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Analysis of Mutual Interaction Effect of Six-Individual Characteristic Factors of Safe Weight Lift Model

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Abstract: An ergonomic mathematical model to compute Safe Weight Lift (SWL) was formed with principle of strain energy to limit risk of low back pain amid construction employees in Nigeria. However, mutual interaction effect of the selected factors were not yet studied. Therefore, analysis of mutual interaction effect of compounded chosen male distinctive factors of biomechanical of body weight, spinal shrinkage, and spine length, with physiological of age, and gender as well as psychophysical of surrounding temperature and lift frequency were done. The factors data were gotten using ZT-160 scale, tailor-tape rule, fly-back timing and RH/Temperature pen from fifty masculine manual construction workers selected using purposive sampling technique. The data were inputted into Ms Excel and SPSS for analyses using Multiple Linear Regression (MLR), Regression Curve Estimate (RCE), and ANOVA at alpha level 0.05. The MLR investigation shown that mutual interactions of the compounded factors were significant (p=0.00) and gave R^2=0.94, while RCE predicted quadratic relationship with the SWL (p=0.00), and the ANOVA revealed that factors were significant (p=0.00) with F-test=404.53. The mutual interactions of the model selected factors were significant. Therefore, it can be used as a tool for decision-making for safety management of male labourers involve in manual load handling.

Keywords: Low back pain; Male; Mutual interaction effect; Safe Weight Lift; Strain energy

1. Introduction

The construction industry has most reported low back pain problem among their workers compared to other industries. [13] identified thirty factors seem to be affecting construction ergonomic performance in India, and these were categorised into three parts (1) Human/Labour related factors (2) Task-related factors (3) Equipment/tools-related factors. There were 14 factors identified as human/labour related out of which spine was ranked first, ten factors were identified as task-related in which methods of work and workload were ranked first and second, respectively, and lastly six factors were identified as equipment/tools related in which effect of equipment/tools used and accident while using a hand tools were ranked first and second, respectively. The data were gotten from 220 construction workers in which 30% aged between 25 and 34years, and 30% were less than 25years. The construction workers performance were influenced by low back pain problem due to workload, methods of work, equipment/tools and all these significantly impacted their spine. However, most activities in the construction industry in Nigeria are still being done manually such as lifting of cement, concerete, sandcrete, mixed sand etc. The need for improvement in ergonomic performance of construction workers remain a major focus because their involvement plays major role and cost almost half of the total cost in construction industry. However, most existing ergonomic models are task-based, while this present model is based on the subject (the manual worker). The main effect analysis of the considered factors {age, gender (male/female), spine length, spinal shrinkage, lift frequency, body weight and surrounding temperature} of the developed safe weight of lift model based on biomechanical, physiological and psychophysical approach shown that weight of the body and reduction in spinal were substantial (p<.05) in determine load weight that will not increase risk of experiencing low back pain amid constructions workers [12]. While in the two-way interaction effect analysis of the selected factors the interaction between body weight and spinal shrinkage revealed highest effect (R^2=0.81) compared to other factors interaction in the developed model. However, in this present study the mutual interaction effect of the considered factors is being studied.

2. Materials and Methods

The balance between individual characteristics and work demand or work load are seeing as concept of work ability. Therefore, workers personal characteristic as relate to work demands may effectually be part of healthy living for manual workers. The gender and age difference in workforce had been suggested to influence work ability and findings showed that personal characteristics were more important than work load as well as working environment for efficient performance of the workers of all gender and age groups [16]. Work Ability Index (WAI) showed that male manual workers WAI between 25 and 29years was 43.90 but dropped to 42.00 at 65^{+}years, while female manual workers' WAI between 25 and 29years was 42.50, which dropped to 37.00 at 65^{+}years [16], this explained importance of age and gender as factor in the SWL model. Age and gender of manual workers have been pointed out to influence manual workers' performance (10, 13, 14, 16]. The manual lifting worker anthropometry parameters that comprised stature change (x), spine length (L), chest length and width (l_f and l_s), in addition to these; Young Modulus of elasticity of articular cartilage (E), lifting velocity (u), gravitation acceleration (g), load-vertical position (V), horizontal distance (H), vertical shift (D) and angle of lift (θ) has been used to create a model to calculate safe weight lift [6], however, the created model is laboratorial and require strict measurement of workers, also not included age, gender, physical body weight and surrounding temperature. It has been reported that consideration should be given to differences in anthropometry of manual lifting workers [1, 8]. [12] reported significant effect of physical body weight and spinal shrinkage. National Institute for Occupational Safety and Health (NIOSH) reported task-based recommended weight limit, which may not be appropriate for all lifting task [9], however, lifting task should not only be objective but also subjective. The developed revised NIOSH (1991) lifting equation to aid in considering lifting demand for manual lifting workers did not consider full range of factors involved in manual lifting

