# ADVANCING INDUSTRIAL ENGINEERING IN NIGERIA THROUGH TEACHING, RESEARCH AND INNOVATION

## A BOOK OF READING

*Edited By*
Ayodeji E. Oluleye
Victor O. Oladokun
Olusegun G. Akanbi

# ADVANCING

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### THROUGH

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(A Festchrift in honour of Professor O. E Charles-Owaba)



Professor O. E. Charles-Owaba

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# FOREWORD

It gives me great pleasure writing the foreword to this book. The book was written in recognition of the immense contributions of one of Nigeria's foremost industrial engineers, respected teacher, mentor, and lover of youth – Professor Oliver Charles-Owaba.

His commitment to the teaching and learning process, passionate pursuit of research and demonstration of excellence has prompted his colleagues and mentees to write this book titled – Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation (A Festschrift in honour of Professor O. E Charles-Owaba) as a mark of honour, respect and recognition for his personality and achievements.

Professor Charles-Owaba has written scores of articles and books while also consulting for a medley of organisations. He has served as external examiner to various programmes in the tertiary educational system. The topics presented in the book cover the areas of Production/Manufacturing Engineering, Ergonomics/Human Factors Engineering, Systems Engineering, Engineering Management, Operations Research and Policy. They present the review of the literature, extension of theories and real-life applications. These should find good use in the drive for national development.

Based on the above, and the collection of expertise in the various fields, the book is a fitting contribution to the corpus of knowledge in industrial engineering. It is indeed a befitting gift in honour of erudite Professor Charles-Owaba.

I strongly recommend this book to everyone who is interested in how work systems can be made more productive and profitable. It represents a resourceful compilation to honour a man who has spent the last forty years building up several generations of industrial engineers who are part of the process to put Nigeria in the rightful seat in the comity of nations. Congratulations to Professor Charles-Owaba, his colleagues and mentees for this festschrift.

Professor Godwin Ovuworie
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CHAPTER 18

# Evaluation Of Mechanical Strain Resulting From Working With Two Locally Fabricated Engine Powered Stationary Grain Thresher

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**Abstract**

In place of the combine harvesters, stationary grain threshers are the most common among the farmers in the developing countries, many are being produced locally to meet up with the local demands by the farmers which they find to be relatively cheap and affordable. To ascertain the level of their user friendliness, two threshers of heights 92 cm (M1) and 161.5 cm (M2) with capacities 3000kg/hr. and 6500kg/hr. respectively were selected for evaluation to determine the possible biomechanical strain that may result from working with these locally fabricated threshers. Questionnaire and physical measurements were employed for data collection of thirteen randomly selected operators, with ages ranged in-between 20 and 35 years. The results of machine performance tests showed that quantity threshed on average ± SD per minute are 12.59kg ± 2.41 (M1) and 20.38kg ± 3.84 (M2),corresponded to the mean (SD) of weight per lift of 1.75kg (0.44) and 2.06 (0.22), and mean; SD of frequency of lift/minute of 7lift/min;1.59 and 10lift/min;1.81. The body kinematics analysis showed flexion, extension, lateral deviation and abduction with respective highest mean values of 167.750 at kneel (M1), 111.500 at ankle (M1), 24.750 at neck (M2) and 72.000 at shoulder (M2) at the end of lift. Regression analysis of biomechanical parameters, and frequency of lift and weight per lift gave F-value of 425.987 (R2 =0.974), which shows no relationship at α= 0.01. Subjects' indications of body parts discomforts showed highest percentages of 78.3%; 84.6% and 72.9%; 80.8% for M1; M2 at shoulder and lower back respectively. Conclusively, the overall result showed that the two machines need to be ergonomically modified to prevent the users from the risk of musculoskeletal disorder (MD).

**Keywords**: biomechanical strain, developing countries, ergonomics, local demands, operators, stationary grain thresher

## 1.0 Introduction

The industrialization of agriculture has introduced new equipment with little attention paid to ergonomic design. Most machinery turned out in the developing nations to meet the need of the farmers are products from artisans with little or no consideration to operators but the operations of the machinery. As many technological approaches in solving associated problem with manual operations in agriculture are on the increase, the need for application of ergonomics/ human factors in machinery development become indispensable. There are diverse forms of occupations carried out by men and women; hence, the risk of musculoskeletal injuries as a result of occupational vulnerabilities may vary by sex (Messing *et al.,* 2009). An ample of occupational risk factors existing in the course of working life are regarded to be detrimental to musculoskeletal health that resulted to various forms of musculoskeletal disorder diagnosis and eventually damages the physical functioning of workers in their latter lives (Prakash *et al.,* 2017)

The aim of this study is to evaluate the level of ergonomic factor consideration in the design and fabrication of locally manufactured agro-processing machinery and to determine biomechanical strains that may result through the performance evaluation of the selected grain threshers.

