ABSTRACT

Manufacturing workers are exposed to many physical tasks during their work that require repetitive movements, forceful exertions and handling of components at different working heights. Due to variation of working heights in the tasks, workers may adapt extended or overhead postures that generate adverse responses like fatigue and musculoskeletal discomforts. The working height is an external exposure of work that forces the worker to adapt extended or overhead posture, which is an internal exposure. The adverse responses that develop among workers due to the exposures lead to Musculoskeletal Disorders (MSDs). The research reported here has been carried out in Submersible Bore-Well Pump (SBWP) assembly task in which the workers adapt extended or overhead postures during their work.

In this research, the development of fatigue and musculoskeletal discomforts in SBWP assembly workers has been investigated. The research has devised strategies to reduce these adverse responses. The adverse responses among SBWP assembly workers have been assessed based on external exposures of the task. The external exposures considered in this research are working height, work duration, work cycles and workplace design. The research has also explored relevance of effect modifiers like age, experience and Body Mass Index (BMI) of workers in generating adverse responses. Both qualitative and quantitative methods have been used in these investigations.

The qualitative assessments of fatigue have been carried out with Borg's Category Ratio (CR-10) scale, Samn-Perelli Fatigue Scale (SPFS) and task relevant dimensions of Swedish Occupational Fatigue Inventory (SOFI). From the research, it has been found that increasing rate of fatigue among the workers declines during the workday. It has been revealed that Borg's CR-10 scale is a reliable tool for predicting fatigue than SPFS. Also, physical discomfort has been found as a predominant dimension of SOFI to predict fatigue in physical tasks. Age and experience of the workers have been identified as the effect modifiers in generating fatigue, while the contribution of BMI is less evident. The predictive models developed based on the fatigue measures have indicated the effect of rest pauses in restraining fatigue. It has also been observed that, proper work design with adequate rest pauses during the work could reduce the effects of fatigue in physical tasks with overhead work.

The quantitative assessment of fatigue has been carried out with measurement of Heart Rate Variability (HRV) and hand strength evaluation during experimental trials in simulated assembly tasks. Three simulated assembly tasks have been developed with different working heights and work cycles for this purpose. The tasks have incorporated assembly of external components of SBWP. The experimental trials have been carried out for 60 minutes duration. Results have indicated that average heart rate and ratio of Low Frequency to High Frequency components (LF/HF) of HRV among subjects increase with workload involved in the tasks. It has also been observed that, Standard Deviation of Normal-to-Normal intervals (SDNN) and square Root of Mean of the Sum of Squared Differences (RMSSD) of successive normal-to-normal intervals of HRV decrease with workload. LF/HF and SDNN have decreased with increase of fatigue during last 10 minutes of the simulated tasks in comparison with first 10 minutes. The

simulated task with overhead work has indicated significantly higher ($p < 0.05$) fatigue than the task without overhead work. The research has revealed that irrespective of working heights, HRV is an indicator of workload and fatigue in physical tasks. It is also evident from this research that design of work cycles has impact on workload and fatigue. The hand strength evaluation before and after the task has been carried out with hand dynamometer and pinch gauge. The results have indicated a significant increase ($p < 0.05$) of grip strength in dominant hand of workers after the tasks. This effect may be due to the muscle adaptation strategies of motor units to reduce fatigue. It is also evident from the results that hand strength evaluation is not suitable for measurement of fatigue in SBWP assembly task.

The musculoskeletal discomforts in the SBWP assembly workers have been assessed using Cornell musculoskeletal discomfort questionnaire. All the workers have reported discomfort at shoulders while 83.3% of them have reported the discomfort at wrists. They have also reported higher discomfort at lower back (83.3%) and neck (70%). To investigate further, existing workplace has been modelled using Digital Human Modelling (DHM) software. Also, virtual postural analysis has been carried out with Rapid Upper Limb Assessment (RULA) method. The existing workplace has been modified by applying ergonomic interventions to reduce the musculoskeletal risk. RULA final risk score in the modified workplace has been reduced to a value of ‘3’ from a higher value of ‘7’. Also, the modified workplace accommodates 90% of SBWP assembly worker population with reduced musculoskeletal risk. This part of research has revealed that the effect modifiers of age, experience and BMI have less impact in generating musculoskeletal discomforts at body parts of SBWP assembly workers.

In order to reduce fatigue and musculoskeletal discomfort among SBWP workers, various strategies have been formulated based on the outcomes of the research. The strategies have indicated the relevance of adequate rest pauses, work cycles and workplace design in reduction of the adverse responses among workers. Further strategies can be developed based on the concept that fatigue is worker dependent; musculoskeletal discomfort in body parts is task dependent. Importance in implementing the strategies has been revealed from the feasibility study conducted among workers and supervisors of SBWP assembly.

Real time data collection procedure has been adopted in this research. A large sample size could not be incorporated for the qualitative and quantitative methods. However, suitable methods for further investigation of fatigue and musculoskeletal discomforts among SBWP assembly workers have been revealed. Future research could be done by including other relevant external exposures, effect modifiers and evaluation methods to improve the reliability of results. Based on the methodology adopted in this research, the study can be extended to analyse similar tasks to reduce the adverse responses.