International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-1, October 2012

Physiological evaluation of manual lifting tasks on Indian male workers

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Abstract—***The present study follows a physiological approach to evaluate physical work capacity (PWC) during manual material handling (MMH) tasks on Indian male workers. This study involves six independent lifting variables such as lifting frequency (2, 5, and 8 lifts/min), lifting load (7, 14, and 21 kg), vertical height (waist, shoulder, and maximum reach), horizontal distance (25, 40, and 55 cm), laboratory condition (21°C, 27°C, and 33°C) and three different rectangular box size{X (35×24×28 cm),Y (44×34×17 cm), and Z (58×38×24 cm)}. The selected two response variables were oxygen intake and heart rate. Taguchi L_{27} Orthogonal array (OA) was applied to evaluate the effect of these lifting variables and plots of raw and signal- to- noise ratio data was used for computing the significance and their effect on the response variables. The analysis of variance (ANOVA) used to evaluate an optimal result of the variables. After analysis; it was found that all six variables (i.e. lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size) had significant effect on oxygen intake; whereas five variables (i.e. lifting frequency, lifting load, vertical height, horizontal distance and laboratory environment) showed a significant effect except one factor of box size was found insignificant in case of heart rate.***

Index Terms— Physical work capacity (PWC), Physiological approach, Manual material handling (MMH) tasks, Oxygen intake, Heart rate.

I. Introduction

Manual material handling (MMH) tasks play a vital role in a various manufacturing industries. Many jobs and activities in industries require manual materials handling. This includes a wide variety of activities such as loading and unloading boxes or carbons, removing materials from a conveyor belt, stocking items in a warehouse, etc. As a result, workers may suffer from cardiovascular and musculoskeletal disorders (MSDs). Various short and long term health effects can be attributed to MMH. Some of these are (National Institute for Occupational Safety and Health, 1981) lacerations, bruises, and fractures; cardiovascular strain, such as increased heart rate and blood pressure; muscular fatigue; chronic bronchitis; musculoskeletal injury, especially to the spine; and back pain. The National Institute for Occupational Safety and Health (NIOSH) developed a lifting equation in 1981 to indicate ''safe'' occupational lifting limits. This equation was revised in 1991. The equation uses a series of lifting multipliers (parameters) to calculate corresponding recommended task weight limits. Due to the nature of risk factor interactions, the limits obtained from the NIOSH equation may not be appropriate for all lifting tasks. The major causes of severe industrial injury due to the manual material handling (MMH) (Ciriello, 2005; Dempsey and Hashemi, 1999). . The MMH tasks are also very common in construction sites, and are one of the major contributors for musculoskeletal symptoms for construction workers (Lee, et.al, 2003). One of the most widely accepted approaches in designing MMH tasks is to design the job so as not to exceed the capabilities of the materials handlers (Ciriello and Snook, 1999; Ciriello et al., 1999). In order to control the frequency, severity and tremendous economic losses of these injuries, a variety of research and design guidelines have been proposed (Davis and Stubbs, 1980; Waters et al., 1993; National Occupational Health and Safety Commission, 1995). A study on combines manual material handling (MMH) tasks under different frequencies and height combination shows the significant affect on the worker's physiological and subjective responses on whole body strain (Li, et.al, 2009). Maiti, et.al, 2006 studied the effect of lifting variables and their interactions on heart rate and concluded that the interaction effects between lifting variables must be considered in addition to the effects of individual lifting variables. The maximum acceptable weights (MAW) lift having a significant effect due to the high lifting frequency (20 lifts/min) (Ciriello, 2007).For several decades the elimination or at least a reduction in the risk of injury due to lifting tasks has been a topic of interest in many fields of research. According to Chung and Kee (2000), evaluating a task ergonomically based on the 1991 revised NOISH lifting equations can help to identify risk variables causing musculoskeletal disorders and thereby facilitate to redesign the unsafe tasks towards eliminating the risk variables. The basic approaches for assessing the manual material handlings are physiological, psychophysical and biomechanical, NIOSH (1981). The physiological approach is best suited to manual material handling (MMH) tasks that are done frequently and over some duration of time. Various researchers have developed equations for predicting the energy costs of various types of manual material handling (MMH) tasks (Genaidy, et.al, 1987).

