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Article Type: Research Article

Received: 19/07/2021

Published: 29/07/2021

Open Access Journal of Biogeneric Science and Research

ISSN 2692-1081

DOI: *10.46718/JBGSR.2021.09.000212*

Assessment of Manual Lifting Tasks in Terms of Biomechanical and Metabolic Responses in Young Indian Adults: A Pilot Study

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Abstract

An insight on injury potential of frequently performed manual lifting tasks(MLT), in terms of simultaneously collected biomechanical and metabolic responses, is important for optimizing such activities involved in different Industrial and Non-industrial operations. Present study aimed to assess simple MLTs with objectives of drawing a relationship between biomechanical, electromyography and metabolic responses, validating authenticity of using prediction biomechanics for categorizing MLTs and to identify an optimized lifting weight-frequency-height combination that incurs least physical workload. Three dimensional realtime biomechanics (kinematics, kinetics and electromyography) and metabolic data were recorded while participants carried out given MLTs and for each experiment, video-photography was done for analyzing 2D biomechanics using ErgoMaster ergonomics evaluation software. Real time and prediction biomechanics, electromyography and metabolic responses, all showed significant increase during lifting higher 'magnitude of load' with higher 'lifting frequency' and lifting from floor height to either knuckle or shoulder heights. This may be due to higher muscular activity and higher joint angular stress resulting in higher physical workload. It was observed that lifting 10 kg weight at frequency of 1lift.min^{-1} from Knuckle to Shoulder (K-S) height resulted in least physical workload. It is suggested that as an ergonomics intervention, for all practical purposes involving MLTs, loads should be placed initially at K-S height for minimizing lifting hazards.

Relevance to Industry

Complete ergonomic assessment of lifting tasks required to formulate safe lifting strategies for Industrial operations. Lifting 10 kg at 1lift.min^{-1} from 'knuckle to shoulder' height was ergonomically best combination. For lifting 10 kg or more, bending should be avoided. Predicted biomechanics may be effectively used to assess lifting tasks.

Keywords: Manual Lifting Tasks; Biomechanics; Metabolic Responses; Electromyography; Physical Workload.

Introduction

Manual lifting tasks (MLTs) are integral part of many occupations across the globe. A study carried out in Europe established that 35% of the employees working in different conditions were involved in manual lifting and carrying loads on a regular basis [1]. The health hazards associated with MLT in different occupational sectors like Industry, Agriculture, Defence, Health care and Housekeeping have been identified in previous studies [2-6]. Troupe [7] discussed the reported incidents of musculoskeletal disorders occurring due to lifting heavy loads and indicated that awkward postures assumed while performing MLTs might lead to musculoskeletal stress. Paul et al. [8] characterized lifting tasks by a number of variables related to the task, e.g., load magnitude, 3D location of the origin, lifting frequency and destination of the lift. Garg et al.[9] established metabolic evaluation model through prediction of metabolic cost due to given MLT. However, metabolic basis of MLT was pointed out in NIOSH lifting equation and its revised form in 1991 [10] and later [11,12]. Sean et al. [13] focused on assessing changes in metabolic cost during lifting in stooped and kneeling postures using Beckman

Metabolic Measurement Cart I. Samanta and Chatterjee [14] computed energy expenditure while participants performed MLTs with maximum working capabilities. The study by Sean et al. [1] also assessed muscular load of MLTs using electromyography (EMG) of thigh and trunk muscles while lifting in stooped and kneeling postures. Ming-Lun et al. [15] recorded EMG responses of lower limb muscles in 44 professional roofers while they performed lifting tasks on different inclined surfaces for estimating their workload. Hoozemans et al. [16] measured EMG responses of trunk musculature while participants (n=10) lifted box using four different handle heights and concluded that lifting height and weight were important determinants of low back load during manual material handling.

Jorgensen et al. [17] carried out a psycho-metabolic study on fifteen male college students which aimed to determine a method to identify maximum acceptable weight of lift (MAWL) that would reduce the incidences of lower back disorder. The study reported heart rate, trunk positions, velocities and accelerations along with estimated spinal loading in terms of moments and spinal forces in three dimensions measured with help of the EMG-assisted biomechanical model. Responses of all parameters were found to increase with increase in lifting load magnitude. Straker et al. [18] determined maximum acceptable weights (MAWs) in single and combination of tasks, respectively, involving varying lifting frequencies and lifting heights. Combination of tasks included one each of the single tasks, namely pulling, lifting, carrying, lowering and pushing. Eighteen college students, comprising of equal numbers of males and females, participated in the study. The MAW of each of combination tasks were compared to the MAWs of the single tasks. It was concluded that use of MAWs for single tasks to estimate the risks involved in combination tasks were not acceptable. Thus, it is important to distinguish between the maximum load carrying capacity and load carrying ability of an individual (e.g., a soldier) that enables him to retain the capacity to perform other tasks, e.g., observation, navigation, combat operation, etc. Past studies [19-25] indicated physical and physiological load of load lifting and load carriage under varying operational and environmental conditions. However, physiological studies remained inconclusive about definition of a maximum load, but suggested that one-third body weight or in terms of relative workload equivalent to one-third of VO_2max for a working day as optimal load [25]. These studies, though did not consider biomechanical aspects of load carriage and lifting, indicated that proper distribution of load around the human body and minimization of biomechanical stress were of utmost importance for optimal performance. Literature is rich in reported studies on 2D biomechanics assessment of lifting [2,26-32]. However, reported studies on simultaneously collected 3D and 2D biomechanics, EMG and metabolic responses of MLT are rare in literature. Authors have not come across any such reported study dealing with the fact that how the metabolic parameters would behave with respect to biomechanical parameters while participants and tasks remained same under given set of environmental conditions.

Thus, a study was designed to assess the responses of participants, in terms of simultaneously recorded 3D realtime biomechanics, EMG and metabolic parameters along with 2D predicted biomechanics, while participants, experimental and environmental conditions remained same. It was visualized that such an unified study, though conducted as a pilot study, may help to expand on the existing knowledge base. The gap in the literature existed as each of above parameters were considered under separate studies in the past (i.e., either biomechanics (2D or 3D realtime) or metabolic and /or EMG) carried out under different experimental conditions and timelines and hence, a relationship between them could not be drawn directly [8, 16, 26-29]. It is understood that through simultaneously recorded data on biomechanics (realtime and predicted), metabolic and EMG of load lifting, a complete picture could be obtained for understanding how these parameters would behave with respect to each other. It was hypothesized that keeping all conditions constant, the onset of biomechanical stress due to lifting load to different heights will be earlier on timeline than the onset of metabolic workload. Further, it was hypothesized that all conditions and participants remaining same, the biomechanics responses as obtained from 3D realtime data collection would be similar to that obtained using 2D predicted biomechanics and therefore,

Table 1: Physical characteristics of the participants (n=11) involved in current pilot study of manual lifting tasks.

