Physiological modelling for combined manual material handling tasks using weighted heart beat

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Abstract : Manual material handling results in biomechanical and physiological strain on material handlers. There is a need to focus on exposure modelling and its integration into intervention framework to mitigate MMH exposures. This paper therefore is focused on physiological analysis of combined MMH tasks. Physiological response measurement is difficult for combined MMH tasks in a field setting. Each of the task elements are influenced by different work factors. An experimental study is devised to capture the effects of task variables on physiological response while performing combined MMH. The objective of this paper is to compare physiological response measured through heart rate with existing energy expenditure model. A fractional factorial experiment with ten factors each at two levels was conducted in a bearing manufacturing plant. Net weighted heart beat model was proposed for capturing the physiological response of the worker for each trial. Performance analysis in terms correlation and kappa statistic indicates that net weighted heart beat for quantifying physiological exposure from MMH tasks.

1 Introduction

Work related musculoskeletal disorders related to lifting, pushing, pulling, holding, carrying or throwing is a major cause of concern worldwide [6]. Work-related MSDs occur because of a mismatch between the physical capacities of workers and the physical demands of their jobs resulting in pain and functional impairment of lower-back, neck, shoulders, elbows, forearms, wrists and hands. The focus today is on cumulative exposure modelling of physical activity involving high force and posture interactions as found in combined manual material handling tasks. A combined manual material handling (MMH) tasks involves combinations of lifting-lowering, carrying, and pushing-pulling task elements.

Manual material handling results in biomechanical and physiological strain on material handlers. MMH exposure leads to discomfort, fatigue, fatigue and finally, musculoskeletal disorders. The compatibility between MMH task demands and worker capacity (biomechanical, physiological, and psychological capacities) influences the occurrence of potential undesirable outcomes. The worksystem characteristics [8] that influence the physical demand during combined manual material handling are, i.e., worker (e.g., anthropometry, team), material (e.g., weight, shape, handle), task/workplace (quantity, pace, MHE), environment and organization (e.g., humidity, work schedule). Designing MMH tasks require careful ergonomic evaluation through biomechanical, physiological and psychophysical measurements and analysis. There is a need to focus on exposure modelling and its integration into intervention framework to mitigate MMH exposures. This paper focuses on physiological analysis of combined MMH tasks. Physiological response measurement is difficult for combined MMH tasks in a field setting as each of the task elements are influenced by different work factors. Heart rate

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and oxygen consumption are the common physiological responses on the worker due to a physical activity that are measured to quantify the physiological effect, i.e., instantaneous and cumulative [1,3,9]. A possible extension to the cumulative concept as applied in biomechanical analysis to represent the overall physiological response needs to be explored. The objective of this paper is to compare physiological response measured through heart rate with existing energy expenditure model. The methods section of the paper gives a brief description of the fractional factorial experiment undertaken at a bearing manufacturing plant in India. In the next section, the physiological modelling using net weighted heart beat is described. Finally, conclusion section presents the physiological model, its limitation and scope for future work.

2 Methodology

2.1 Experiment

A fractional factorial experiment with ten factors each at two levels was conducted in a bearing manufacturing plant. The independent variables are 'Weight', 'Distance', 'Pace', 'Cycle', 'Height', 'Team', 'Combined', 'Direction', 'Motion pattern', 'MHE'. The dependent variables considered are 'net weighted heart beat' and 'ratings of perceived exertion'. Four male subjects are randomly selected from the general population to take part in the study. Informed consent on the procedure, questionnaire and data collections sheet by the management of the organization was obtained prior to the actual data collection. The experimental trials (22 x 4) were randomized. The task performed by the material handler consisted of lifting-lowering-carrying of 30 boxes from storage-rack onto material handling equipment, then by pushing-pulling the material handling equipment, the load is moved by a fixed distance, and finally by lifting-lowering-carrying, the load is unloaded into storage-rack. The combined MMH task performed by the material handler was video recorded, real-time hand forces from LUTRON force gauge recorded into a laptop, and heart rate recorded using POLAR heart rate monitor. Heart rate was measured using Polar heart rate monitor at intervals of 15 s. HR data is downloaded onto a personal computer for further analysis. On completion of the task CR10 scale was used to record rating of perceived exertion [2]. After each trial, the participants were given a break of 45 minutes before commencing the next trail. On an average three trials per day was undertaken those spread over 7 weeks. Energy expenditure was estimated using Garg's model [4]. Details of the experiment can be found in Rajesh & Maiti [7].

