Ergonomic Assessment of Manual Material Handling Tasks in a Manufacturing System

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ABSTRACT

Manual material handling (MMH) is one of the most physically demanding operations where workers are exposed to repetitive movements, awkward postures, contact stresses, and forceful exertions. A survey of the MMH work system characteristics in a manufacturing system was conducted. The musculoskeletal stress on lower-back and shoulder on the material handlers for combined MMH tasks were ascertained through biomechanical analysis of the MMH tasks. The survey indicated that 83% of the lifting tasks and 60% of pushing-pulling tasks are moderate to high exertion tasks. Digital human model in CATIA was used for biomechanical analysis and for redesign of MMH work systems where higher levels of physical exertions are observed. The ergonomic solutions for the manufacturing system are presented.

Key words: Manual material handling, biomechanics, ergonomic design, CATIA

INTRODUCTION

MMH tasks are among the major contributors to MSD, and are the most frequent and costly category of compensable loss [1, 2]. Mechanization has brought a change in the loads handled, frequency of loads or the composition of the task elements used in accomplishing material handling [3, 4, 5]. Kuijer et al. [6] reported that nearly half of manual material handling consists of pushing and pulling. Further, tasks previously undertaken by lifting-lowering or carrying alone are now undertaken by combinations of MMH tasks such as lifting-carrying-lowering, lifting-carrying-pushing or lowering-pushing-lifting. There is significant amount of literature pertaining to ergonomic evaluation of MMH tasks at a single task level alone, i.e., lifting, lowering, carrying, pushing and pulling, but the research at combined MMH tasks, i.e., combination of MMH task elements are being perused actively only recently. Biomechanical, physiological, psychophysical studies for lifting, lowering and carrying have been extended to pushing and pulling recently [4-5, 7-11].

The objective of the paper is to undertake a survey of work system parameters, biomechanical assessment of MMH tasks in an Indian manufacturing system and to provide design solutions. A study was undertaken at a bearing manufacturing system situated in eastern part of India. The study procedure is given in section 2.1. Section 3 highlights the results with discussions to highlight on the biomechanical assessment of MMH. Finally, section 4 presents conclusions from biomechanical assessment, and intervention recommendations for the company studied.

METHOD

Study procedure: Fig 1 shows the overall study procedure. During phase-1 a work-sampling based study was used to record the characteristics of the MMH task element in a check-list based form, i.e., task Form-1. Subsequently, the posture details were recorded using the posture Form-2 [12]. Phase-2 involves estimation of forces for the MMH tasks observed in phase-1 using on-field trials representative of the unit MMH loads observed during phase-1. The phase-2 study covers mainly the pushing and pulling activities, as the force estimates for lifting, lowering and carrying can be obtained directly from the weights of the materials. The real-time push-pull forces have been recorded for those tasks using a force-gauge (LUTRON make) into a laptop at 1 Hz. Phase-3 involves biomechanical assessment of the observed MMH tasks and redesign of high exertion workplace/worksystem.