S.No.	Physical Attributes	Value (mean ±SD)
1.	Age (years)	24.2±2.23
2.	Height (cm)	174.5 ±3.04
3.	Weight (kg)	72.7±8.72
4.	Hand Grip Strength-Right (kg)	41.5 ±5.02
5.	Hand Grip Strength-Left (kg)	38.1 ±4.03
6.	Maximum Oxygen Consumption (VO_2max, $ml.min^{-1}.kg^{-1}$)	38.4 ±3.96

DOI: *10.46718/JBGSR.2021.09.000212*

the use of 2D predicted biomechanics data to understand the injury potential of the MLTs would be acceptable where realtime 3D biomechanics data collection is not feasible.

Objectives

a. To assess the biomechanical and metabolic workload of simple manual lifting tasks under conditions of varying load magnitude, height and frequency of lifting

b. To identify best combination of lifting load magnitude, lifting height and frequency of lift that would cause least biomechanical and metabolic workload

c. To compare and validate predicted biomechanics responses computed from 2D images of different postures of participants while carrying out MLTs with the 3D realtime biomechanics responses recorded simultaneously

Methodology

Participants

Eleven (11) physically fit and active male university students with urbanized life style participated in this study and their demographical data is given in Table 1. The inclusion criteria for the study were that the participants should be young, healthy adults between age ranges 20-30 years without prior exposure to load lifting tasks. Participants with any surgery or major illness throughout lifespan or any complaint of musculoskeletal disorder in any part of the body within last two years were excluded.

Instrumentation

Hand grip strength was recorded with Baseline Hydraulic

Hand Dynamometer (M/s Patterson Medical, UK).The 3D motion analysis system (3D MAS) with 6 Raptor Hawk digital cameras, Cortex 3.6 and OrthoTrack (OT) 6.6.1 software (M/s Motion Analysis Corp., USA), integrated with 16 Channel EMG system (5V bipolar mode, M/s Motion Lab System, USA)were used to collect and analyze the realtime 3D kinematics (120 Hz/Camera) and surface EMG (1000 Hz) data, respectively. One Kistler Force Plate (model no. 9286 AA) with BioWare® software (Type 2812A1-3, version 3.24 (7648), M/s Kistler Instrument AG, Winterthur, Switzerland) was used to collect and analyze the realtime 3D kinetics data at a sampling rate of 200 Hz. As the tasks did not involve any change of position or displacement of the participant, the sampling rate of 200Hz was thought to be adequate [33]. Metabolic measurement system (K4b^2, Cosmed s.r.l, Italy) was fitted on the participants to record metabolic parameters. Sony Handy Cam(M/s Sony Corporation, Tokyo, Japan)was used for video photography of each MLT trial for extracting images of participants to carry out ergonomics evaluation using ErgoMaster software (M/s NexGen Ergonomics, Canada) for reporting prediction kinematics and kinetics of the given tasks.

Experimental Protocol

Experimental protocol was screened and approved by Institutional Ethics Committee (Ref. No. IEC/DIPAS/D-1/2 dated 8 December 2015) in compliance to Helsinki Protocol (1964-2013). Accordingly, each participant was explained and familiarized with the study design and they signed informed consent before commencement of the study. Also, they were requested to refrain from smoking, drinking or other such activities during the period of study. Participants took light breakfast at least one hour before reporting to the laboratory and reported one hour prior to the experiment, so that they would be in a state of rest before starting the experiment. Their basic physical characteristics were noted in a demographical questionnaire and their Hand Grip Strengths were recorded (Table 1). Maximum oxygen consumption (aerobic) capacity or VO_2 max was measured on a separate day as per the standard methodology followed previously in authors' laboratory [34]. These values indicated basic fitness level of currently recruited participants thus, enabling the applicability of results of current study to similar populations elsewhere.

During experiments participants wore minimal clothing (Black shorts and vests only). Each of the participants performed MLT while standing over the force plate. (Table 2) gives the details of MLT performed by each participant (n = 11) along with skeletal images of activity postures. Two different loads (10 kg and 20 kg) were lifted by each volunteer at two lifting frequencies (1 lift.min^{-1} and 4 lifts.min^{-1}) through three lifting heights [Floor to Knuckle (F-K), Knuckle to Shoulder (K-S) and Floor to Shoulder (F-S)]. Lifting tasks were performed on a wooden rack which contained two wooden platforms, one at average knuckle height (0.72 m) and the other at shoulder height (1.41 m) of the participants. As shown in (Table 2), total number of 30 experimental trials was performed by each participant. Three trials for 1lift. min^{-1}were collected for each experimental condition while 2 trials for 4lifts.min^{-1}frequency were recorded, totaling to 5 trials for frequency of lift for each participant. Five minutes rest pause was given between each trial.

For simultaneously recording data for 3D realtime kinematics, participants were fitted with sets of 29 and 25 retro-reflective Heylen Hayes markers for static trials and motion trials, respectively. Surface EMG electrodes were place on selected pairs of muscle bellies taking proper precautions (Cram and Kasman, 1998). Six Raptor-Hawk

***DOI:** 10.46718/JBGSR.2021.09.000212*

Table 2: Details of the manual lifting tasks performed by each participant (n = 11) with the skeletal images of activity postures.

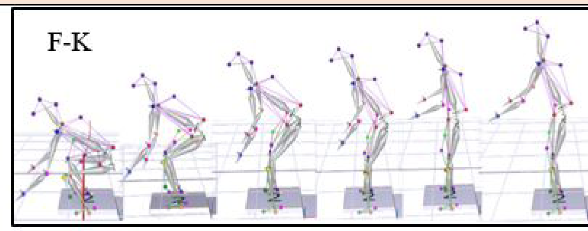
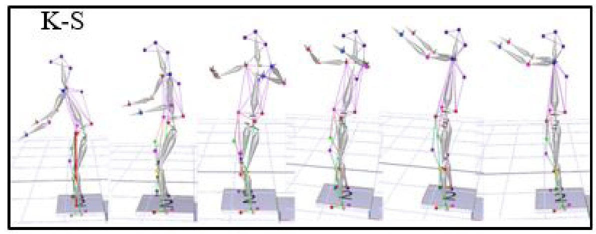
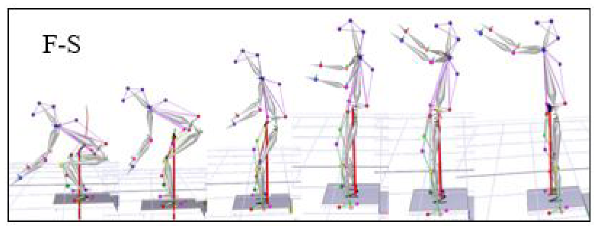
Height/ Vertical Distance	Weight	Frequency	Combination	Trial nos. (Lift Count x Repetition)	Sequence of events
Floor to Knuckle (F-K) 0.72m	10 Kg	1 lift/min	FK10K1	3 (1 x 3)	
		4 lift/min	FK10K4	2 (1x 2)	
	20 Kg	1 lift/min	FK20K1	3 (1 x 3)	
		4 lift/min	FK20K4	2 (1x 2)	
Knuckle to Shoulder (K-S) 0.69m	10 Kg	1 lift/min	KS10K1	3 (1 x 3)	
		4 lift/min	KS10K4	2 (1x 2)	
	20 Kg	1 lift/min	KS20K1	3 (1 x 3)	
		4 lift/min	KS20K4	2 (1x 2)	
Floor to Shoulder (F-S) 1.41m	10 Kg	1 lift/min	FS10K1	3 (1 x 3)	
		4 lift/min	FS10K4	2 (1x 2)	
	20 Kg	1 lift/min	FS20K1	3 (1 x 3)	
		4 lift/min	FS20K4	2 (1x 2)	
Total number of trials				30	

Table 3: Metabolic responses (Mean±SEM) during manual lifting of different load magnitudes through different heights at different frequencies of lift in young Indian adults (n=11).