Net weighted heart beat model is proposed for capturing the physiological response of the

$$\text{Net weighted heart beat, } NWHB_i = HRR_i * (\Delta HR_i * t_i) \qquad (1.1)$$

Where i represent i^{th} time duration, HRR_i represents relative heart rate, and ΔHR_i represents the change in heart rate, and t_i represents the duration of the recording 'HR' pulse.

Relative heart-rate is obtained using equation 1.2 and physical work capacity of a worker corresponding considering his age is obtained using equation 1.3.

$$\text{Relative heart rate, } HRR_i = \left(\frac{\Delta HR_i}{HR_{max,i} - HR_{r,i}}\right) \quad (1.2)$$

Where ΔHR_i represents the change in heart rate during the ith time duration, HR_{max} represents the physical work capacity of the worker, and $HR_{r,i}$ represents rest heart rate

$$\text{Physical work capacity, } \quad HR_{max} = 220 - age \quad (1.3)$$

$$\text{Net weighted heart beat, } NWHB_{no} = \sum_1^n \frac{NWHB_i}{T} \quad (1.4)$$

Where no represents the task no, T represent task duration in seconds, 'n' represents the number of recorded 'HR' pluses, and $NWHB_i$ represents the net weighted heart beat for each recorded 'HR' pulse.

Net weighted heart beat for heavy work ($NWHB_{HW}$) and extremely heavy work ($NWHBE_{HW}$) are .231 and 3.267 respectively. The following values were used as inputs to equations 1.1 to 1.4. Heart rate values for heavy and very heavy work conditions are taken from Kroemer et al. [5].

Average age of sample, age = 35 years
Rest heart rate, ΔHR_{rest} = 90
Heart rate for heavy work condition, HR_{HW} = 120
Heart rate for extremely heavy work condition, HR_{EHW} = 160
Time for a recording pulse, t_i=1 min

2.3 Performance analysis

Two evaluations are done to examine how NWHB has performed with respect to existing physiological measure. First, correlation analysis of the NWHB with energy expenditure rate and rating of perceived exertion is done. Second, attribute agreement analysis is done using Kappa statistic to examine how NWHB as a physiological measure has performed against mean HR. For this, each of the experimental setting is classified into 'Low', 'Medium' and 'High' category based on mean HR, NWHB and RPE values.

3 Results

3.1 Net weighted heart beat

The concept highlighted in Section 2 shall be presented using two specific trials from the experiments done, i.e., trial 3 from experimental setting 1 and trial 1 from experimental setting 3. E13 consists of (i) loading component, i.e., cycle 1-1: loading 30 boxes of 10 kg located at below waist height on rack to four-wheeled cart, by 2 men, at a rate of 5 or more lifts/min; (ii) moving component, i.e., cycle 1-2: pushing for a distance of 32 m at a speed of > 0.3 m/s, and (iii) unloading component, i.e., cycle 1-3: unloading 30 boxes of 10 kg located from the cart back to rack at above shoulder and below waist heights, by 2 men, at a rate of 5 or more lifts/min. The heart rates for E13 are closer to 120 bpm and the work can be classified as heavy work [5]. It is observed that the instantaneous HR and NWHB during Cycle 1-2 (moving MHE) is lower than that during Cycle 1-1 (loading onto MHE) and Cycle 1-3

