90^0 angle, this requires the least muscular effort to hold the foot in position. The next best position is with the arch of the foot over the pedal axis; the toe and heel are least effective for heavy pressures. For small pressures it is satisfactory to use toe-operated pedals, with the fulcrum at the base of the heel for rapid and continued pedal movements. As per Indian Standard (IS 12343: 1998), *i.e.* the pedals should be placed in the following order from the left hand side to the right hand side clutch (operated by the left foot), brake (operated by the right foot) and, if installed, the foot throttle (operated by the right foot). The position of the clutch, brake and foot accelerator pedals from the SIP is mainly dependent on the angle between the operator's upper and lower leg. The pedals should be located 355 - 770 mm forward and 380 - 620 mm downward of SIP.

The three considerations in locating foot controls for the seated position within the optimum areas are the fore-and-aft location, the vertical location and the lateral location. Fore-and-aft seat reference point to pedal distance is an important determinant of the amount of pressure exertable on the foot control. The shorter the distance, the greater is the force exertable. Where comfort matters more than the force exertable, pedals can be placed below the seat reference point by vertical distances varying with the type of task. This distance should never exceed 400 mm. Dupuis et al. (1955) recommend that for tractors the centre of the pedal should be about 137 mm below the seat reference point. As pedals are moved laterally from the midline of the leg, the force exertable decreases and the discomfort increases. If pedal placement at the leg midline is not feasible, pedals should be displaced no farther than 75 - 125 mm from the midline.

23. Considerations involved in the arrangement of controls:

Three major factors are considered while arranging the controls within the workplace area. These are priority, grouping and association. Priority depends on frequency and extent of use. The highest priority controls should be placed within the optimum spaces. Emergency controls must be placed in readily accessible positions. frequent shift in eye fixation or hand movement have made over a wide span of the work layout.

24. Work load:

Stress and fatigue are both linked with the level of physical and mental workload but they are also linked with factors such as posture, environmental conditions and certain psychological factors.

25. Physical workload:

The human body provides power to locomotory system (muscles and skeletal tissues) using oxygen (which enters through respiratory system) and food (which enters through digestive system). The efficiency of this human machine is only 25%. Physical workload in any activity may be expressed in terms of cardio-respiratory responses of the workers and the main parameters measured are heart rate and oxygen consumption rate. Measurement of oxygen consumption is essentially an absolute measurement. On the other hand heart rate is an indicator of cardiac stress due to physical workload. The human energy expenditure during a physical work may be quantified by indirect measurement of the rate of the oxidation process in which carbohydrates, fats and proteins are converted into energy. The rate of oxygen consumption in this process may be measured as the difference between the quantities of oxygen in inspired and expired air. On an average one litre of oxygen consumed in the human body is equivalent to an energy expenditure of 20.88 kJ. Energy expenditure and cardiac capacity set limits to the performance of physical work and these two functions are often used to assess the degree of severity of a physical task. Table 19.7 presents the classification of physical work according to severity of workload. While considering these categories it is most important to recognize the very considerable individual differences. A fit young man used to physical work might be able to endure an energy expenditure rate of 40 kJ min^{-1} for significant periods, whereas an older man or woman may only be able to sustain 20 kJ min^{-1} As mentioned above only about 25% of the energy produced by the oxidation of food stuffs appears as useful mechanical work, the remainder being dissipated in the form of heat, but despite differences in this proportion depending on the source of energy, the type of work being undertaken and the person, a useful value for the work may be calculated from oxygen consumption. The time delay between mechanical work output and associated changes in oxygen consumption is small; but significant, varying from a few seconds to a minute or two, but it does set a limit to the minimum period over which work can usefully be measured, and it will normally be found necessary to think in terms of energy expenditure rates over periods of five minutes or more.

The energy expenditure rate indicates the level of bodily stress and in relation to heavy work it can be used to assess the level of effort to work out necessary rest periods, and to compare the efficiency of different tools and different ways of arranging the work. As there are individual differences in physical working capacity, many research workers have proposed the concept of "Acceptable Work Load" (AWL), which depends on the maximum oxygen uptake or maximum aerobic power (VO_{2max}). In view of the fact that VO_{2max} varies greatly from one person to another, a workload that is fairly easy for one worker may be quite exhausting for another. Therefore, expression of workload in absolute values (kJ min^{-1}) may not be much useful and it is preferred to express the same as the percentage of the individual's maximum aerobic power (VO_{2max}). According to Saha *et al.* (1979), the acceptable workload for average young Indian worker is about 35% of VO_{2max}. For Indian workers the VO_{2max} values are about 2.2 *l* min^{-1} for male workers and 1.8 *l* min^{-1}

for female workers, which corresponds to an energy expenditure rate of 46.0 and 37.6 kJ min^{-1}, respectively. Therefore, the upper limit of workload for day long work can be taken as about 0.77 and 0.60 *l* min^{-1} of oxygen uptake, which corresponds to 16 and 12.5 kJ min^{-1} of energy expenditure for male and female workers, respectively..