		1 lift.min^{-1}						4 lift.min^{-1}					
		10kg			20kg			10kg			20kg		
		F-K	K-S	F-S	F-K	K-S	F-S	F-K	K-S	F-S	F-K	K-S	F-S
Heart Rate (beats.min^{-1})	Mean	82.1	86.2	95.1	87.6	91.6	95.3	92.0	94.0	99.32	95.0	102.6	110.6
	±SEM	4.36	4.18	4.17	4.26	4.35	3.81	3.29	3.91	5.58	3.21	3.89	4.65
Oxygen Consumption (ml.min^{-1}.kg^{-1})	Mean	6.93	6.93	9.12	7.3	9.1	11.1	8.9	9.4	11.1	7.3	8.8	13.0
	±SEM	0.43	0.36	0.67	0.38	0.61	1.07	0.77	0.86	0.91	0.79	0.87	1.01
RWL (% of VO_2 max)	Mean	18.30	18.12	24.0	19.11	23.96	28.87	22.53	24.49	29.05	19.87	20.00	34.91
	±SEM	1.33	0.91	2.01	1.07	1.62	2.72	2.53	2.53	2.95	2.29	2.0	3.55
Energy Expenditure (Kilojoules)	Mean	9.12	11.164	14.08	11.15	12.66	15.16	12.87	14.19	16.18	10.95	13.54	19.72
	±SEM	0.77	0.60	0.92	0.67	0.61	0.93	0.69	0.66	1.00	1.30	1.03	0.31

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Camera based 3DMAS integrated with 16 Channel EMG system was used to record kinematics and EMG data while participants carried out MLT. Videography was accomplished with Sony Handy Cam for each trial of the entire MLTs carried out. The frequency of4lifts.min^{-1}included four times lifting in one minute, which was considered as one single trial. This trial was repeated twice at an interval of five minutes, making the number of repetitions to be 'two'. In order to get maximum response due to MLT under this condition, the 2D images at four different points on timeline were extracted from 4th lift of second repetition. Recording of metabolic parameters were carried out using metabolic measurement system with face mask worn tightly, preventing leakage of exhaled air following standard protocol [34].

Data Analysis

Realtime kinematics parameters (Ankle, Knee, Trunk and Elbow angles) were taken directly from Cortex 3.6 software using the stick diagrams of the participants. Muscle responses through EMG and physical workload were processed in OrthoTrack 6.6.1 and K4b^2 software, respectively. The EMG responses were obtained as analog unit (or Bits) which were converted to Volts using standard conversion formulae (DAH 2004-2012). In the present study, four pairs of muscle maximally used in MLT (Gastrocnemious, Hamstring, Erector Spine and Trapezius) were considered. Vertical Ground Reaction Force (VGRF), Anterior Posterior Moment (M A-P), Work and Power were obtained from kinetic data recorded during MLT. For statistical analysis of Kinematics, Kinetics and EMG data, peak values obtained in each trial were considered and finally average peak values of three repetitions for 1lift.min^{-1} and two repetitions for 4lifts.min^{-1}for each individual were considered. From the recorded video files, still photographs were extracted at pre-determined positions during the lifting experiments and analyzed to report prediction kinematics (angles of Neck, Forearm, Upper Arm and Leg) and prediction kinetics responses [Total Compressive Forces (TCF), Total Shearing Forces (TSF), Compressive Force due to Load (CF-L), Shearing Force due to Load (SF-L) exerted on L5/S1 disc of spine] for each MWL tasks using Lifting Toolkit of ErgoMaster software (M/s NexGen Ergonomics, Canada), an ergonomics evaluation software. Required information like participants' height, weight and lifting distance were keyed in the software manually. Four frames at different points on timeline of 3rd trial of 1 lift.min^{-1} were used for prediction analysis. Metabolic parameters considered were heart rate (HR, beats.min^{-1}), Oxygen consumption (VO_2, ml.min.kg^{-1}), relative workload (% of VO_2max), energy expenditure (EE, kilojoules).

Statistical Treatment

The data was analyzed using the Statistical Package for Social Sciences (SPSS) version 21 (M/s SPSS Inc., Chicago, IL, USA). All the descriptive statistics were presented as mean values and standard error of mean (SEM). Three ways repeated measure analysis of variance (MANOVA) for all the parameters followed by Bonferroni post hoc test was applied for the pair-wise comparison of main effect within group. A value of $p \leq 0.05$ was considered to be statistically significant.

Results

Salient findings of the study with respect to kinematics, kinetics, EMG and metabolic parameters are given in Figures 1-5 and Table 3. These observations and analyzed results are individually explained in next few subsections.

Realtime 3D Kinematics

Angular displacements of Trunk, Elbow, Knee and Ankle joints in response to lifting weights, frequencies of lift and lifting heights are reported in Figure 1. The angular changes reported were lower at K-S than F-K and F-S. The Trunk, Elbow and Knee showed statistical significance for lifting weight and height variations. Ankle showed significant changes for lifting weight, frequency and height variations. The levels of significance under different experimental conditions are reported in Tables 4 & 5.

Realtime 3D kinetics

Vertical Ground Reaction Force (VGRF), Anterior Posterior Moment (M A-P), Work done and Power generated due to lifting loads, frequencies of lift and lifting heights are presented in Figure 2. Values of VGRF and M A-P reported were significantly lower during lifting at K-S as compared to F-K and F-S height. Work and power variations reported were significantly lower during lifting through K-S as compared to F-K and F-S height. Levels of significance under different experimental conditions are given in Tables 4 & 5.

Electromyography

Electrical activities observed for right and left Gastrocnemius, Hamstring, Erector Spine and Trapezius muscles during given MLTs are reported in Figure 3. Each of the muscle pairs showed lower muscular activity during lifting at K-S height in comparison to other two heights. Reported results showed statistically significant differences Tables 4 & 5.