## 2.0 REVIEW OF LITERATURE

In contempt of the existing information on the corresponded work-related disorders in musculoskeletal systems, a profound number of occupations are still linked to poor working postures and awkward body movements in association with a heavy physical work load (Karla *et al.,* 2012). Competition and increased work demands have also increased farmer's exposure to risk factors through increased work pace and/or duration. In American, Mazza *et al.* (1997) recorded that of the thirteen most common agricultural health related problems reported by rural health care providers, heavy lifting was the most common exposure of patients, while repetitive motions was fourth.

External loads are given rise to in the physical work environment and are communicated through the biomechanical forces of the body, specifically the limbs and trunk, to produce intramural loads on tissues and bodily structures. Biomechanical variables include posture of the body, bodily strain, intensities and movements, as well as individual factors such as age, strength, agility and dexterity, and additional components that mediate in the transferal of outer loads to inside loads on bodily structures. Tissue injury may transpire when the applied load transcends the inner forbearance of the tissue and resulted to tissue irritation and pain, impairment or disability. As with most biomechanical systems, loading is influenced greatly by the external moment imposed on the system. However, because of biomechanical disadvantage at which the torso muscles operate relative to the trunk fulcrum during lifting, very large loads can be generated by the muscles and imposed on the spine (Marras, 2006).

In occupational setting human anatomy can be affected by traumas that lead to musculoskeletal disorders, these are; acute trauma (this can transpire when a single application of a force is so huge that it transcends the endurance limits of the body structure during occupational task) and cumulative trauma (this refers to repeated application of force to a structure that tends to wear down the structure, thus, lowering its tolerance to the point where it is exceeded through a reduction of this tolerance limit). The latter type of the trauma may of necessity common in the threshing of grain with stationary thresher, in that the process of manual loading of un-threshed grain into the threshing machine is more of repetitiveness. The repetitive application of force can affect either the tendons or the muscles of the body, the process which results in terrible joint discomfort and a chain of musculoskeletal reactions such as decrease strength, lower tendon movement, and decrease mobility. A disorder, as presented by musculoskeletal disorders, has a slow start as juxtaposed to an acute injury, which is as a result of a single distinguishable occurrence. A disorder is essentially arbitrated by some pathogen or pre-pathological progression (Kurmar, 2001).

Kasey *et al.* (2014) reported that musculoskeletal disorders are non-harmful soft tissue disorders, which may resulted from and/or heightened by workplace exertions. Sergey *et al.* (2017) presented that diverse forms of damage to the bones and soft tissues of the elbow joint are corresponded with particular postures of flexion and turning of the forearm on the elbow during injury. Mechanical degradation of tissue may occur due to exposure over time from mechanical stresses that are repetitive, prolonged or forceful. The expression “load” is habitually used to relate the physical stresses at work on the body and structures inside the body. These stresses comprise kinetic (force), kinematic (motion), oscillatory (vibration), and thermal (temperature) energy sources (Radwin *et al.*, 2001). Repetitive tendon motion is thought to promote shear damage at the tendon sub-synovial connective tissue (SSCT) interface, which is supported by the finding that fibrosis is exacerbated in SSCT layers adjacent to flexor tendon (Aaron *et al.*, 2014). Loads can originate from the external environment or result from action of the individual.

**3.0 MATERIALS AND METHOD**

Thirteen physically active subjects (11 males, 2 females, age = 24.8 ± 3.2 years, height = 173.91 ± 5.96 cm, weight = 63.38 ± 7.86 kg) volunteered as subjects. Individuals with self-reported health problems related to head injury in the recent past were excluded from the study. All subjects completed 3 iterative testing operations on the selected machine, during which sagittal-plane kinematics and lifting distances were recorded while they performed the threshing from the origin of the lift to the end of the lift, also, individual body temperature was taking before and after the operations to determine the imposed thermal stress. For each replication, that continue for one minute, the quantity of grain is determined by mechanical weigh balance ISO 9001 (Capacity 120kg; Grade 1kg) and the quantity lifted by independent subject was resolved by re-weighing the remaining mass after each iteration. At the end of the experiment questionnaire was given to individual to fill in respect to the degree of discomfort experienced during the threshing operations. Also, oral questions were asked, and their respective responses were recorded.