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activities to recommend weight lift [4]. Revised NIOSH lifting equation (RNLE) is not just a mere multiplier as the study of its interaction revealed other importance of the lifting parameters such that interaction of the parameters contributed 10.01% to total variance of normalised working heart rate, which varies from person to person [9, 15]. Adopting a particular lifting style in construction industry is yet to be reported, however, a load weight that is determined by knowing the individual characteristic might allow for flexibility in lifting style to be adopted [17]. In a multi-objective optimisation shoulder, elbow, knee, ankle and metatarsophalangeal were modelled to decide maximum weight lifting prediction for two dimensional lift [18]. Lifting capacity of sixty-five construction workers were processed through a prediction model using their physical performance that comprises sit and reach test, strength (handgrip test), and endurance (prone plank, trunk flexor, extensor and lateral flexor) [11]. Beyond this lifting capacity the weight of load to be lifted compare to worker characteristic factors are also important. [6] reported age, height, body mass index and frequency as significant factors to consider in establishing acceptable weight lift for worker efficiency. [2] suggested and studied that to determine acceptable load weight should not be based on load characteristic alone, therefore considered factors such as age, gender, physical body weight, anthropometry and ethnicity of 44 workers (22 male and 22 female) adopting psychophysical approach to determine maximum acceptable weight limits and they observed that age, body weight and gender had significant effect, however, other factors such as stature change, varying environmental temperature were not part of the factors considered. The use of individual characteristic factors such as age, gender, physical body weight, height, spine length, stature change and surrounding temperature were adopted using strain energy principle to create safe weight of lift model to generate a normative data of capability of workforce to lift a load that will not raise risk of having low back ache amid construction workers'in Nigeria. The reason for this present paper is to analysis mutual interaction consequence of the selected individual characteristics factors used to create safe weight of lift model.

A purposive sampling procedure was applied to choose 50 masculine who were experienced in construction works, lifting load-weight of 22.50 kg, but not below 20.00 kg for 8-hour per day in Ibadan, Nigeria. For every participants their parameters such as age, physical-body weight, stature change, vertebra length, lift frequency, and surrounding temperature values were gotten. The physical-body weight, stature change, vertebra length, lift rate, and workshop temperature were recorded by means of ZT-160 scale (weight-height scale machine), tailor- tape rule, stop-clock (flying-back timing), and pen-alike Extech RH/Temperature. The recorded data were punched into Microsoft Excel and SPSS to evaluate mutual interaction effects (MIE) of the selected ergonomics human characteristic factors and varying workshop temperature. Data were evaluated via Multiple Linear Regression (MLR), Regression Curve Estimate (RCE) and ANOVA at $\alpha_{0.05}$.

The model developed by [3] is stated as:

$$SWLwT = x \times \frac{m_b}{L \times AG \times TF \times GN \times FM} \qquad 1$$

Equation 1 is the SWL with varying Temperature ($SWLwT$) model developed to compute the SWL that may reduce threat of increasing low back injuries for manual lifting workers in Nigeria

where

x = stature change

m_b = lifter's weight
L = lifter's spine length
AG = age factor
TF = temperature factor
FM = frequency of lift factor
GN = gender factor.

3. Results

Table 1. Safe Weight of Lifts (SWL) results

Age (year)	*AG*	*GN*	Temperature (°C)	*TF*	Frequency of lifts (lifts/min)	*FM*	m_b (m)	*L*(m)	*x*(m)	SWL (kg)
30.00	0.88	0.72	31.20	0.90	2.00	0.89	55.00	0.43	0.015	**3.78**
37.00	0.86	0.72	28.45	0.98	1.00	0.95	72.00	0.49	0.015	**3.82**
20.00	1.00	0.72	29.43	0.95	1.00	0.95	79.00	0.50	0.017	**4.13**
28.00	0.88	0.72	29.50	0.93	2.00	0.89	81.70	0.51	0.014	**4.27**
46.00	0.78	0.72	28.61	0.95	2.00	0.89	70.20	0.48	0.014	**4.31**
42.00	0.86	0.72	32.30	0.88	2.00	0.89	55.40	0.52	0.021	**4.61**
45.00	0.78	0.72	28.71	0.95	2.00	0.89	68.70	0.47	0.016	**4.92**
33.00	0.88	0.72	26.80	1.00	2.00	0.89	70.60	0.45	0.018	**5.00**
31.00	0.88	0.72	29.30	0.95	2.00	0.89	57.20	0.46	0.022	**5.10**
42.00	0.86	0.72	27.30	1.00	1.00	0.95	73.00	0.47	0.020	**5.28**
29.00	0.88	0.72	29.20	0.95	2.00	0.89	54.10	0.47	0.025	**5.37**
30.00	0.88	0.72	29.10	0.71	1.00	0.95	75.00	0.45	0.014	**5.46**
39.00	0.86	0.72	27.30	1.00	1.00	0.95	62.00	0.51	0.027	**5.58**
35.00	0.88	0.72	30.10	0.95	1.00	0.95	59.00	0.46	0.026	**5.83**
35.00	0.88	0.72	37.20	0.76	2.00	0.89	66.00	0.42	0.016	**5.87**
22.00	1.00	0.72	30.30	0.93	2.00	0.89	59.00	0.47	0.028	**5.90**
29.00	0.88	0.72	31.40	0.90	1.00	0.95	59.00	0.46	0.025	**5.91**
40.00	0.86	0.72	34.30	0.83	2.00	0.89	60.00	0.44	0.020	**5.96**
30.00	0.88	0.72	26.50	1.00	1.00	0.95	74.00	0.47	0.023	**6.01**
28.00	0.88	0.72	31.40	0.90	2.00	0.89	51.50	0.45	0.027	**6.09**
28.00	0.88	0.72	30.10	0.93	1.00	0.95	63.40	0.50	0.027	**6.11**
32.00	0.88	0.72	29.50	0.93	1.00	0.95	59.00	0.49	0.029	**6.24**
28.00	0.88	0.72	29.60	0.95	1.00	0.95	55.00	0.46	0.030	**6.27**
50.00	0.69	0.72	32.30	0.88	2.00	0.89	55.00	0.51	0.023	**6.37**
41.00	0.86	0.72	27.50	0.98	2.00	0.89	77.20	0.51	0.023	**6.45**
36.00	0.88	0.72	26.90	1.00	2.00	0.89	71.80	0.46	0.024	**6.64**
32.00	0.88	0.72	27.10	1.00	2.00	0.89	60.00	0.48	0.030	**6.65**
25.00	0.91	0.72	29.60	0.95	2.00	0.89	54.00	0.44	0.030	**6.65**
30.00	0.88	0.72	31.30	0.90	2.00	0.89	80.30	0.45	0.019	**6.68**