Predicted 2D kinematics

Neck, forearm, upper arm and leg angular responses

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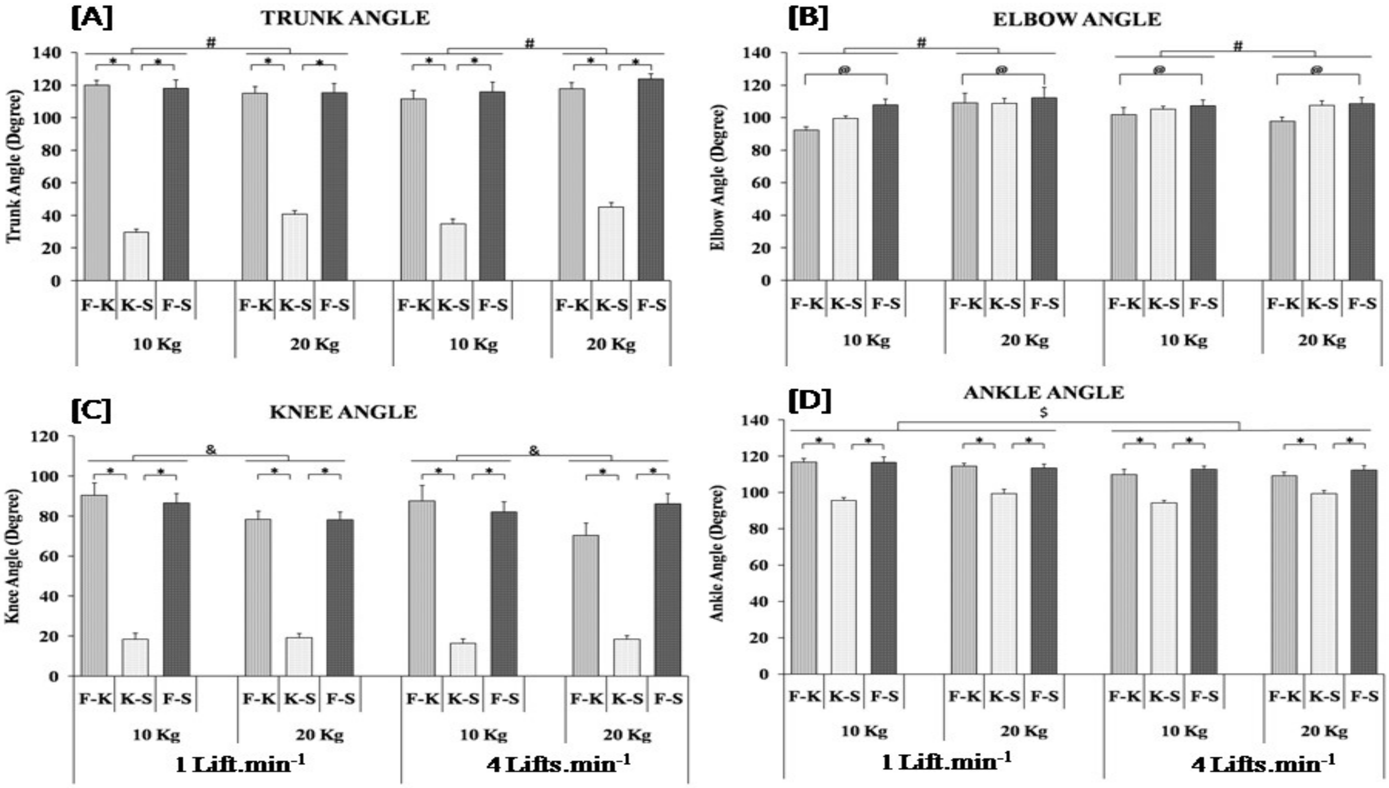

Figure 1: Three dimensional realtime kinematics (A. Trunk Angle, B. Elbow Angle, C. Knee Angle & D. Ankle Angle) changes (Mean±SEM) during manual lifting of different loads at different heights and frequencies of lift (n=11).

*Significance levels- *: p=0.0001; $: p=0.008; # : p=0.03; & : p=0.04; @ : p=0.05.*

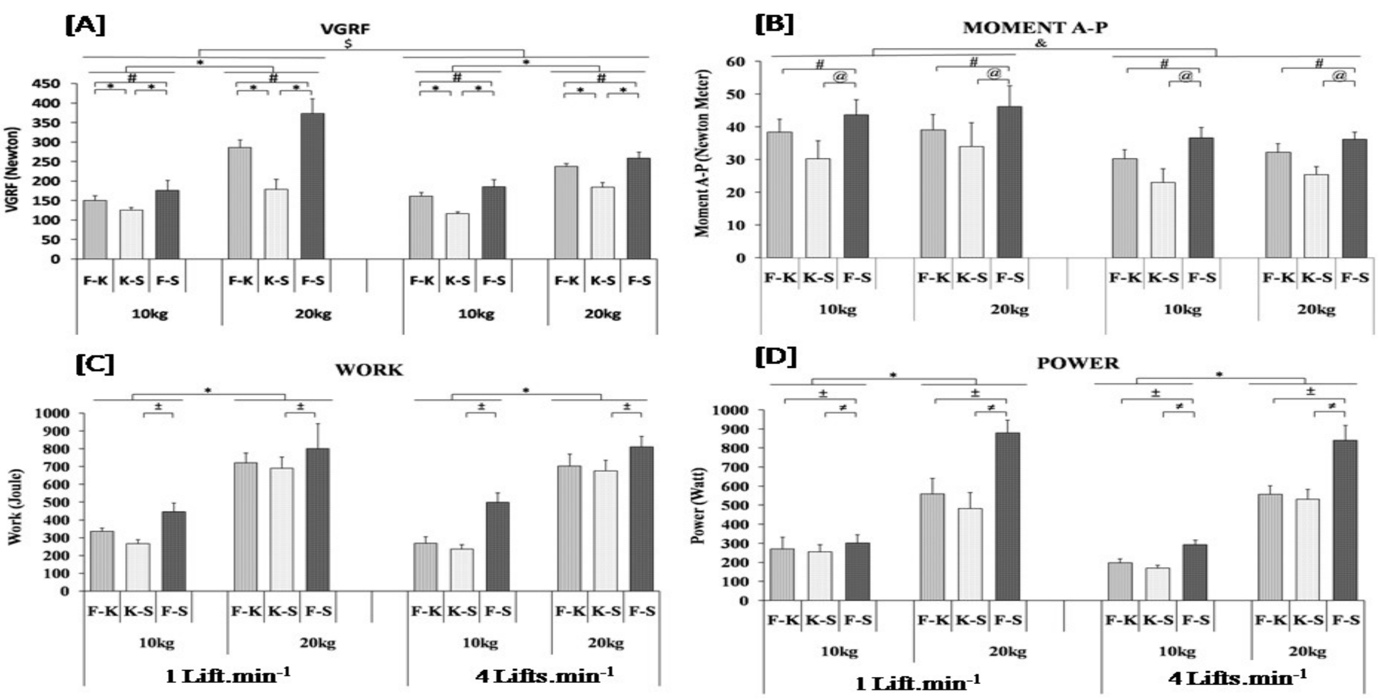

Figure 2: Three dimensional realtime kinetics (A. VGRF, B. Moment A-P, C. Work &D. Power) changes (Mean±SEM) during manual lifting with different loads, heights and frequencies of lift (n=11).