For the purpose of this study, body dimensions and mobility descriptions are put into consideration; data is as shown in Table 1. Scope of this work is focused and limited to basic descriptive data, rather than workplace design requirements.

### 3.1 Kinematics

The motions of the subjects tasks were recorded by Samsung digital camera (SL102; 10.2 mega pixels; 3Xzoom6.3-18.9mm lens) during the operations, the pictures were taking and were analysed, and the degrees of variations from neutral position were determined by using AutoCAD 2007.

Knee angle, wrist angle, ankle angle, elbow flexion-extension angle, neck flexion-extension and lateral deviation angle, shoulder flexion and abduction and lumbosacral flexion angle at the initiation and at the end of the lift were determined throughout the experiment and were indicators of lifting posture. Knee angle was defined as the included angle of the thigh and lower leg segments, wrist angle was defined as included angle of the fore arm and hand, ankle angle was defined as included angle of the lower leg and foot, and elbow flexion-extension angle was defined as included upper arm and forearm segments.

Neck flexion-extension and lateral deviation angle was defined as included head and upper trunk and head and shoulder, shoulder abduction is defined as the elevation of the shoulder in the lateral direction to the trunk, while lumbosacral flexion angle was defined as the angle of the trunk with respect to the vertical axis.

## 4.0 RESULTS AND DISCUSSIONS

Age, sex, occupation, health history and formal education are bio-data considered relevant to this study. The primary principle behind the use of bio-data is that the best predictor of present and future occurrence is the past. Among the most significant is their power as a predictor across a number of work related body injuries.

### 4.1 Corresponding BMI to Age and Sex

Figure 1 simply shows ages, sexes and corresponding body mass indexes (BMIs). The modal ages are 21and 24 years while the modal sex is male (m). The highest BMI is correspondent to the female subjects of ages 21 and 22 followed by male subject of age 25, also, the lowest BMI is traced to male subject of age 25.

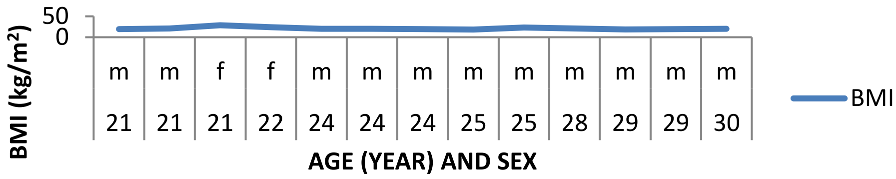


Fig. 1: age, sex and respective body mass indexes (BMI) of the subjects

### 4.2 Occupational Lifestyles of the Subjects

The occupational lifestyles of the subjects are; Farming, Mechanical work, Driving, Hawking, and Schooling. The percentages distribution are 23%, 15%, 8%, 15%, and 39% respectively as shown in figure 2. It can be deduced that energy requirements for this group of works ranges from 10KJ/min to more than 30KJ / min, from student through to farming (Rowett, 2008).

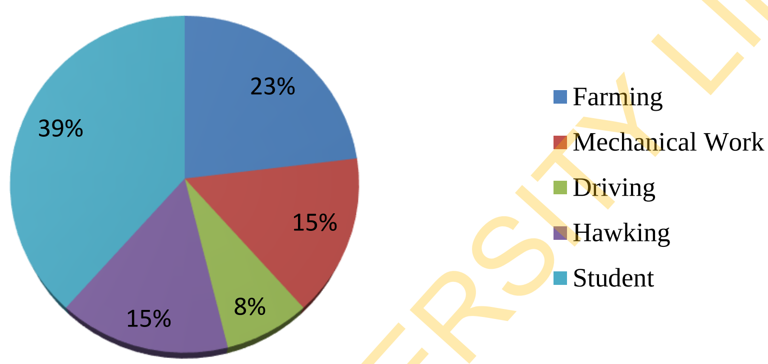


Fig 2: percentage of occupational description of the subjects

### 4.3 Relative Anthropometry Measurements for the Study

Table 1 shows the parameters that are essential in the process of threshing by stationary grain thresher. Mean (SD) of height/stature is 173.91 (5.96), and the subjects' weight ranged from 53kg to 78kg. Arm reaches can explain the degree of flexion and extension of the different parts of the body and it ranged from 69.5cm to 83.5cm; hand length and hand width explain gripping effect with mean ±standard deviations of 19.75cm ± 1.13 and 9.19cm ± 0.46; ankle height ranges from 8.3cm to 9.2cm with mean ±standard deviations of 0.31cm ± 8.71, these are indispensable as all joints play important roles in operations that involves dynamic movement of the body parts.