26. Noise:

Farm workers experience one of the highest rates of hearing loss among all occupations. This is caused in part by the many potential sources of loud noise on the farm *i.e.* tractors, combines, choppers, power tillers, threshers, etc. The normal range of hearing for a healthy young person extends from approximately 20 - 20,000 Hz. The audible sound pressure level range from the threshold of hearing at 0 dB(A) to the threshold of pain which can be more than 130 dB(A). Although an increase of 6 dB represents a doubling of the sound pressure, an increase of about 10 dB is required before the sound subjectively appears to be twice as loud. The smallest change one can hear is about 3 dB(A). The human ear is most sensitive to sounds between 2 and 5 kHz, and less sensitive at higher and lower frequencies. The Indian Standard (IS 12207: 1999) recommends that maximum ambient noise emitted by the tractor and maximum noise at operator's ear level should not exceed 90 dB (A) for continuous working of 8 h. If noise level exceeds 90 dB(A) manufacturer should provide ear protectors appropriate to the noise spectrum produced by tractor. It is generally conceded that 40 h of exposure per week of noises of 90 dB (A) or greater will result in hearing loss. The letter 'A' refers to a frequency weighting scale which is approximately like human hearing acuity. The permissible noise duration (T) as per NIOSH (1991) can be calculated by the Equation

$$T = 16 \div 2^{\frac{L-85}{5}}$$

27. Vibration:

On agricultural equipment high frequency vibrations generally arise from internal combustion engines or from the mechanisms of the machinery. Between 20 - 30 Hz resonance of the head is encountered with head vibration amplitude exceeding that of the shoulders by as much as 3:1. A further disturbing frequency between 60 - 90 Hz is due to eyeball resonance. Whole body vibration may cause physical damage to organs if excessive. High frequency vibration affects performance on physical and mental tasks. Vision, particularly the ability to judge depth, is greatly impaired by vibration frequencies between 25 - 40 Hz and between 60 - 90 Hz. Intense vibration of the hands can lead to nervous and circulatory damage. There is evidence to suggest that 40 - 250 Hz is the frequency range most likely to cause these ailments. Below 2 Hz, the human body responds to vibration as a dead weight. Above this frequency, relative motion occurs between regions and organs due to resonance effects within the skeleton and connecting tissues. A main body resonance occurs in the range 4 - 8 Hz and leads to a considerable amplification of this vibration between the buttocks and the upper body regions and results in increased discomfort. Above 8 Hz, the body characteristics reduce the transmission of vibration to the head. When standing, the legs may provide considerable attenuation of low frequency vibration. Horizontal components of vibration are only transmitted to the upper parts of the body at very low frequencies, particularly when the subject is standing. Above

5 Hz, horizontal vibration applied to seated or standing subjects excites a predominately vertical vibration of the head with the amplitude 10 - 30% of the applied vibration.

Design factors to be taken into account to reduce low frequency vibration by mounting the suspended operator's seat are:

(a) A suspension will only reduce vibration when the frequency of the applied vibration is at least one and a half times that of the suspension natural frequency.
(b) A fairly large static deflection of the suspension may have to be allowed to achieve a sufficiently low frequency.
(c) Damping should generally be included to limit the motion of the suspension near its resonant frequency. A damping factor of 0.2 - 0.5 is reasonable.
(d) The suspension must allow sufficient free movement to avoid impacts against the end stops of the motion when the most severe vibration conditions are met.

The reduction of high frequency vibration may be accomplished either by lowering its generation at the source or reducing its transmission to the operator.

28. Light and colour:

Much agricultural work is carried out in conditions of adequate daylight

29. Intensity:

Illumination intensity is measured in lux (lm m^{-2}), where the lumen is a measure of light flow (*e.g*, a 40 W filament lamp emits approximately 500 lm). The brightness of a surface depends both on the intensity of its illumination and its reflectivity. Brightness is measured in foot-Lamberts (ft.L) where 1 ft.L is the brightness of a surface having unity reflectivity which is illuminated with an intensity of 10.7 lux. Intensity levels encountered in practice vary between 10700 lux for bright sunlight to 10.7 lux with dim lighting of corriders. The brightness of the light in the area where the driver needs to see should be at least 30 lux. The ratio between the brightest and dimmest parts of the work area should be below 3:1. The decrease should be no more than 3 lux per meter (Hansson, 1991).

30. Colour:

Colour of illuminations may be used to advantage to optimize contrast on the working task and to provide psychologically good surroundings for work (*e.g.* 'cool' colours may be used to balance hot environments and vice versa). Colour may be used to mark obstacles, highlight controls particularly emergency controls and to assist in demarcation of instruments and controls on control panels.

31. Placing the operator for optimum vision of the display:

For instruments whose displays are located close to their controls, the viewing distance is limited by reach distance and should not exceed 700 mm. Otherwise there is no maximum limit other than that imposed by practical space limitations and visual acuity. The viewing distance to displays should preferably be not less than 508 mm, because a small viewing distance places an undue strain on the eyes (Matthews and Knight, 1971).

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