5. Conclusions and Recommendations

5.1 Conclusions

5.1.1 From the Results of Anthropometric Data and Frequency Analysis

In the survey under this study, 59 body dimensions, including weight, are measured from 303 subjects with age group of 18 to 60 years from the Maharashtra state of India. The results of the present study are compared with the results of similar studies conducted in other regions of India and other countries.

From the comparison of Maharashtra male worker anthropometric data with that of other studies of various regions in India (Table 4.10), it is observed that Maharashtra male population is:

i. Higher in stature than other region male workers except northern India.
ii. Higher in standing eye height, standing shoulder height, sitting shoulder height and buttock popliteal length than that of the other regions in India.
iii. Higher in popliteal height than other region male workers except Southern India.
iv. Higher in sitting eye height and forearm hand length except Central India population.

From the comparison of Maharashtra male worker anthropometric data with that of other nationals’ (Algerian, Chinese, Filipino, Korean, Singaporean, Taiwanese and Thai) data, it is noticed that Maharashtra male population is:

i. Shorter in stature, standing eye height, sitting height and sitting acromial height.
ii. Smaller in hand length, foot length and foot breadth.
iii. Shorter in standing acromial height except Filipino male workers. It is almost same as that of Filipino population.
iv. Smaller in bideltoid breadth than Thai population.
v. Higher in popliteal height than other nationals.
vi. Smaller in sitting hip breadth than other nationals except Singaporean population. It is almost same as that of Singaporean population.
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Thus, many anthropometric parameter values of Maharashtra (Western India) male agricultural workers are significantly different from other regions of India and other nationals.

5.1.2 From the results of ANOVA

ANOVA analysis shows that there are 22 body dimensions (Table 4.7) with a statistically significant difference in the mean values between the three strata (regions within the Maharashtra). This defines need of region specific databases for the equipment design.

5.1.3 From the Results of Post-Hoc Analysis

Post hoc multiple comparisons analysis (Table 4.8) gives the detailed information about among which strata these 22 body dimensions have significant difference.

5.1.4 From the Results of Correlation and Regression Analysis

Correlation analysis shows that about 24 body dimensions (dependent parameters/variables) can be predicted from other 12 body dimensions (independent parameters/variables) as shown in Table 4.9. Thus, out of 59 body dimensions, 24 body dimensions can be predicted from 12 other dimensions. Hence, one may measure only 35 body dimensions in place of 59 dimensions resulting in the saving of time and cost.

The linear regression equation \( y = bx + a \) is used to predict dependent variable \( y \) from the independent variable or predictor \( x \). The regression coefficients \( (a \) and \( b) \) for the correlated variables are shown in the Table 4.9. The positive values of slope \( b \) for all the 24 dependent variables indicate that correlation is positive i.e. dependent variable value increases as independent variable value increases.

5.1.5 From the Ergonomic Evaluation of Farm Equipments

The study selected and evaluated three farm related equipments for ergonomic analysis namely maize thresher cum dehusker, electric hedge trimmer and knapsack sprayer.

i. Maize thresher cum dehusker

The RULA analysis carried out for the 8 postures (Table 4.20) of the operator and 7 postures (Table 4.22) of the supporting worker shows that the existing working postures of the operator and supporting worker are highly dangerous (score 6 to 7) and must be changed by in-depth investigation of workstation in order to keep away the worker(s) from musculoskeletal disorders.
The reach analysis for the operator shows that operator hand(s) cannot reach the rotor in the drum in case of 5 percentile population, whereas, operator hand(s) can reach the rotor in case of 95 percentile population. Hence, machine is not safe for higher percentile population and may cause injury to the worker(s). In order to prevent the reach of operator hand(s) to the rotor, modified hopper design as shown in Figure 4.24 is suggested. In this design, direct access of the hand to the rotor is restricted.

The lift/lower analysis, gives the recommended weight limit of the lift operation as 2.127 kg limited by the initial posture while the actual bag weight handled by operator is approximately 10 kg with a lifting index (LI) of 4.70 which is unsafe (LI>1) for operator under the initial posture (Table 4.23). Also, though for the final posture, the values of the RWL and LI are less, these postures are unsafe for the current task as LI>1.

The biomechanics analysis gives mean peak compression values for all tasks below 3400N (the ‘safety limit’ of NIOSH) and peak shear load values below 500N (the ‘safety limit’ of NIOSH). This implies that the task (postures) does not propose a high risk of injury.

ii. Electric Hedge Trimmer

RULA analysis (Table 4.25) for two commonly attained postures (postures 1 and 2) by operator (Figure 4.27 (a) and 4.27 (b)) shows unsatisfactory RULA score values (6 to 7) for the existing workstation. New modified workstation suggested in this study reduced RULA score to satisfactory level (2) which offered a provision for the handle height adjustment (Gite and Yadav, 1990), hedge trimmer placement (Figure 4.28 (a) and 4.28 (b)) and shifted hedge trimmer from operator’s hands to cart.

The weight of the hedge trimmer under study is 3.25 kg and maximum acceptable weight shown by carry analysis is 100.42 N for 90th percentile male worker limited by posture 1. Thus, carry analysis (Table 4.26) gives acceptable results for the hedge trimmer carry task with existing workstation.