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(unloading from MHE), indicating that the physiological strain during Cycle 1-1 and Cycle 1-3 is higher than that during Cycle 1-2. The mean HR for this trail is 122.3 bpm and NWHR is 127.4 bpm. It is found that NWHB during the course of task duration is below the limit of .231. From a physiological perspective, since the task is a short duration task and the mean HR is only 122.3 bpm, it is inferred that the physiological load from current task is acceptable. E3[1] consists of (i) loading component, i.e., cycle 1-1: loading 30 boxes of 20 kg located at waist height on rack to four-wheeled cart, by one men, at a rate of 5 or more lifts/min; (ii) moving component, i.e., cycle 1-2: pushing for a distance of 64 m at a speed of > 0.3 m/s, and (iii) unloading component, i.e., cycle 1-3: unloading 30 boxes of 10 kg located from the cart back to rack at waist height, by one men, at a rate of 5 or more lifts/min. This cycle is repeated once again (i.e., Cycle 2). Figure 1 shows the net weighted heart beat for the corresponding trial. The heart rates for E31 are closer to 160 bpm and the work can be classified as extremely heavy work [5]. It is observed that both instantaneous HR and NWHB are increasing over the task duration (Figure 1). The mean HR for this trail is 165.3 bpm. From a physiological perspective, since the task is a long duration task, with mean HR being 165.3 bpm and NWHB being significantly higher than the limit of .231, the task places a very high physiological load on the worker. In this case all MMH task elements need to be examined for appropriate change in its task settings.

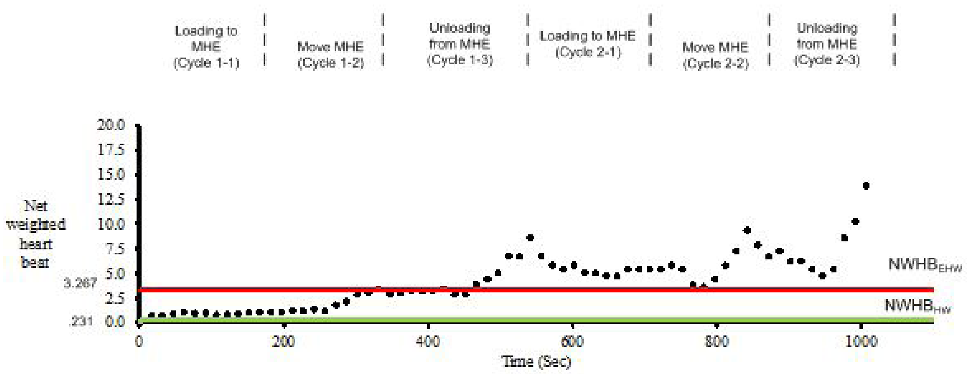

Fig. 1 Physiological response in terms of net weighted heart beat

3.2 Correlation and attribute analysis

The correlation between physiological responses EEr, NWHB and RPE is shown in Table 1. Net weighted heart rate has a high correlation with rating of perceived exertion. There was moderate agreement between classifications based on mean HR and RPE, k = .538, p < .0005. On the other hand agreement between classifications based on NWHB and RPE was high, k = .833, p < .0005.

Table 1 Correlation between energy expenditure rate, net weighted heart beat and rating of perceived exertion

	Net weighted heart beat	Rating of perceived exertion
Energy expenditure rate	.773	.725
Net weighted heart beat		.852

The study could be extended towards addressing the limited small sample size (n=4). The accuracy of the model could be improved by decreasing the pulse duration of 15 seconds from the heart rate monitor. The model criteria values can be standardized by using the average age of an industrial worker in India. The details of interventions for each simulated task settings are not discussed here and can be found in Rajesh & Maiti [7].

3 Conclusion

Net weighted heart beat is proposed as an alternate physiological measure to capture the physiological load while undertaking a combined MMH task. Net weighted heart beat shows good correlation with the existing physiological re-sponses, i.e., energy expenditure. In addition, it has good correlation with the perceptual response 'rating of perceived exertion'. The attribute agreement analysis with RPE is high. Net weighted heart beat is able to aggregate the physiological responses over the task duration, and can be used as a physiological measure for combined MMH tasks. Since heart rate devices are popular and easier to use for on-field measurement of physiological responses, the proposed model 'net weighted heart beat' provides scope for the quantifying physiological exposure arising from MMH tasks.

The study could be extended towards addressing the limited small sample size (n=4). The accuracy of the model could be improved by decreasing the pulse duration of 15 seconds from the heart rate monitor. The model criteria values can be standardized by using the average age of an industrial worker in India.

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