Manuscript published on 30 October 2012.
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The equation or models, take into account such as variables as body weight, weight of load, gender, vertical start and end positions of a lift, and frequency of handling. There are many factors that contribute to the workload experienced by people while engaged in physical work. Astrand and Rodahl (1986) present the major factors that influence the body's level of energy output such as nature of the work; somatic factors; training; motivation and environmental factors. These influence energy output through the physiological service function of supplying oxygen for muscle metabolism. Measurements of heart rate and whole body oxygen intake can be used to predict the maximum aerobic work capacity for a given type of work (Eastman Kodak Company, 1986). A person's aerobic capacity depends upon an efficient cardiovascular system. Aerobic capacity is considered to be the best single measure index of overall physical fitness (Sharkey, 1991). Heart rate is affected by heat, humidity, and emotional and psychological stress. If these are present in significant amounts, the linear relationship between heart rate and oxygen intake will be affected (Astrand and Rodahl, 1977). The objective of this study is to evaluate physical work capacity (PWC) during the manual lifting tasks on Indian male workers using physiological approach.

II. METHODS

A. Participants

Three male workers having at least 5 years experience of lifting tasks participated in the laboratory simulation study. They were free from any cardiovascular and musculoskeletal disorders (MSDs) and were advised not to smoke or drink for at least 2 hours before the experiment. The participants were instructed properly about the test procedures prior to perform them and also anthropometric measurements and resting metabolic rate (RMR) of all three workers were taken. An informed consent form was signed by each participant. The demographic details of the participants were given in Table I.

Table I. Demographic Details of the participants

Subject	Age (Yrs)	Height (cm)	Weigh t (kg)	RMR (kcal/day)
1	27	160	61	1106
2	25	170	68	1225
3	32	174	72	1335
Mean	28	168	67	1222

B. Apparatus details and Experimental scheme

COSMED pulmonary function equipment was used to measure heart rate and oxygen intake simultaneously with respect to time. This equipment consist of face oxygen mask for measuring oxygen intake (ml/kg/min) and POLAR heart rate probe clamped to the belt for measuring heart rate (beats per minute). The desired experimental scheme is to evaluate the effect of process variables such as lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size during lifting tasks on oxygen intake and heart rate of workers were shown in Table II. Before start of the experiment, 10 minutes warm-up session was provided. The response variables were oxygen intake and heart rate. Three different shaped rectangular box size designated as X (35×24×28cm), Y (44×34×17cm), Z (58×38×24cm) generally used for lifting purposes and pebbles as the load material inside the box were used during experiment. Each subject carried out lifting for the period of 15 minutes; during each trial at least 45 minutes break was given to the participant for fully recover from the fatigue stresses. Taguchi L_{27} Orthogonal array (OA) was applied for data analysis. In this study, six independent variables were varied at three different levels; the value of two (i.e.2) degree

Table II. Experimental variables with different levels

S.No.	Variables	Symbol	Levels
1.	Lifting frequency (lifts/minute)	A	2 5 8
2.	Lifting load (kg)	B	7 14 21
3.	Vertical height (cm)	C	Waist Shoulder Maximum Reach
4.	Horizontal distance (cm)	D	25 40 55
5.	Laboratory environment (°C)	E	21 27 33
6.	Box size (cm)	F	X (35×24×28) Y (44×34×17) Z (58×38×24)

Table III. L_{27} (3^{13}) Orthogonal Arrays (OA)

Trial No.	A	B	C	D	E	F
1.	1	1	1	1	1	1
2.	1	1	2	2	2	2
3.	1	1	3	3	3	3
4.	1	2	1	2	2	3
5.	1	2	2	3	3	1
6.	1	2	3	1	1	2
7.	1	3	1	3	3	2
8.	1	3	2	1	1	3
9.	1	3	3	2	2	1
10.	2	1	1	2	3	2
11.	2	1	2	3	1	3
12.	2	1	3	1	2	1
13.	2	2	1	3	1	1
14.	2	2	2	1	2	2
15.	2	2	3	2	3	3
16.	2	3	1	1	2	3
17.	2	3	2	2	3	1
18.	2	3	3	3	1	2
19.	3	1	1	3	2	3
20.	3	1	2	1	3	1
21.	3	1	3	2	1	2
22.	3	2	1	1	3	2
23.	3	2	2	2	1	3

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24.	3	2	3	3	2	1
25.	3	3	1	2	1	1
26.	3	3	2	3	2	2
27.	3	3	3	1	3	3

Symbols A, B, C, D, E, and F represents lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size respectively.