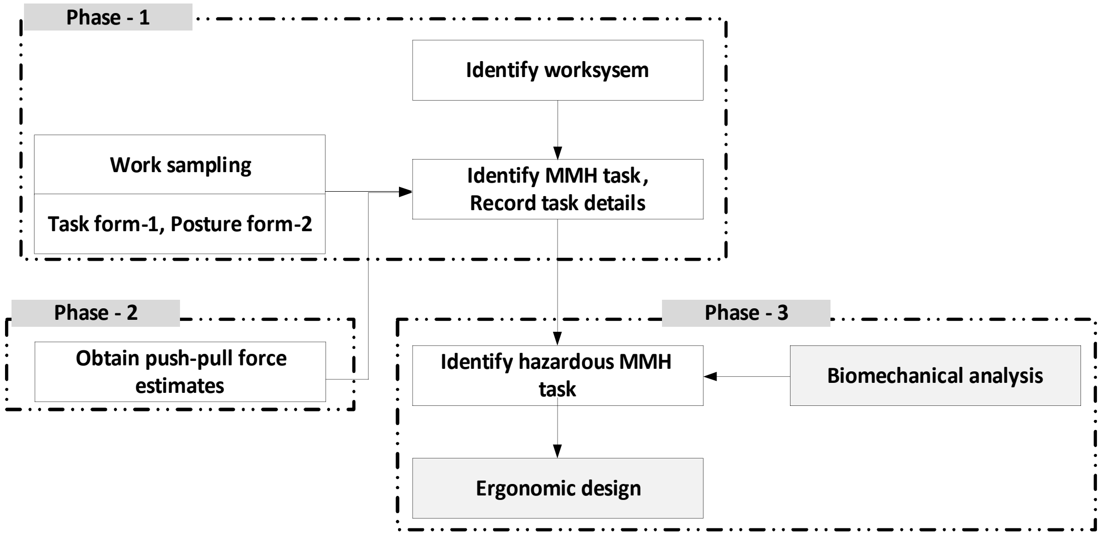

Fig 1 : Study procedure

RESULTS AND DISCUSSIONS

The work-sampling study was conducted over 19 locations in the store section of the plant. A total of 31 work-sampling cycles over a period of one month were involved. The duration of work-sampling cycles to complete observations over all locations was approximately 75 minutes, and three cycles were completed per day. Specific details of each task (e.g., quantity, distance, surface, obstacles) were recorded at the end of each work-sampling cycle (requiring ~ 15 minutes). At completion of the study, 143 MMH tasks and 262 task elements were observed. These MMH tasks were composed of one to four MMH task elements, which included lifting-lowering, carrying, and pushing-pulling activities. Observation times ranged from 2.5 minutes for a single-task element to 7 minutes for a four-element MMH task. Workers were working either individually or in a team. In total, 15 persons were involved with MMH tasks.

MMH task characteristics : Through phase-1 it was observed that manual material handling was done by a combination of lifting/lowering, pushing/pulling and carrying. The field study in store resulted in 143 observations of MMH tasks, out of which lift/lower task elements were present in 57%, push/pull task elements were present in 71% and carry elements in 26% of them. MMH in the manufacturing system is done largely (78%) by unit worker i.e. the material is manual handled by a single worker to its destination. The rest is done by a team of workers. The weights and unit loads handled varied significantly. The mean, standard deviation and range of weight for MMH with lift/lower/carry, and push/pull component was (19, 21, 1-105 kg) and (388, 272, 50-1044 kg) respectively. Repetitions ranged from 0.1 to 15 per min. Repetitions of as large as 80 per worker observed during material unloading from truck or 200 per worker observed during lifting small weights for weighing operations. Work periods of the task undertaken in store varied from 1 to 32 min. The carry distance ranged 3-15 m. Origin-destination height distance during lifting/lowering ranged from 0-160 cm. Walking, standing and stooping are the major postures adopted by the material handler. A great degree of postural activity is observed during the MMH tasks. The postural deviation of more than 15° from neutral posture for each body-segment is recorded in Form-2. The postural details observed during phase-1 using Form-2 is highlighted in Table 1.

Table 1: Postures details for the MMH tasks in store (n=143)

Macro posture	Micro posture	Proportion of macro-posture	Proportion of micro-posture
Standing	Erect offload	10.5	5.1
	Erect twist		3.8
	Erect lift/lower (bilateral)		4.1
Sitting	Sit twist	1.3	0.6
Lean forward	Lean forward twist	1.7	1.9
	Lean forward lift/lower		1.0
	Lean forward lift/lower		1.9
Stooping	Stoop offload	30.1	0.3
	Stoop twist		6.4
	Stoop lift/lower		5.4
	Stoop lift/lower (bilateral)		23.2
Swat	Swat lift/lower (unilateral)	0.4	0.3
Walk	Walk carry (unilateral)	54.4	10.8
	Walk push/pull		30.6
	Walk support		3.2
Others		1.7	1.3

Based on phase-2 study the mean, standard deviation and range for external average and peak push-pull force were (57, 36, 15-130 N) and (165, 78, 55-360 N), respectively. The push/pull distance range was 10-200 m. The push/pull distance coupled with other risk factors (heat, surface and path conditions) can cause ergonomic stress. Aisle widths as narrow as 70 cm were observed which would affect the carrying MMH task. This leads to difficult postural manoeuvring during storage and retrieval of materials during MMH. In a few cases path constraints and obstructions have been observed in the paths during push-pull MMH task. In addition surface conditions like broken tiles/cracks and slope/ramps have been observed in the paths during push-pull MMH task. Such conditions lead to difficult postural manoeuvring and high external hand forces [13].