Table 1: Anthropometric data of the Subjects (cm)

| Parameters | Mean | S.D | Min. Value | Max. Value |
|---|---|---|---|---|
| **Height** | 173.91 | 5.96 | 165 | 186 |
| **Weight*** | 63.38 | 7.86 | 53 | 78 |

| | | | | |
|---|---|---|---|---|
| **Arm Reach (Front)** | 77.04 | 4.14 | 69.5 | 83.5 |
| **Overhead Reach** | 203.88 | 21.09 | 139 | 223 |
| **Shoulder Height** | 142 | 12.9 | 106 | 159.5 |
| **Hand Length** | 19.75 | 1.13 | 18 | 21.2 |
| **Hand Width** | 9.19 | 0.46 | 8.7 | 10 |
| **Elbow Height** | 108.92 | 5.07 | 101 | 118 |
| **Shoulder Width** | 44.07 | 2.09 | 40.2 | 47 |
| **Leg Length** | 100.62 | 4.47 | 90 | 107 |
| **Lower Leg Length** | 50.42 | 4.29 | 43.5 | 58.5 |
| **Lower Arm Length** | 34.23 | 2.49 | 30.5 | 39 |
| **Arm Reach (From Floor)** | 73.85 | 3.92 | 68.5 | 80.5 |
| **Ankle Height** | 8.71 | 0.31 | 8.3 | 9.2 |

SD = standard deviation *kg

**4.4 Determination of Frequency of Lift, Weight per Lift as Corresponded to Quantity Threshed on M1 And M2**

The frequency of lift per minute and weight per lift together with quantity threshed per minute are as shown in the Table 2 in terms of their mean and standard deviations. Statistical analysis indicated that on the average, frequency of lift per minute (7 lift/ min ± 1.59 SD) while working with machine 1 is lesser compare to machine 2 which is 10lift/min ± 1.81 SD. In the same way, weight per lift and quantity threshed are 1.75kg ± 0.44 SD and 12.59kg ± 2.41 SD for M1, and 2.06kg ± 0.22 SD and 20.38kg ± 3.84 SD for M2. These results attested to the machines capacities and efficiencies (Table 2).

| Parameters | | Machine 1 | Machine 2 |
|---|---|---|---|
| Frequency of lift | Mean | 7.00 | 10.00 |
| per minute (lift/min) | S D | 1.59 | 1.81 |

| | | | |
|---|---|---|---|
| Weight per lift (Kg/Lift) | Mean | 1.75 | 2.06 |
| | S D | 0.44 | 0.22 |
| Quantity Threshed | Mean | 12.59 | 20.38 |
| per minute (Kg/min) | S D | 2.41 | 3.84 |

Table 2: Frequency of Lift per Minute, Weight per Lift, and Quantity Shelled Per Minute

S D = standard deviations N = 13 Replication = 3

**4.5 Indication of Body Discomforts before and after Operations on M1 and M2 by the Subjects**

Table 3 gives details about the expressed opinions of the subjects regarding body parts discomforts experienced before and as a result of threshing grain with stationary threshers. Before evaluation it was discovered that 61.5% of the subjects has no body discomforts, 15.4% has shoulder and neck pains with lowest percentage of 7.7% for low-back and wrist as shown in Table 3.

The two machines were said to have produced some level of discomforts by all subjects. When interviewed about the severity of the pain, the subjects commented on how the pain was moderate before commencing shelling and more severe afterwards. Comparing all types of body discomforts, working with machine 2 (M2) proved to be more unfit ergonomically in that it has greater percentages except on wrist where percentages for M1 is 31.2 and 30.8 for M2. Shoulder strain has lesser percentage of body discomfort for M1, 78.3% compare to 84.6% for M2, while upper leg and ankle have the least percentage of 6.0% and 7.7% respectively for M1 and M2 (Table 3).

**4.6 Analysis of the Degree of Variations from Neutral Position while working with M1 and M2**

The posture adopted to operate the M1 and M2 may have resulted in pain or discomfort over much of the body since they involved considerable spinal flexion (Table 4). This was particularly observed with the subjects at initiation of lift in stooping posture and the termination of lift. Results from the measured angles of variation from the neutral position during the evaluation of M1 and M2 suggested that this subsequently resulted in an increase in the incidence of pain or discomfort in most body parts.