Table IV. Experimental Results of Oxygen intake and Heart rate with S/N ratio (Smaller the best)

S.No.	OXYGEN INTAKE (ml/kg/min)				HEART RATE (beats/min)			
	R1	R2	R3	S/N ratio Data	R1	R2	R3	S/N ratio Data
1	5.2	5.8	6.2	-15.19	85.4	86.1	90.3	-38.82
2	7.2	7.6	8.1	-17.66	88.5	92.2	94.7	-39.26
3	8.6	8.8	9.2	-18.96	107.3	109.2	105	-40.60
4	7.6	7.9	7.5	-17.69	84	90.1	91.2	-38.94
5	8.4	8.1	8.3	-18.35	102.1	105.3	103.6	-40.31
6	9.1	9	9.5	-19.28	93.5	91.2	94.2	-39.37
7	4.7	5.4	6	-14.64	100	104.3	110.9	-40.44
8	6.2	6.7	6.4	-16.17	83.5	85.7	88.8	-38.69
9	9.1	9.4	9.6	-19.43	92.1	99.7	106.5	-39.97
10	7.5	7.7	8.2	-17.85	100.4	101.5	105.3	-40.21
11	8.2	8.8	9.1	-18.80	93	97.1	94.6	-39.55
12	6.1	6.3	6.5	-15.99	99.8	101.9	103.5	-40.15
13	9.5	9.8	9.6	-19.68	85.6	91	96.7	-39.20
14	9.6	9.9	9.4	-19.68	98.2	100.6	101	-39.99
15	12.6	11.8	10.5	-21.34	101.3	107.4	109.1	-40.50
16	7.2	8.1	8.4	-17.97	95.2	98	100.4	-39.81
17	12.8	12.2	11.4	-21.69	100.4	107.5	103.8	-40.34
18	7.8	8.2	8.4	-18.21	102.3	103.7	106	-40.34
19	10.1	10.5	10.3	-20.26	99.4	105.7	104.3	-40.27
20	9.1	10	10.8	-19.99	115.6	108.4	112.8	-41.01
21	9.3	9.7	10.3	-19.80	121.1	123.3	127	-41.86
22	10.2	10.7	10.5	-20.40	108.6	103.1	108.2	-40.56
23	9.8	10.2	9.3	-19.80	110.5	113.6	109.9	-40.93
24	15.3	14.9	15.1	-23.58	118.4	127.5	131.4	-42.00
25	12.5	12.7	13.5	-22.22	109.7	111.2	107.3	-40.78
26	15.9	16.4	16.1	-24.16	102.3	109	115.1	-40.74
27	20.7	21	20.8	-26.38	131.8	138	136.2	-42.63

of freedom (d.o.f) is associated with each variable; thus the total d.o.f required will be 12. Three-level interactions i.e. (i) lifting frequency × lifting load (A×B), (ii) lifting frequency × vertical height (A×C), and (iii) lifting load × vertical height (B×C); requires 12 d.o.f. So; total d.o.f. will be 24 used in this study. So, the most appropriate orthogonal array in this case is L_{27} with (27-1) d.o.f. i.e. 26. Standard L_{27} OA with the variables assigned by using linear graphs. The experiments were carried out at each trail conditions as given in Table III. The unassigned column was treated as error.

III. RESULTS AND DISCUSSION

In experimentation, the S/N ratios (smaller the best) were computed for Oxygen intake and Heart rate for each of the 27 trials and are given in Table IV. Table V and Table VI represent the main effect of raw as well as S/N data on oxygen intake respectively whereas Table VII and Table VIII represent the main effect of raw as well as S/N data on heart rate respectively. Figure 1 and Figure 2 showed the effect of lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size on oxygen intake and heart rate. In case of lifting frequency, there was a variation in oxygen intake as well as heart rate from 2lifts/min to 5lifts/min and then increased the stress when lifting frequency changed from 5lifts/min to 8lifts/min. This increase focused to the fact that task becomes more strenuous while lifting frequency beyond 5lifts/min. According to the NIOSH lifting equation (1981), the maximum allowed weight is 23kg, so the effect of lifting load showed that oxygen intake & heart rate starts increasing when lifting load increases from 7kg to14kg and then go on increasing when load increases from 14 kg to 21 kg. This increase can focus to fact that oxygen intake & heart rate continuously increases with the increase in lifting load. In case of vertical distance, there was continuous increase in oxygen intake & heart rate during lift from waist to shoulder level and shoulder to maximum reach height. This increase can focus to fact that the anthropometric data of worker such as weight, height, lifting capacity etc. leads to a significant effect on physiological response during lift above the shoulder height. The effect of horizontal distance showed that there was increase in oxygen intake & heart rate when horizontal distance increased from 25cm to 40cm and this effect was continuous when horizontal distance from 40cm to 55cm. This continuous increase can focus to fact that the most appropriate horizontal distance was 25cm, considered as a comfort zone. Astrand and Rodahl (1986) present the major variables that influence the body's level of energy output are such as nature of the work, somatic variables, training, motivation and environmental variables.