*Foot note :Significance levels- *: p=0.0001; ≠: p=0.002; ±: p=0.005; $: p=0.01; & : p=0.02; # : p=0.03; @ : p=0.05.*

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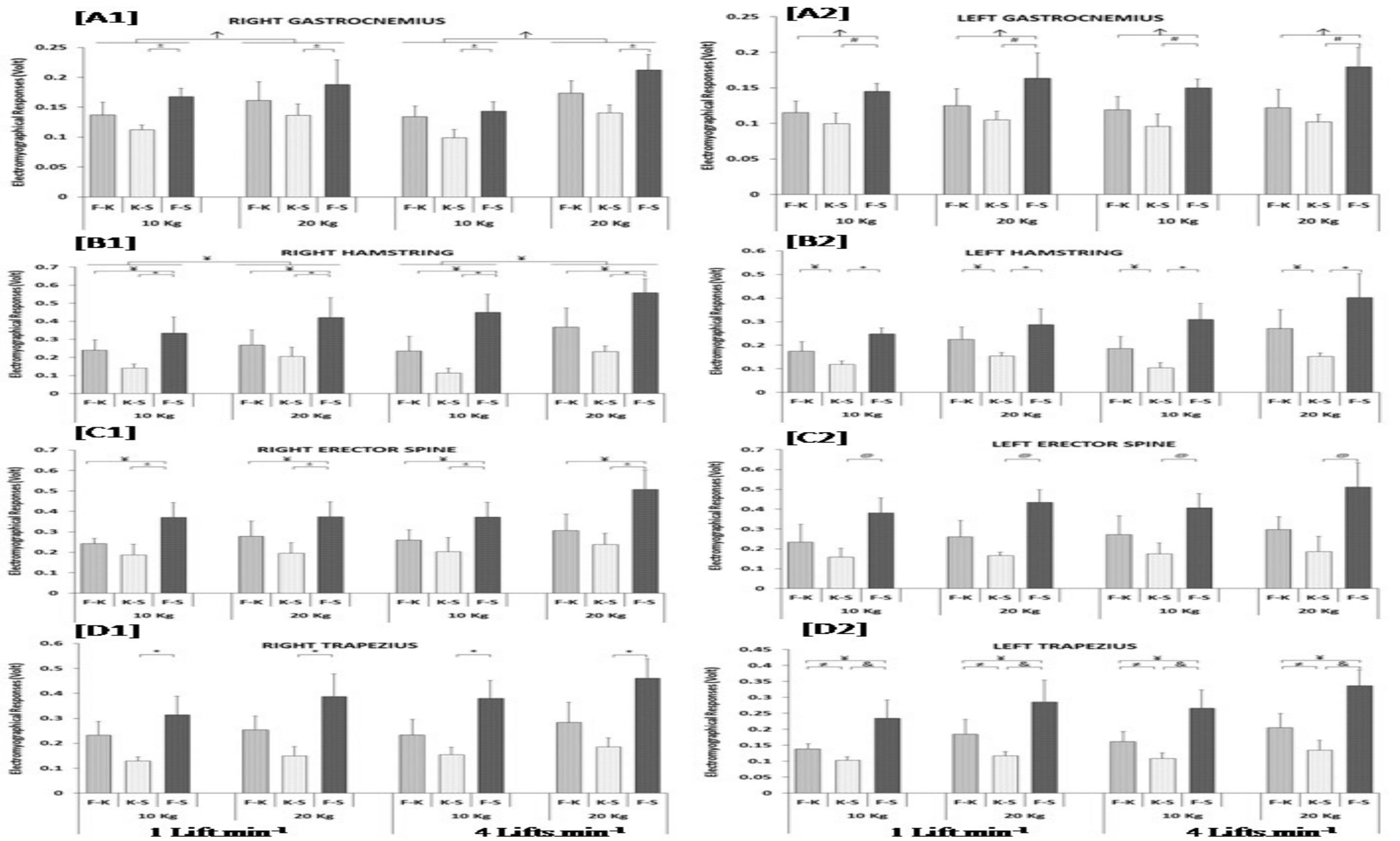

Figure 3: Electromyography (EMG) responses (Mean±SEM) of different muscle pairs during manual lifting tasks with different loads, heights and frequencies of lift (n=11).

(A1 &A2 :Right & Left Gastrocnemius; B1& B2 : Right & Left Hamstring; C1 & C2 : Right & Left Erector Spine; D1 & D2 : Right & Left Trapezius, respectively)

*Foot note: Significance levels- * : p=0.001; # : p=0.002; @ : p=0.003; & : p=0.004; $: p=0.007; ±: P=0.02; ≠: p=0.03; ¥: p=0.04; ↑: p=0.05.*

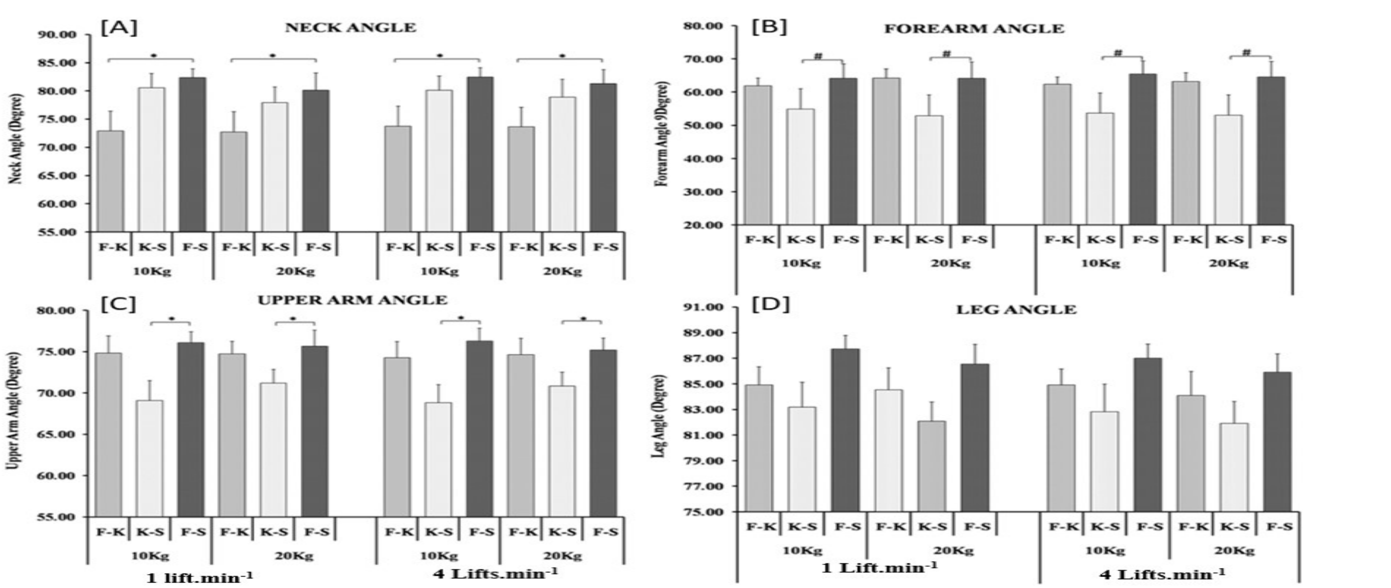

Figure 4: Prediction kinematics responses as computed using 2D images of participants (n=11) during manual lifting tasks with different loads, heights and frequencies of lift (A. Neck Angle; B. Forearm angle; C. Upper Arm angle; D. Leg Angle).