The distribution of manual material handling parameters in US context is provided by the study undertaken by Ciriello et al. [2]. The findings here provide an insight into the material handling parameters relevant for small-medium scale enterprise with significant amount of manual effort. It can help industrial designers of material handling equipments in providing ergonomic designs. The observational study of the MMH tasks in store has revealed the presence a number of risk factors, i.e., material characteristics, force, posture, repetitive motion, duration, heat, work space-layout, surface-layout, material and floor conditions, distance moved, pace, hand interaction interface, MMH technique, team composition, MMH type and its components/sequence.

Biomechanical analysis : In phase-3 a biomechanical analysis of the static postures corresponding to each task element is undertaken [14]. The static postures were obtained from the posture recordings using Form-2. A digital human manikin based on 172 cm stature and 62 kg weight is modelled in CATIA software and its biomechanical analysis is undertaken. The anthropometric data is based on 75 percentile Indian population [15]. The details of the biomechanical assessment are presented in Rajesh and Maiti [16]. The highlights of the findings are shown in Fig 2 and 3.

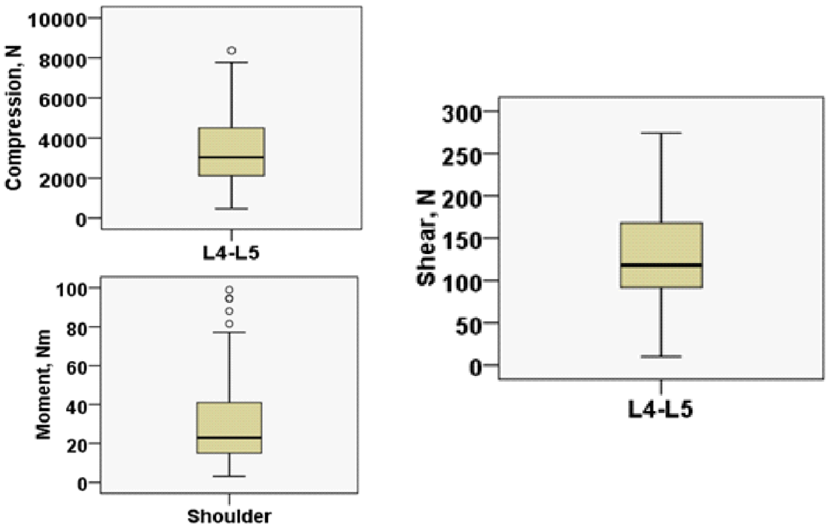

Fig 2: Box plot of the peak L4-L5 compressive force, shear force and shoulder moment, n=143

The physical exertion during lifting tasks is higher followed by pushing and carrying tasks. Biomechanical joint loads on lower back has been estimated to be high leading to 83% of the lifting tasks being classified as above acceptable limits (i.e. compressive force > 3400, shear and torsion force > 100), while exposure on shoulder is moderate for pushing-pulling tasks leading to 60% of pushing tasks being classified as above acceptable limits (i.e. shoulder moment > 34.5 Nm). Some of the high exertion tasks identified include task2-'unload 82 boxes from truck', task52 -'lift from container into green container, weigh and unload for 17 min', task38-'unload 21 kg boxes, 125 nos, 4 workers carry front from end of truck to rear end, 2 workers lower to floor level, 1 worker push to storage'. A location specific analysis found some of the locations to be more hazardous. For example, in location-2 and location-11 rack system and aisle width influences the mechanical exposure due to lifting and lowering, while in location-15 and location-8 path conditions influence the mechanical exposure for pushing and pulling. In location-12, truck unloading is done where significant repetitions occur with high number of lifting, carrying and pushing task elements. Fig 3 shows some of the MMH tasks in different locations.