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The room temperature was sustained in 23-26 ºC range to avoid exhausting work, which is in line with the study of Ftaiti et al. (2010) that indicates that heat is associated with greater heart rates and body mass losses compared to a less thermally demanding environment. The laboratory environment showed that that there is change in response variables when laboratory environment changed from 21°C to 27°C, and then oxygen intake & heart rate increases when temperature changed from 27°C to 33°C. This increase can focus to fact that

Table V. Main effects- Raw data (Oxygen intake)

LEVEL	A	B	C	D	E	F
L_1	7.61	8.34	8.64	9.61	8.92	9.93
L_2	9.10	10.15	9.85	9.85	10.00	9.35
L_3	12.80	11.02	11.02	10.65	10.59	10.23
L_2-L_1	1.49	1.81	1.21	0.24	1.08	-0.58
L_3-L_2	3.70	0.87	1.17	0.21	0.59	0.88
Difference	2.21	-0.94	-0.04	-0.03	-0.49	1.46

In the above table: - L_1, L_2, and L_3 represent the average values of raw data of the corresponding variables at levels 1, 2, and 3, respectively. L_2-L_1 is the average main effect when the corresponding parameter changes from level 1 to level 2 and L_3-L_2 is the average main effect when the corresponding parameter changes from level 2 to level 3, Difference = {(L_3-L_2) - (L_2-L_1)}; where factors A, B, C, D, E and F represent the independent variables such as lifting frequency (lifts/minute), lifting load (kg), vertical height (cm), horizontal distance (cm), laboratory environment (°C) and box size (cm) respectively.

Table VI. Main effects- S/N data (Oxygen intake)

LEVEL	A	B	C	D	E	F
L_1	-17.49	-18.28	-18.43	-19.00	-18.79	-19.57
L_2	-19.02	-19.98	-19.59	-19.72	-19.60	-19.07
L_3	-21.84	-20.10	-20.33	-19.62	-19.95	-19.71
L_2-L_1	-1.53	-1.70	-1.16	-0.72	-0.81	0.50
L_3-L_2	-2.82	-0.12	-0.74	0.10	-0.35	-0.64
Difference	-1.29	1.58	0.42	0.82	0.46	-1.14

In the above table: - L_1, L_2, and L_3 represent the average values of raw data of the corresponding variables at levels 1, 2, and 3, respectively. L_2-L_1 is the average main effect when the corresponding parameter changes from level 1 to level 2 and L_3-L_2 is the average main effect when the corresponding parameter changes from level 2 to level 3, Difference = {(L_3-L_2) - (L_2-L_1)}; where factors A, B, C, D, E and F represent the independent variables such as lifting frequency (lifts/minute), lifting load (kg), vertical height (cm), horizontal distance (cm), laboratory environment (°C) and box size (cm) respectively.

Table VII. Main effects- Raw data (Heart rate)

LEVEL	A	B	C	D	E	F
L_1	95.76	102.72	99.03	102.22	100.09	103.84
L_2	100.20	102.86	101.40	104.05	101.88	103.93
L_3	115.16	105.53	110.68	104.84	109.15	103.34
L_2-L_1	4.44	0.14	2.37	1.83	1.79	0.10
L_3-L_2	14.96	2.67	9.28	0.79	7.27	-0.59
Difference	10.52	2.53	6.91	-1.04	5.48	-0.69

In the above table: - L_1, L_2, and L_3 represent the average values of raw data of the corresponding variables at levels 1, 2, and 3, respectively. L_2-L_1 is the average main effect when the corresponding parameter changes from level 1 to level 2 and L_3-L_2 is the average main effect when the corresponding parameter changes from level 2 to level 3, Difference = {(L_3-L_2) - (L_2-L_1)}; where factors A, B, C, D, E and F represent the independent variables such as lifting frequency (lifts/minute), lifting load (kg), vertical height (cm), horizontal distance (cm), laboratory environment (°C) and box size (cm) respectively.

Table VIII. Main effects- S/N data (Heart rate)

LEVEL	A	B	C	D	E	F
L_1	-39.60	-40.19	-39.89	-40.12	-39.95	-40.29
L_2	-40.01	-40.20	-40.09	-40.31	-40.13	-40.31
L_3	-41.20	-40.42	-40.82	-40.38	-40.73	-40.21
L_2-L_1	-0.41	-0.01	-0.20	-0.19	-0.18	-0.02
L_3-L_2	-1.19	-0.22	-0.73	-0.07	-0.60	0.10
Difference	-0.78	-0.21	-0.53	0.12	-0.42	0.12