Table 3: Subjects' Indication of Body Parts Discomfort

| | | Percentage of Subjects Affected | | |
|---|---|---|---|---|
| | | | After Evaluation (%) | |
| S/N | Body Discomforts | Before Evaluation (%) | M1 | M2 |
| 1 | Lower Back | 7.7 | 72.9 | 80.8 |
| 2 | Shoulder | 15.4 | 78.3 | 84.6 |
| 3 | Wrist | 7.7 | 31.2 | 30.8 |
| 4 | Forearm | nill | 14.1 | 15.4 |
| 5 | Neck | 15.4 | 9.8 | 11.5 |
| 6 | Upper Leg | nill | 6.0 | 7.7 |
| 7 | Ankle | nill | 6.0 | 7.7 |
| 8 | None | 61.5 | nill | nill |

A stooping posture, as adopted during threshing operation, is generally considered to be undesirable, with spinal flexion causing deformation of the intervertebral disc and exerting a risk of the nucleus being extruded (Pheasant, 1991). Any mechanical advantage from the weight of the body through a tilted trunk will thus be offset by the risk of cumulative musculoskeletal damage or overexertion from such a posture. Repetitive lifting of load involves asymmetrical movement that further increases the risk of musculoskeletal damage. With spinal rotation there will be an increase in the loading on the spine, causing further deformation of the discs (Pheasant, 1991).

Table 4: Results of Different Degrees of Variation from Neutral Position

| | Stooping | | Standing M1 | | Standing M2 | |
|---|---|---|---|---|---|---|
| | Mean | S D | Mean | S D | Mean | S D |
| Lumb-osacral | 102.25* | 7.72 | 28.75* | 15.22 | 22.5** | 3.7 |
| Knee | 129.25* | 33.05 | 167.75* | 3.86 | 164.25* | 6.45 |
| Neck | 101.50* | 28.10 | 16.00* | 11.43 | 24.75[d] | 7.27 |
| Ankle | 17.57* | 98.00 | 111.50** | 8.27 | 84.00* | 27.65 |
| Elbow | 139.75* | 24.66 | 115.00* | 14.14 | 136.25* | 23.53 |
| Wrist | 54.41* | 133.5 | 145.50* | 8.43 | 145.75* | 23.81 |
| Shoulder | 70.50* | 16.9 | 84.50* | 9.15 | 72.00[a] | 9.09 |

S D = standard deviation    N = 13 * flexion    ** extension

d= lateral deviation    a = abduction

**4.7 Regression Analysis of Biomechanical Parameters**

The F-value was 425.987, which was not significant at 1% level i.e. biomechanical factors have no significant effect on quantity shelled per individual on the two machine. The R-SQUARE value was 0.974 which means that the model (Weight per lift, Frequency of lift) has accounted for the 2.6% variance in the dependent variable which is the quantity shelled (Table 5).

Considering the impact of each predictor variable, on the criterion variable (Weight per lift and frequency per lift), the following findings were deduced. The weight per lift, and frequency of lift per individual subject was negatively related to quantity shelled per individual and was significant at 1% level respectively (Table 5). This indicates that the factors are significant to the study and have significant effect on the quantity shelled per individual on the two machines.

This suggested that the oxygen consumption is somewhat higher in the evaluation of the two machines than would be expected for the weight lifted at the observed frequencies

**Table 5: Result from Regression Analysis for Biomechanical Parameters**

| **Model** | **Unstandardized Coefficient** | | **Standardized Coefficient** | | |
|---|---|---|---|---|---|
| | **B** | **Standard Error** | **Beta** | **t** | **Sig.** |
| Constant | -15.986 | 1.16 | | -3.784 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Frequency of Lift | 1.956 | 0.082 | 0.811 | 23.95 | 0 |
| Weight Per Lift | 8.141 | 0.456 | 0.604 | 17.845 | 0 |
| F | 425.987 | | | | |
| $R^2$ | 0.974 | | | | |

Dependent variable: quantity shelled per individual N = 13

**5.0 CONCLUSIONS AND RECOMMENDATION**

This study has brought to the limelight how agricultural machinery developed for use in a developing country can be improved by employing human factors/ergonomics approach to design. The so called technological interventions in agriculture have revealed how would be users are exposed to hazards through ergonomics evaluation. By incorporating ergonomics into the design process, drudgery associated with the machine will be reduced and productivity, user comfort and satisfaction will be increased. Improving the posture and manual handling to be adopted to operate the machine will result in a significant reduction in physical strain and incidence of body-part discomfort and can be expected to reduce the risk of musculoskeletal damage.