Foot note: Significance levels- : P=0.02; # : P=0.04.*

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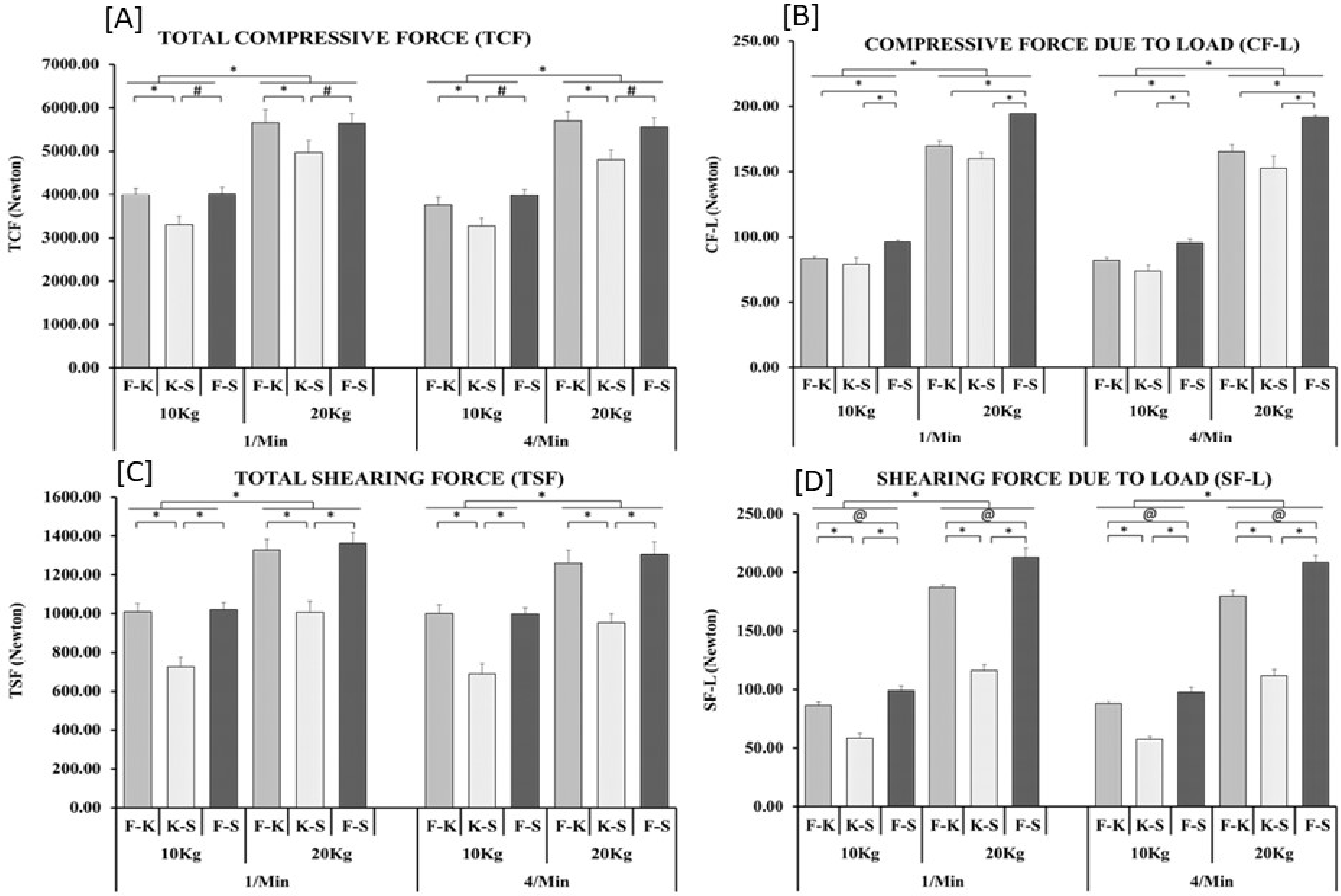

Figure 5: Prediction kinetics responses computed from 2D images of participants (n=11) during manual lifting tasks with different loads, heights and frequencies of lift (A. TCF; B.TSF; C. CF-L and D. SF-L)

Foot note: Significance levels- : P=0.000; # : P=0.001; @ : P=0.01.*

due to MLT are reported in Figure 4. All of the four joints showed higher angular deviations during lifting condition F-S followed by K-S and F-K. Significant changes were observed in predicted kinematics for lifting height as presented in Tables 4 & 5.

Prediction Kinetics

Figure 5 represents Prediction kinetic parameters (total compressive force (TCF), total shearing force (TSF), total compressive force due to load (CF-L) and total shearing force due to load (SF-L) exerted on L5/S1 segment of spine). These parameters showed increase in values in the order K-S<F-K<F-S. Significant responses obtained are indicated in Tables 4 and 5.

Metabolic Cost

Metabolic responses during load lifting tasks involving different load magnitudes, heights and frequencies are represented in Table 3. Metabolic parameters considered were heart rate (HR, beats.min^{-1}), Oxygen consumption (VO_2, ml.min.kg^{-1}), relative workload (RWL, % of VO_2max) and energy expenditure (EE, kilojoules). Energy expenditure was calculated using Weir's formula (Weir 1949). Oxygen consumption gradually increased with increases in lifting load magnitude, height and frequency of lift. Oxygen consumption and RWL changed significantly for lifting frequency and height conditions, as reported in Tables 4 & 5.

Discussion

Under current study, manual lifting tasks (MLTs) have been assessed in terms of simultaneously recorded biomechanics, metabolic and electromyography profiles to get an idea about injury potential of such activities in young Indian adults. Globally, health hazards due to MLTs in wide

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Table 4: Levels of significant differences in 3D realtime biomechanics, 2D prediction biomechanics, EMG and metabolic responses of manual lifting tasks with different loads, frequencies and heights of lift (n=11).