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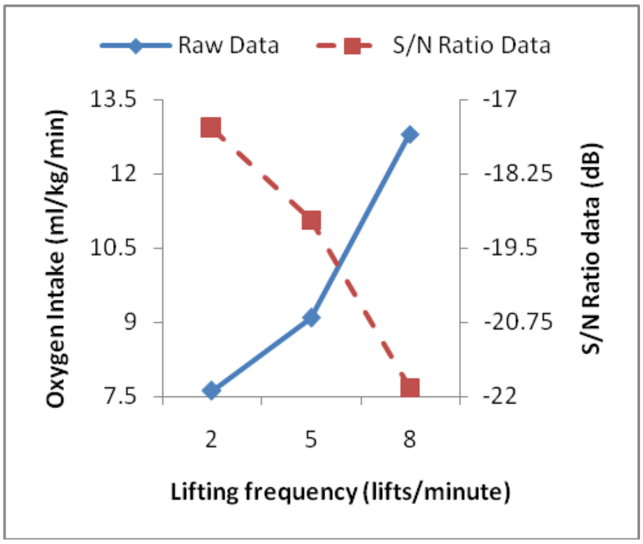
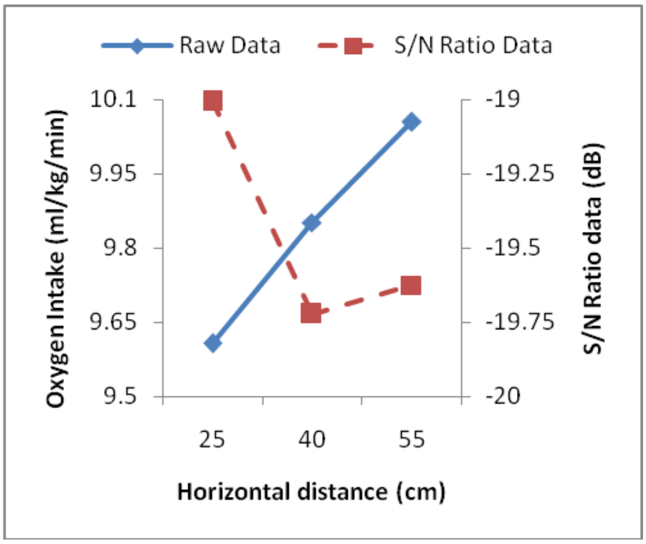
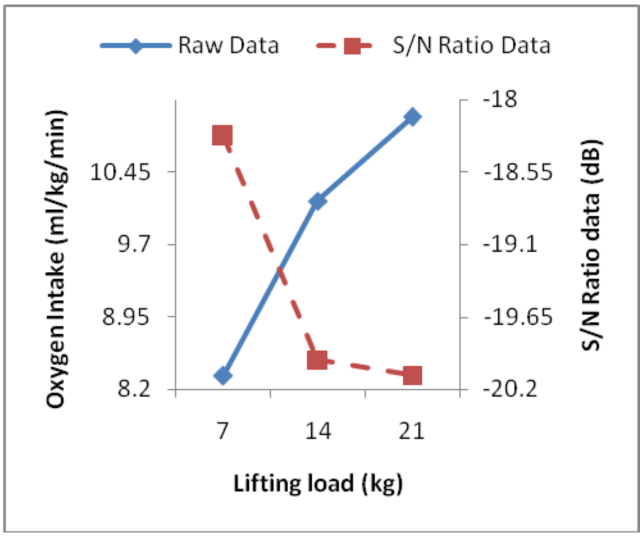
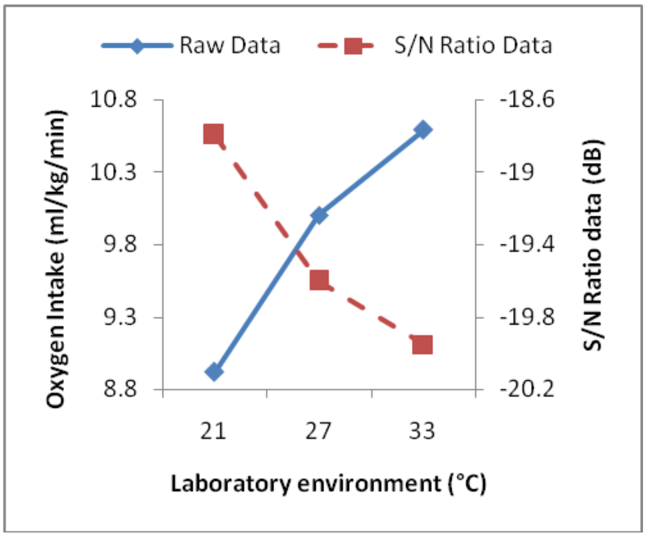
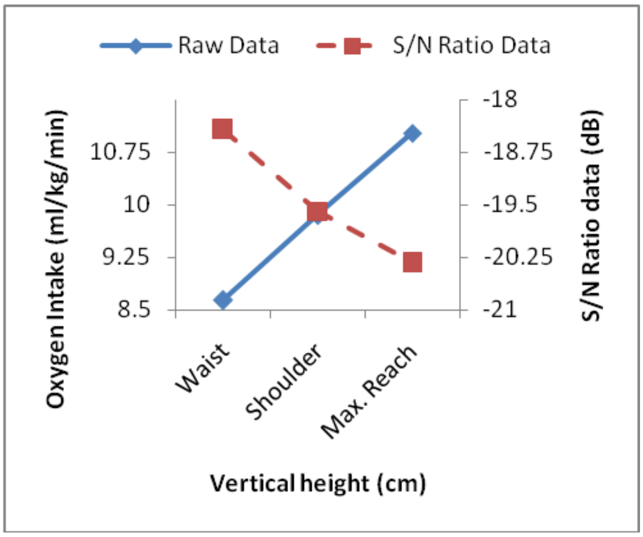
In the above table: - L_1, L_2, and L_3 represent the average values of raw data of the corresponding variables at levels 1, 2, and 3, respectively. L_2-L_1 is the average main effect when the corresponding parameter changes from level 1 to level 2 and L_3-L_2 is the average main effect when the corresponding parameter changes from level 2 to level 3, Difference = {(L_3-L_2) - (L_2-L_1)}; where factors A, B, C, D, E and F represent the independent variables such as lifting frequency (lifts/minute), lifting load (kg), vertical height (cm), horizontal distance (cm), laboratory environment (°C) and box size (cm) respectively.