**5.1 Conclusions**

The study had shown that biomechanical strain resulted through the performance evaluation results. On this premise, the following conclusions were drawn:

1) Machines capacities and heights, hopper shapes and orientation and concave sizes as well as personal limiting factors of individual subjects may be the determinant for frequency of lift and weight per lift as they varied across the machines.

2) Lifting process in repetitive manner by the operators has shown some significant deviations from neutral position, the accumulation of which could result in musculoskeletal injury, therefore make the use of the types of the evaluated machines ergonomically unfit and hazardous to human.

**5.2 Recommendation**

Based on the results from the evaluation, the following recommendations are hereby suggested in order to correct and improve on the existing locally developed stationary threshers and to prevent likely work related musculoskeletal disorder (WRMSD).

1. Incorporation of adjustable plat-form on which the unshelled crops will be put to check stooping posture involved in the initiation of lift.
2. Design and development of stationary grain thresher involving height adjustable mechanism, capable of accommodating $5^{th}$ to $95^{th}$ percentile of the operators' population to check repetitive variations from neutral positions.
3. The importance of ergonomic/human factors intervention in the design and fabrication of agricultural machinery produced locally.

## REFERENCES


Aaron M. Kociolek, Jimmy Tat, Peter J. Keir (2014) Biomechanical Risk Factors and Flexor- Tendon Frictional Work in the Cadaveric Carpal Tunnel *Journal of Biomechanics, pp 449-456.* Elsevier Ltd. http://dx.doi.org/10.1016/j.jbiomech.2014.12.029 0021-9290/& 2014.

Karla G. G., Gabriel I., and Juan L. H. (2012) Biomechanical Analysis of a Manual Material Handling Tasks in a Local Manufacturing Company, *Proceedings of the 1st Annual Conference of the Society for Industrial and Systems Engineering*, Washington, D.C, USA September 16- 18.

Kasey C., Ashish D. N., Xiaopeng N. and Majid J. (2014) A Biomechanical Strain Index to Evaluate Shoulder Stress *Proceedings of the 2014 Industrial and Systems Engineering Research Conference Y. Guan and H. Liao, eds.*

Kumar S. (2001) Theories of Musculoskeletal Injury, *Ergonomics. 44(1), 17-47.*

Marras W.S. (2006) *Basic Biomechanics and Workstation Design (*Handbook of Human Factors and Ergonomics (ed. Salvendy, G.), John Wiley and Sons.

Mazza J. J., Lee B. C., Gunderson P.D., and Stueland D.T. (1997) Rural Health Care Providers' Educational Needs Related to Agricultural Exposures, *Journal of Agricultural Health and Safety. 3(4), 1997, 207-215.*

Messing K., Stock S.R. and Tissot F. (2009) Should Studies of risk Factors for Musculoskeletal Disorders Be Stratified by Gender? Lessons from the 1998 Québec Health and Social Survey. *Scand J Work Environ Health*. 35(2):96–112.

Pheasant S. (1991) *Ergonomics, work and health*, (Macmillan, London)

Prakash K. C., Subas N., Päivi L., Mikaela B. von Bonsdorff, Taina R., Monika E. von Bonsdorff, Jorma S., Juhani I. and Clas-Håkan N. (2017) Work-Related Biomechanical Exposure and Job Strain as Separate and Joint Predictors of Musculoskeletal Diseases: A 28-Year Prospective Follow-up Study. *American Journal of Epidemiology Vol. 186, No. 11DOI: 10.1093/aje/kwx189 Advance Access publication: June 2, 2017*

Radwin R.G., Marras W.S. and Lavendar S.A. (2001) *Biomechanical Aspects of Work-Related Musculoskeletal Disorders* (Theoretical Issues in Ergonomics Science. 2(2),153-217.

Rowett Research Institute (2008) "Energy Expenditure."http://www.rowett.ac.uk/edu-web/sec-pup/energy-expenditure.

Sergey S., Ievgen L., Vasily M. and Jan A. (2017) Comparative Biomechanical Analysis of Stress–Strain State of the Elbow Joint After Displaced Radial Head Fractures. *Journal of Medical Biology Engineering (2018)38:618-624*