Parameters	Weight			Frequency			Height		
	df	F-value	p-value	df	F-value	p-value	df	F-value	p-value
Trunk Angle	1,10	6.13	0.03	--	--	--	2,20	435.88	0.0001
Elbow Angle	1,10	6.81	0.03	--	--	--	2,20	3.33	0.05
Knee Angle	1,10	5.18	0.04	--	--	--	2,20	126.24	0.0001
Ankle Angle	--	--	--	1,10	11.14	0.008	2,20	66.94	0.0001
VGRF	1,10	78.85	0.0001	1,10	9.51	0.01	1.28, 12.79	44.35	0.0001
Moment A-P	--	--	--	1,10	7.45	0.02	1.90, 11.90	7.03	0.01
Work	1,10	161.55	0.0001	--	--	--	2,20	10.07	0.01
Power	1,10	221.85	0.0001	--	--	--	2,20	16.83	0.0001
R-Gastrocnemius	1,10	4.72	0.005	--	--	--	2,20	6.41	0.007
L-Gastrocnemius	--	--	--	--	--	--	2,20	8.49	0.002
R-Hamstring	1,10	5.60	0.04	--	--	--	2,20	12.50	0.0001
L-Hamstring	--	--	--	--	--	--	2,20	13.74	0.0001
R-Erector Spine	--	--	--	--	--	--	2,20	8.49	0.002
L-Erector Spine	--	--	--	--	--	--	2,20	10.30	0.001
R-Trapezius	--	--	--	--	--	--	2,20	11.10	0.001
L-Trapezius	--	--	--	--	--	--	2,20	13.35	0.001
Neck Angle	--	--	--	--	--	--	2,20	6.652	0.006
Forearm Angle	--	--	--	--	--	--	2,20	3.440	0.05
Upper Arm Angle	--	--	--	--	--	--	2,20	7.147	0.005
Leg Angle	--	--	--	--	--	--	1.36, 13.59	4.061	0.05
TCF	1,10	131.52	0.001	--	--	--	2,20	27.586	0.001
CF-L	1,10	1011.4	0.001	--	--	--	1.35, 13.52	28.689	0.001
TSF	1,10	92.297	0.001	--	--	--	2,20	70.340	0.001
SF-L	1,10	1412.9	0.001	--	--	--	2,20	112.33	0.001
HR	1,10	5.69	0.04	1,10	33.72	0.0001	2,20	37.35	0.0001
VO_2	--	--	--	1,10	7.84	0.02	2,20	31.95	0.0001
RWL	--	--	--	1,10	7.88	0.02	2,20	27.63	0.0001
EE	--	--	--	1,10	27.20	0.0001	2,20	69.88	0.0001

variety of industrial sectors have been established by past studies [2-6]. Though MLTs are 'part and parcel' of different occupations worldwide, they are most commonly practiced in industrially developing countries like India. Known health risks, especially musculoskeletal disorders like low back pain (LBP), due to occupational manual lifting in professional lifters, e.g., porters, construction workers, industrial workers, soldiers, etc., are very common [35-39]. According to Punnet et al. [40], world report attributed 37% cases of LBP in adults to occupational exposures and estimated that an annual loss of 818,000 disability-adjusted life years was incurred worldwide. Part of this current study was published earlier [41] in which authors calculated the injury potential of MLTs (Table 2) using revised National Institute of Occupational Safety and Health [42] equations and showed that for lifting 10 kg and 20 kg loads, overloading of spine was ≥100% and ≥150%, respectively. This corroborated with the observation of past studies that during walking with load or lifting loads, maximum trauma was encountered by lower body joints which absorbed additional forces

Table 5: Levels of significant differences in 3D realtime biomechanics, 2D prediction biomechanics, EMG and metabolic responses of manual lifting tasks with respect to different lifting heights (n=11).

Parameters	p-value		
	F-K vs F-S	F-K vs K-S	K-S vs F-S
Trunk Angle	0.0001	--	0.0001
Elbow Angle	0.05	--	--
Knee Angle	--	0.0001	0.0001
Ankle Angle	--	0.0001	0.0001
VGRF	0.03	0.0001	0.0001
Moment A-P	0.03	--	0.05
Work	--	--	0.02
Power	0.005	--	0.002
R-Gastrocnemius	--	--	0.02
L-Gastrocnemius	0.05	--	0.002
R-Hamstring	0.04	--	0.001
L-Hamstring		0.03	0.001
R-Erector Spine	0.04	--	0.02
L-Erector Spine	--	--	0.003
R-Trapezius	--	--	0.001
L-Trapezius	0.04	0.03	0.004
Neck Angle	0.02	--	--
Forearm Angle	--		0.04
Upper Arm Angle	--	0.000	0.001
Leg Angle	--	--	--
TCF	--	0.000	0.001
CF-L	0.000	--	0.000
TSF	--	0.000	0.000
SF-L	0.01	0.000	0.000
HR	0.0001	0.003	0.002
VO_2	0.0001	--	0.002
RWL	0.0001	--	0.005
EE	0.0001	0.001	0.0001

proportional to the load magnitude being lifted or carried [33,43]. The study by Mondal et al. [41] further stated that there was a close association between 'manual lifting tasks' and LBP, increasing the injury potential when such tasks were performed without adhering to lifting norms.

The revised NIOSH [42] lifting equation had been established on basis of three criteria of MMH, i.e., biomechanical, psychophysical and metabolic [12]. Snook and Ciriello [10] chose metabolic basis of the revised equation to arrive at maximum acceptable weight of lifting. In order to explain the results of current study, metabolic basis of manual lifting as given by Samanta and Chatterjee [14] was considered which had established that linear proportionality remained between 'metabolic workload and independent determinants of lifting, namely 'lifting height' and 'lifting frequency', whether considered separately or together. It has been established that physical workload should be kept below 35% of VO_2max during an 8-h workday for general population [44] and for more robust population like military personnel physical workload should never exceed 50% of VO_2max for a work-day of 8-h duration. Metabolic responses in present study, in spite of getting statistically significant changes, none of the MLTs carried out could be categorized as highly physically demanding tasks as opposed to the responses obtained for realtime and predicted biomechanics and EMG parameters. This contradicting response affirms the hypothesis of the authors and indicates that the onset of fatigue during such activities in terms of biomechanics of human body occurs much before the onset of fatigue in terms of metabolic cost. This is a unique finding of the current study and drawing such inference was possible only because this study involved unified assessment of MLTs in terms of biomechanics, EMG and metabolic parameters recorded simultaneously. This finding may provide important basis for developing guidelines for designing MLTs for different industrial operations and may revolutionize the erstwhile considered criterion, as till now, in Industrially Developing Countries like India, such guidelines were formed on the basis of metabolic parameters only.

Past studies have established the mechanism by which disc disruption and degeneration occurs and eventually results in back pain [38]. The most affected region of spine is the vertebral endplate where spinal load is sufficiently higher. These endplates are attached to the spinal discs and are important in disc nutrition from blood vessels of the vertebral bones. When fracture occurs in discs, body's healing mechanism seal the crack with scar tissue, inhibiting the flow of nutrition from blood to discs. This inadequate nutrition supply will gradually degrease the discs, leading to fissures or tears of disc fibers with inflammation response and ultimately result in sensation of LBP [35]. There are several views as regards to how the disc fracture occurs. One of the most possible causes of disc fracture is the fatigue failure or the overuse injury where a small fracture appears in the endplate, very commonly due to occupational MLTs. In the long duration, with repeated MLTs it transforms into full-fledged fracture. Thus, a sub-maximal repetitive loading can lead to an injury experienced that is similar to an injury due to one-time overload of the tissue beyond its strength [37,39]. Industrial workers are most susceptible to LBP caused due to disc disruption or degeneration and this factor accounts for about 39% of chronic back injuries [40]. Reducing the probability of occurrence of initial endplate fracture could possibly be the best method to minimize degeneration of endplates. Therefore, adequate manual material handling (MMH) task design approach is needed to reduce LBP resulting from MMH, including MLT. The study by Hoozemans et al. [16] measured EMG responses of trunk musculature while participants (n=10) lifted a box using four different handle heights. They established that lifting height and load magnitudes were important determinants of low back loading during MMH.