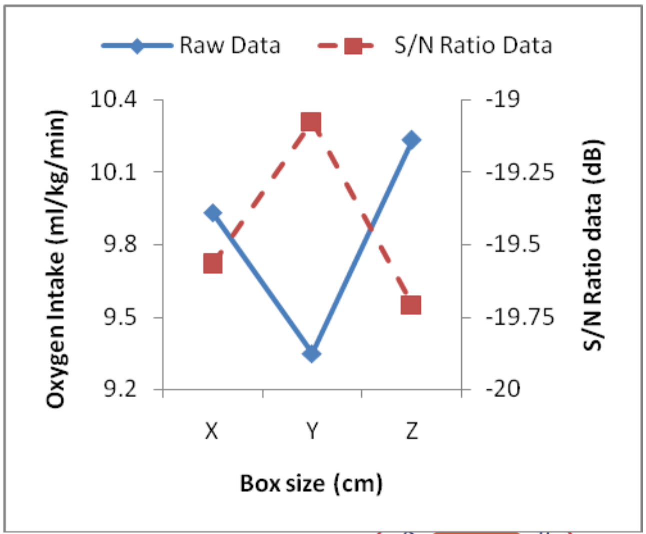


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Fig.1. Effect of lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size on Oxygen intake and S/N ratio