The task durations in the current study varied from 1 to 32 min. The biomechanical assessment of the MMH tasks made here through 'peak' joint load estimation has identified the exertion levels of the MMH tasks. The question of physiological effect due to the MMH tasks remains to be addressed.

(a)

(b)

(c)

(d)

Fig 3: MMH task at different locations- (a) Lifting-carrying at location-3, (b) Lifting at location-15, (c) Pushing between location-5 & 18, (d) Pulling between A1 & 1

Ergonomic solutions: The ergonomic solutions provided to the company studied are from analysis through biomechanical assessment. As an example the ergonomic solution for location 3 is described here. The issues identified were heavy box weight, low aisle width, long distance push/pull, and unfavorable origin and destination heights.

Fig 4: Existing location-3 and redesigned location-3

Table 2 : Redesign suggested at Location-3

Work system resource	Current specification	Redesigned specification
Box	28 x 28 x 16 cm; 31 kg	28 x 28 x 16 cm; 27 kg; 13 x 3 handle slot at 6 cm from the top on both sides
Rack	100 x 45 x 90 cm with 3 shelves holding 2-4 columns of boxes in each shelf.	100 x 45 x 90 cm with 2 shelves (64 and 104 cm) to hold two columns of boxes in each shelf.
Container	52 x 36 x30, 9 x 3 handle slot at 6 cm from the top	52 x 36 x30, 13 x 4 handle slot at 6 cm from the top
Aisle	47 to 68 cm wide	90-110 cm wide
MHE	Manual pallet truck with 115 x 50 cm leg with 20 cm lift	Height adjustable manual pallet truck with range 81-90 cm.
Task	Material loaded onto pallet truck by lifting, carrying and lowering	Material loaded onto pallet truck by lowering

The redesign changes suggested in location-3 include: aisle width to be increased from 47 to at least 90 cm, rack shelf at 20 cm height to be removed, height adjustable pallet truck with weight indicator to be introduced, reduce the weight of the box and redesign the box for hand slot (Table 2). Some of the design solutions were formulated based on the recommendations of Le et al. [11], Jung et al. [17],Oliveira et al. [18], Silva et al. [19], Young et al. [20], and Boyer et al. [21]. Fig 4 shows the redesigned location-3. The peak biomechanical forces observed at the existing location-3 were 6521 N compressive force on L4-L5. The corresponding biomechanical force for the redesigned work system (Fig 4) was 4278 N when a lifting-lowering task is undertaken. The redesign of the current work system brings about a 39% reduction in peak forces when the worker undertakes lifting task. The safe material handling operation under redesigned location-3 involves replacing lifting-lowering activity by pushing-pulling activity. By this the compressive forces on lower-back can be lowered to below 1500 N.

CONCLUSION

The survey highlighted the work system characteristics specific to MMH work environment in terms of the MMH task types, material handled, weight and size, push-pull forces, vertical and horizontal movement distances, constraints relating to aisle and surface, repetition and durations involved. It can help industrial designers of material handling equipments in providing ergonomic designs. The biomechanical analysis indicated that 83% of the lifting tasks and 60% of pushing-pulling tasks are moderate to high exertion tasks. This indicated that the MMH work system had ergonomic issues whereby the material handlers are exposed to the risk of developing musculoskeletal disorders. Location specific ergonomic issues were identified and ergonomic solutions specific to the location are provided towards mitigating the problem.

RELEVANCE TO INDUSTRY

The survey is first of its kind highlighting the task characteristics for MMH tasks in a typical manufacturing system in India. Further the design solution to the specific industry shall help in mitigating their MSD problems.

CONFLICTS OF INTEREST

The authors express no conflict of interest in undertaking the study.