Paul et al. [8] in their review article reported that lifting objects of less than 3 kg could be manually handled at frequency of more than 2 times.min^{-1} but loads more than 25 kg, regardless of the frequency of lift, were considered to be risk factor for LBP. The study by Oliveira et al. [45] established that lifting of box (7 kg and 15 kg, respectively) from waist level to either higher surface or to lower surface could be highly demanding for upper limbs, particularly shoulders. Taking cue from this study, for present study experimental load magnitudes selected were medium (10 kg) and heavy (20 kg). Salient findings of present study corroborated the results of Oliveira et al. [45] with respect to 3D biomechanics, predicted 2D biomechanics and EMG data. Both the studies indicate that during low level (Floor) to higher level (Shoulder) lifting, all these parameters were adversely affected, irrespective of load magnitude and frequency of lift. The EMG responses of both right and left Trapezius muscles in the current study showed maximum activity during F-S lifting which may be due to the fact that these muscles worked more intensely for lifting any object at F-S height.

Lifting with kneeling posture was found to be less demanding than lifting with squatting posture in terms of knee extensor and flexor EMG responses [1]. Erector spine was found to be much more active in terms of EMG responses during lifting with kneeling posture than stooped [13]. Inclination and lifting tasks performance caused a significant increase in the normalized EMG amplitudes of all postural muscles [15]. Present study reflected similar results as activities of erector spine, gastrocnemius, hamstring and trapezius muscle pairs increased with increased lifting load and while lifting through F-K and F-S heights as compared to K-S heights. It has been reported earlier that not only lifting weight, but vertical distance of lifting also acts as an important determinant for safe lifting [45]. Similarly, force data obtained in the current study showed higher values during F-S height lifting than either F-K or K-S height lifting which agreed well with these past studies.

The Indian Council of Medical Research (ICMR) Bulletins have repeatedly indicated that incorporating ergonomic approach in designing of MLTs is urgently needed to overcome injury risks, enhancing safety and productivity [11,42]. It was stated that implementation of mechanical lifting equipment or incorporation of technique to adjust manual lifting height could be beneficial to reduce lower back injury while lifting block load of 11-16 kg range [46-49]. Present study results also indicated that such an arrangement would be beneficial for our population too, as the height of lift 'Knuckle to Shoulder' was found to be biomechanically least demanding with lifting load of 10 kg at lifting rate of 1 lift.min^{-1}. This inference was possible as present study investigated the effects of MLT on biomechanics, metabolic and EMG responses simultaneously in a single study, keeping independent variables constant (e.g., participants, tasks and experimental/environmental conditions). Thus, as a pilot study it accomplished all objectives and proved all hypotheses taken at the commencement of experimentation. It indicated best combination of lifting load-height-frequency combination with least biomechanical stress and metabolic cost. In addition, it vetted the fact that biomechanical stress as quantified by 3D realtime kinematics and kinetics was comparable with that indicated by 2D predicted kinematics and kinetics; therefore it may be assumed that under conditions where 3D kinematics and kinetics assessments are not feasible, one could use 2D images to predict the biomechanics stress status of manual material handling tasks for different occupational situations. Data generated in the current study may be effectively utilized for designing a database of our participants for establishing an optimized combination of load-height-frequency of lift with minimal physical demand. Salient findings of the study could also be extrapolated and / or applied for developing load lifting norms for populations with comparable physical characteristics across the globe.

Merits of the Study

1. Present study seems to be a unique attempt of establishing the relationship between metabolic and biomechanical responses of manual lifting tasks by recording data of both responses simultaneously. So far authors have not come across any published article which looks into such diverse aspects MLT under the umbrella of a single study.

2. Authors have not come across any reported study so far that assessed 2D predicted and 3D realime biomechanics under single study design. Current study has made a novel attempt for establishing the relationship between realtime 3D kinematics and kinetics data with that of 2D Prediction kinematics and kinetics data for given MLTs. The salient realtime 3D biomechanics responses of present study completely corroborated with 2D predicted biomechanics responses, which was a unique value addition to the

***DOI:** 10.46718/JBGSR.2021.09.000212*

database in present context. This may indicate that under adverse field situations where collection of realtime motion data was not possible, one could draw valid inferences using the 2D images of the workers while carrying out those tasks.

Limitation of the Study

Though as a pilot study sample size was adequate and the current study has added wealth of new information on MLTs for young Indian adult population, no conclusive inference could be drawn or no lifting norms or guidelines could be formed based on data with sample size of 11. Therefore it is required to repeat the study with statistically defined larger sample size for formulating load lifting norms or guidelines or designing ergonomic interventions facilitate load lifting with least injury risk for similar population.

Conclusion

a. Designing manual lifting tasks on the basis of only metabolic responses is inadequate. Simultaneously reported biomechanical and EMG responses are also needed to be considered.

b. Metabolic responses indicate that all lifting tasks in the current study were acceptable. However, when realtime and predicted biomechanics and EMG responses were considered, the combination of lifting load, height and frequency with least physical workload was "lifting a load of 10 kg from knuckle to shoulder (K-S) height at a frequency of 1 lift.min^{-1}". This may be termed as optimal combination for manual lifting that can be practiced for an 8h workday. All other MLT combinations were biomechanically demanding whereas, metabolically they were not demanding.

c. Valid inferences could be drawn using the 2D images of the workers while carrying out such tasks, if realtime biomechanics data collection is not feasible.

d. Salient findings of present study indicated that 'lifting height' was an important determinant of injury potential in MLTs and that by incorporating mechanical techniques to reduce the initial height for manual lifting (thus reducing the vertical distance through which one needs to lift the load), may reduce injury potential of such lifting tasks.

e. In the present study, physical demand was found to increase with the increase in 'lifting load magnitude and while lifting from lower level to higher lifting height, involving greater extent of bending and stretching. It could be safely suggested that for reducing physical demand, higher load magnitude and lifting through greater vertical heights, both above and below one's waist, needs to be avoided.

Acknowledgement

Authors are grateful the Dr Shashibala Singh, Director, DIPAS, M/o Defence, GOI, Delhi for her support at all stages of conducting the experiment. Unconditional and whole-heartened co-operation of participants in every step of data collection, inspite of busy schedule of university classes, is duly acknowledged. Funding of the study was done by Defence R&D Organization, M/o Defence, Government of India, India.

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