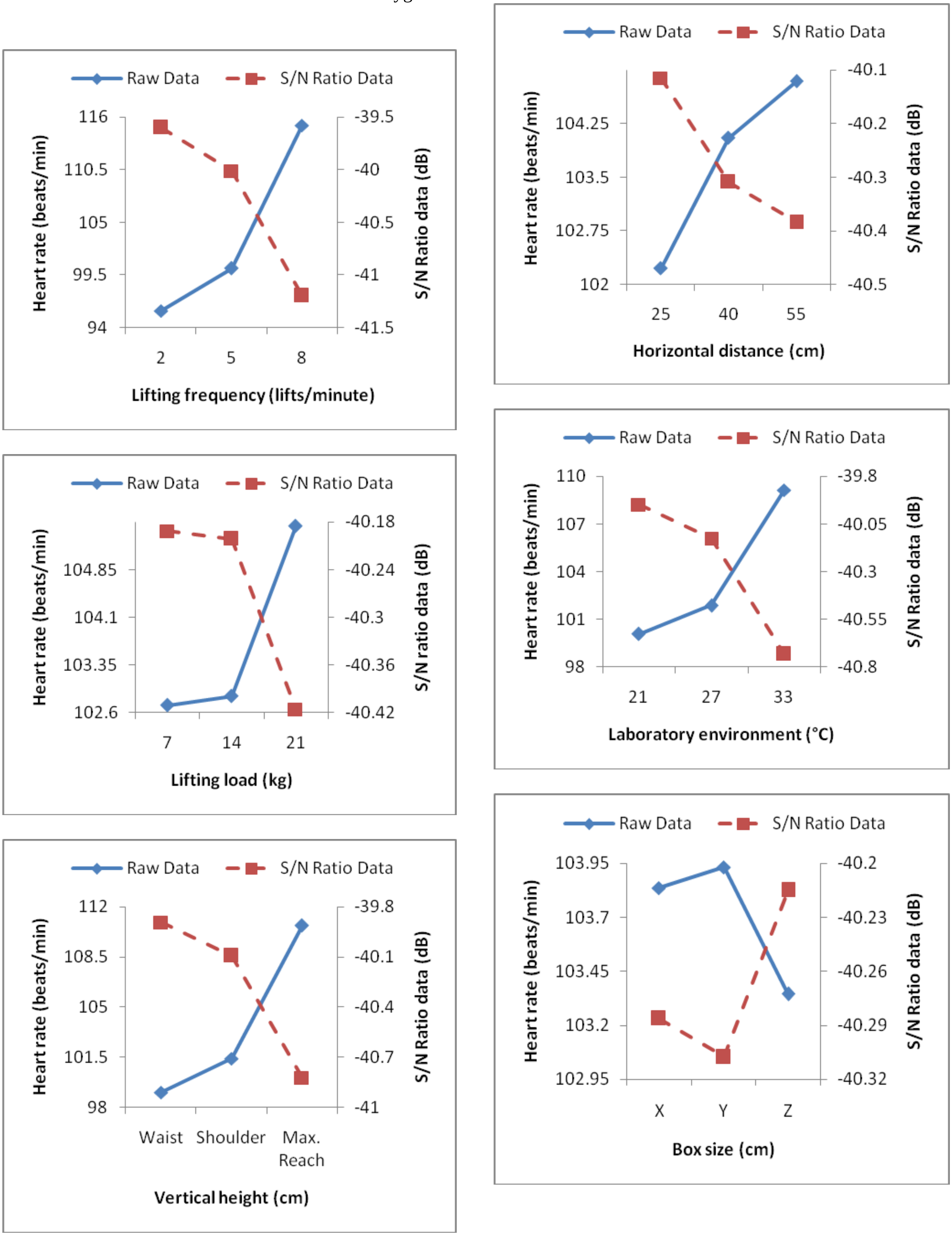

Fig.2. Effect of lifting frequency, lifting load, vertical height, horizontal distance, laboratory environment and box size on Heart rate and S/N ratio

Table IX. ANOVA Calculation- Raw data (Oxygen intake)

Source	SS	DOF	V	F-ratio	P (%)
A	385.78	2	192.89	730.68*	43.28
B	101.05	2	50.53	191.40*	11.34
C	76.57	2	38.29	145.03*	8.59
D	2.72	2	1.36	5.15*	0.30
E	38.94	2	19.47	73.76*	4.37
F	10.94	2	5.47	20.73*	1.23
AxB	152.23	4	38.06	144.16*	17.08
AxC	58.90	4	14.73	55.78*	6.61
BxC	49.51	4	12.38	46.89*	5.55
Error	14.78	56	0.26	-	1.66
Total	891.43	80	-	-	100

*where, * implies Significant at 95% confidence level, SS implies Sum of squares, DOF implies Degree of freedom, V implies Variance, P(%) implies Percentage contribution*

Table X. ANOVA Calculation- S/N ratio data (Oxygen intake)

Source	SS	DOF	V	F-ratio	P (%)
A	87.85	2	43.93	1069.18*	47.72
B	18.61	2	9.30	226.49*	10.11
C	16.46	2	8.23	200.34*	8.94
D	2.72	2	1.36	33.06*	1.48
E	6.37	2	3.18	77.47*	3.46
F	1.99	2	1.00	24.25*	1.08
AxB	25.42	4	6.35	154.67*	13.81
AxC	14.69	4	3.67	89.42*	7.98
BxC	9.89	4	2.47	60.20*	5.37
Error	0.08	2	0.04	-	0.04
Total	184.09	26	-	-	100

*where, * implies Significant at 95% confidence level, SS implies Sum of squares, DOF implies Degree of freedom, V implies Variance, P(%) implies Percentage contribution*

environmental condition was one of an influence factor to control the physical work capacity of the workers. In case of box size in figure 1, oxygen intake firstly decreased when box size change from X to Y and then there was drastic increase in oxygen intake when box size change from Y to Z. It indicated that workers were found to have less oxygen intake during lifting of box size (Y) but on the other hand; case of box size in figure 2 showed that heart rate firstly increased when box size changed from X to Y and then there was decrease in heart rate when box size changed from Y to Z. It focused to the fact that there was a less influence of heart rate on the worker due to change in box size during lifting task.