Biomechanics analysis shows that for new modified workstation, values of L4-L5 moment (18 to 3 Nm), L4-L5 compression (734 to 301 N), Body load compression (283 to 240 N), Axial twist compression (1 to 0 N), Flex/Ext compression (293 to 56 N) and L4-L5 joint shear (47 to 1 N Posterior) are
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reduced considerably. Thus, in redesigned workstation, moments and loads on body parts are reduced substantially.

iii. Knapsack Sprayer

RULA score of 4 for left side of body and 3 for the right side of the body for the existing Knapsack Sprayer reduced to 3 and 2 respectively for the modified sprayer.

For the validation of above RULA results, redesigned sprayer handle and lance were manufactured and tools such as ODR analysis, questionnaire, BPDS and pulse rate and blood oxygen saturation level are used. ODR analysis showed reduction in the final score from 6.4 to 3.8 for modified sprayer. Opinion of farmers from questionnaire technique about modified sprayer is found satisfactory. BPDS reduced from 51 to 40.6 for the modified sprayer. Pulse rate and blood oxygen saturation level test by pulse-oximeter shows reduction in average pulse rate from 117.4 to 105 beats per minutes for the modified sprayer maintaining average blood oxygen saturation level at 97.4% which is within normal limits (95 to 100 %). Thus, all these validation tools supported the RULA analysis results confirming modified sprayer to be better in ergonomic design over existing one.

In the nutshell, it may be concluded that,

i. Anthropometric data of user population is very important for the design of farm equipments in order to fit the equipment to the operator.

ii. Existing agricultural equipments/implements need to be evaluated considering user population dimensions and ergonomic principles and modifications may be incorporated wherever necessary.

iii. DHM and simulation tools can be successfully used to develop the ergonomically sound products based on anthropometric data of user population. Moreover, the use of a virtual model of the product for the analysis purpose reduces time and cost of the development of the product. The reach and fit of the operator to the product can also be checked easily. Also, other advanced analyses such as lift/lower analysis, carry analysis and biomechanics single action analysis can be performed. Further, various postures that are demanded by particular operation can be simulated virtually for detailed analysis of the workstation.
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iv. The ergonomically designed machines/equipments can reduce drudgery, increase efficiency, safety and comfort.

5.2 Recommendations from this Study

Few recommendations are made based on the results and conclusions of the study for the design/improvement of the farm equipments/ implements/ machinery based on ergonomic considerations. These are as follows:

i. Manually operated equipments need to be designed for the user population considering their capabilities and limitations.

ii. Along with the strength design, the ergonomic aspects need to be incorporated in the design of equipments to make it safe, comfortable and user friendly to the operator.

iii. Awareness among agricultural workers / farmers may be made about identification of wrong postures and safe handling of equipments in order to avoid musculoskeletal disorders.

iv. Training programs may be arranged for the artisans, manufacturers of the agricultural equipments for the awareness of the ergonomic design of a product and its importance.

v. Attention need to be paid by the manufacturers to make the product full proof, so that it cannot be used in the wrong way which will result into awkward postures and stressful working.

5.3 Contributions of this Study

i. The study presented a literature review on the anthropometric data collection studies and ergonomic evaluation studies carried out so far by various researchers which provides guidelines for the new researchers in this field.

ii. The study presented values of 59 anthropometric dimensions of Maharashtra state agriculture workers/farmers which are useful to the farm equipment manufacturers, researchers, etc. for the design of farm equipments or evaluation of existing farm equipments for suitability to the Maharashtra agricultural worker population.

iii. Study made an attempt to use virtual modeling concept for the product analysis by use of 3D modeling technique which is very rare in the agricultural field. It is motivation to the manufacturers to use such tools who are just fabricating the equipments or designing the tools by traditional methods.
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iv. Most of the previous ergonomic evaluation studies in the agricultural field used traditional methods with hardly any CAD approach. However, this study made an attempt to use various modern tools such as RULA analysis, Lift/lower analysis, carry analysis, biomechanics analysis, reach analysis etc. in ergonomic analysis which are being used in the sophisticated industries.

v. The suggestions given by the study for the modification of the few existing farm equipments based on ergonomic design are useful to the research community and equipment manufacturers in this field.

In short, our nation’s economy is agriculture based and major portion of the population is dependent on the agriculture for their survival. So health, safety, comfort, productivity of this group is very much essential for the progress of our country.

5.4 Scope for Future Work

There is a lot of scope to work in the area under study. Future work in this area can be undertaken as follows:

i. Anthropometric data collection study may be conducted for the female agricultural workers in the region.

ii. Data collection study may be conducted for strength data of agricultural workers in the Maharashtra.

iii. Modern economic methods for the anthropometric data collection may be developed and used to speed up the data collection.

iv. Evaluation of various agricultural equipments/implements/machinery may be done in order to improve them on ergonomic as well as productivity front. Moreover, other sections of equipments/implements/machinery where human interaction is involved may be included in the ergonomic evaluation.

v. The standard guidelines which can be used by common man may be developed for assessment of product for ergonomic design.