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REFERENCES

1. Dempsey PG, Hashemi, L (1999). Analysis of workers' compensation claims associated with manual materials handling. Ergonomics, **42(1):** 183-195.
2. Ciriello VM, Snook SH (1999). Survey of manual handling tasks. International Journal of Industrial Ergonomics, **23(3):** 149-156.
3. Ciriello VM, Snook SH, Hashemi L, Cotnam J (1999). Distributions of manual materials handling task parameters. International Journal of Industrial Ergonomics, **24(4):** 379-388.
4. Dempsey PG, Ciriello VM, Maikala RV, O'Brien NV (2008). Oxygen consumption prediction models for individual and combination materials handling tasks. Ergonomics, **51(11):** 1776-1789.
5. Garg A, Waters T, Kapellusch J, Karwowski W (2014). Psychophysical basis for maximum pushing and pulling forces: A review and recommendations. International Journal of Industrial Ergonomics, **44:** 281-291.
6. Kuijer PPFM, Hoozemans MJM, Frings-Dresen MHW (2007). A different approach for the ergonomic evaluation of pushing and pulling in practice. International Journal of Industrial Ergonomics, **37(11-12) :** 855-862.
7. Hoozemans MJM, Kuijer PPFM, Kingma I, et al. (2004). Mechanical loading of the low back and shoulders during pushing and pulling activities. Ergonomics, **47(1):** 1-18.
8. Genaidy A, Karwowski W, Ravelo E, Abdallah S, Shell R, Holley MB (2006). Theoretical basis for general mixed object handling equations based on mechanical work required. Theoretical Issues in Ergonomics Science, **7(5):** 469-490.
9. Marras WS, Knapik GG, Ferguson S (2009). Loading along the lumbar spine as influence by speed, control, load magnitude, and handle height during pushing. Clinical Biomechanics, **24(2):** 155-163.
10. Maikala RV, Ciriello VM, Dempsey PG, O'Brien NV (2010). Comparison of psychophysiological responses in healthy men and women workers during cart pushing on two walkways of high and low coefficient of friction. International Journal of Industrial Ergonomics, **40(2):** 171-179.
11. Le P, Dufour J, Monat H, et al. (2012). Association between spinal loads and the psychophysical determination of maximum acceptable force during pushing tasks. Ergonomics, **55(9):** 1104-1114.
12. Genaidy AM, Al-Shedi AA, Karwowski W (1994). Postural stress analysis in industry. Applied Ergonomics, **25(2):** 77-87.
13. Rajesh R, Maiti (2011). Implication of container clearance on materials handling by pallet truck. International Ergonomics Conference HWWE 2011.
14. Dempsey PG, Mathiassen, SE (2006). On the evolution of task-based analysis of manual materials handling, and its applicability in contemporary ergonomics. Applied Ergonomics, **37(1 SPEC. ISS.):** 33-43.

15. Chakrabarti, D (1997). Indian Anthropometric dimensions for ergonomic design practice. National Institute of Design, Ahmedabad.
16. Rajesh R, Maiti, J (2013). Application of Cube Model for Biomechanical Exposure Assessment of Combined MMH Tasks in a Manufacturing Plant in India. IIE Transactions on Occupational Ergonomics and Human Factors, **2:** 39-51.
17. Jung M, Haight JM, Freivalds A (2005). Pushing and pulling carts and two-wheeled hand trucks. International Journal of Industrial Ergonomics, **35(1):** 79-89.
18. Oliveira AB, Silva LCCB, Pálinkás ESL, Padula RS, Coury HJCG (2012). How is a box handled when all surfaces can be freely held? Ergonomics, **55(1):** 78-86.
19. Silva LCCB, de Oliveira AB, Silva DC, Paschoarelli LC, Coury HJCG (2013). Evaluation of reusable cardboard box designs: Biomechanical and perceptual aspects. International Journal of Industrial Ergonomics, **43(2):** 154-160.
20. Young JG, Lin J, Chang C, McGorry RW (2013). The natural angle between the hand and handle and the effect of handle orientation on wrist radial/ulnar deviation during maximal push exertions. Ergonomics, **56(4):** 682-691.
21. Boyer J, Lin J, Chang C (2013). Description and analysis of hand forces in medicine cart pushing tasks. Applied Ergonomics, **44(1):** 48-57.