In order to evaluate the significance of the process variables towards the response variables, Table IX and Table X showed the ANOVA calculation for oxygen intake where as intake whereas Table XI and Table XII showed the pooled ANOVA calculation for heart rate of raw as well as S/N data respectively. After an analysis; all six variables i.e. lifting frequency, lifting load, vertical height, horizontal distance, environment conditions and box size were found to have a significant effect on oxygen intake. All three interactions (lifting frequency vs. lifting load, lifting frequency vs. vertical height and lifting load vs. vertical height) were found to have significant effect on oxygen intake. In case of heart rate, five variables i.e. lifting frequency, lifting load, vertical height, horizontal distance, and environment condition were found to have a significant effect but box size had insignificant effect on heart rate. Two interactions (lifting frequency vs. vertical height and lifting load vs. vertical height) were found to have significant effect but interaction between lifting frequency vs. lifting load had insignificant effect on heart rate.

IV. CONCLUSIONS

It is concluded from this study that:-

1. Lifting frequency (percentage contribution: 43.28%) and lifting load (percentage contribution: 11.34%) were found to be the more significant variables; whereas box size (percentage contribution: 1.23%) and horizontal distance (percentage contribution: 0.30%) were found to be the least significant factor in among all the variables in the case of oxygen intake.
2. In the case of heart rate; lifting frequency (percentage contribution: 49.85%), vertical height (percentage contribution: 18.28%) and environmental condition (percentage contribution: 11.12%) were found to be

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Table XI. Pooled ANOVA Calculation- Raw data (Heart rate)

Source	SS	DOF	V	F-ratio	SS'	DOF'	V'	P (%)
A	5583.22	2	2791.66	211.36*	5583.22	2	2791.66	49.85
B	135.67	2	67.84	5.14*	135.67	2	67.84	1.21
C	2046.84	2	1023.42	77.48*	2046.84	2	1023.42	18.28
D	97.60	2	48.80	3.69*	97.60	2	48.80	0.87
E	1244.97	2	622.48	47.13*	1244.97	2	622.48	11.12
F	5.39	2	2.69	0.20	-	-	-	-
AxB	30.38	4	7.60	0.58	-	-	-	-
AxC	808.97	4	202.24	15.31*	808.97	4	202.24	7.22
BxC	507.30	4	126.82	9.60*	507.30	4	126.82	4.53
Error	739.66	56	13.21	-	775.43	62	12.50	6.92
Total	11200	80	-	-	11200	80	-	100

*where, * implies Significant at 95% confidence level, SS implies Sum of squares, DOF implies Degree of freedom, V implies Variance, SS' implies pure sum of squares, P(%) implies Percentage contribution*

Table XII. Pooled ANOVA Calculation- S/N ratio data (Heart rate)

Source	SS	DOF	V	F-ratio	SS'	DOF'	V'	P (%)
A	12.40	2	6.20	819.39*	12.40	2	6.20	53.65
B	0.29	2	0.14	19.10*	0.29	2	0.14	1.25
C	4.33	2	2.17	286.34*	4.33	2	2.17	18.73
D	0.35	2	0.17	22.87*	0.35	2	0.17	1.51
E	3.05	2	1.52	201.26*	3.05	2	1.52	13.19
F	0.04	2	0.02	2.80	-	-	-	-
AxB	0.05	4	0.01	1.52	-	-	-	-
AxC	1.22	4	0.31	40.35*	1.22	4	0.31	5.27
BxC	1.36	4	0.34	44.79*	1.36	4	0.34	5.88
Error	0.02	2	0.01	-	0.11	8	0.01	0.47
Total	23.11	26	-	-	23.11	26	-	100

*where, * implies Significant at 95% confidence level, SS implies Sum of squares, DOF implies Degree of freedom, V implies Variance, SS' implies pure sum of squares, P(%) implies Percentage contribution*

the more significant variables and horizontal distance (percentage contribution: 0.87%) was found to be the least significant factor in among all the variables.

From the above research work, following ways should keep in mind during manual material handling in order to improve the physiological cost (i.e. oxygen intake and heart rate) of a worker are:-

1. In this study, we have found that after 5lifts/minute; tasks become more strenuous so, reduce the frequency of lift as per anthropometric detail of a worker.
2. According to the NIOSH (1981), the maximum allowed weight is 23kg to lift. There is a drastic change in oxygen intake and heart rate of a worker to lift beyond 23kg, so use two or more people to move heavy or large objects/containers instead of single.
3. Heavy objects should be avoided to lift higher than shoulder height.
4. Minimize horizontal distances between start and end of the lift (i.e. minimize carrying distance). The comfort zone of the horizontal distance found in this study was 25cm.
5. Provide a suitable work environment (i.e. 27°C) to enhance the work capability of a worker.
6. Design an adequate handle of box to lift.
7. Provide a proper rest period after a continuous work.
8. Proper training such as proper handling, proper posture etc. should be instructed while lifting tasks.

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