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Age (year)	*AG*	*GN*	Temperature (°C)	*TF*	Frequency of lifts (lifts/min)	*FM*	m_b (m)	*L*(m)	*x*(m)	SWL (kg)
22.00	1.00	0.72	29.30	0.95	2.00	0.89	61.40	0.45	0.030	**6.72**
25.00	0.91	0.72	30.20	0.93	2.00	0.89	61.00	0.51	0.031	**6.83**
26.00	0.88	0.72	31.40	0.90	2.00	0.89	59.00	0.44	0.026	**6.86**
29.00	0.88	0.72	29.30	0.95	2.00	0.89	65.70	0.41	0.023	**6.88**
24.00	0.91	0.72	31.10	0.90	2.00	0.89	58.00	0.48	0.030	**6.90**
23.00	0.91	0.72	31.30	0.90	2.00	0.89	55.00	0.45	0.030	**6.98**
43.00	0.78	0.72	27.80	0.98	2.00	0.89	75.00	0.48	0.022	**7.01**
34.00	0.88	0.72	31.80	0.88	1.00	0.95	55.00	0.47	0.032	**7.07**
27.00	0.88	0.72	31.40	0.90	1.00	0.95	60.00	0.49	0.032	**7.23**
34.00	0.88	0.72	27.50	0.98	2.00	0.89	60.50	0.47	0.032	**7.45**
33.00	0.88	0.72	33.80	0.83	2.00	0.89	74.50	0.48	0.023	**7.63**
38.00	0.86	0.72	30.84	0.93	1.00	0.95	83.20	0.49	0.025	**7.76**
37.00	0.86	0.72	31.80	0.88	2.00	0.89	69.00	0.47	0.027	**8.17**
27.00	0.88	0.72	29.60	0.95	2.00	0.89	70.00	0.48	0.030	**8.17**
52.00	0.69	0.72	32.32	0.88	1.00	0.95	57.30	0.50	0.030	**8.28**
40.00	0.86	0.72	33.80	0.83	2.00	0.89	83.60	0.47	0.022	**8.55**
37.00	0.86	0.72	29.53	0.93	2.00	0.89	90.00	0.49	0.024	**8.60**
35.00	0.88	0.72	31.23	0.90	1.00	0.95	85.30	0.46	0.028	**9.58**
35.00	0.88	0.72	31.80	0.88	2.00	0.89	87.60	0.45	0.025	**9.80**
33.00	0.88	0.72	31.34	0.90	2.00	0.89	82.00	0.44	0.033	**12.11**
36.00	0.86	0.72	33.80	0.83	1.00	0.95	101.90	0.49	0.030	**12.77**

Table 2. Independent factors mutual interactions effect on Safe Weight Lift

Independent Variables interaction	**Safe Weight of Lift (SWL)**		
	Beta	B	p-value
Age (year)	0.23	0.06	0.00
Physical body-weight (kg)	0.69	0.11	0.00
Stature change (m)	0.86	285.08	0.00
Workplace-Temperature (°C)	0.25	0.18	0.00
Spine length (m)	-0.18	-13.29	0.00
Frequency of lifts (lifts/min)	0.14	0.52	0.00
R-square 0.94			

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Table 3. Analysis of Variance (ANOVA)

Model		**Sum of squares**	**df**	**Mean square**	**F**	**Significance**
1	Regression	157.96	6	26.34	404.53	0.00
	Residual	2.80	43	0.07		
	Total	160.76	49			

Table 4. SWLwT Regression curve estimate summary and parameters

Equation	**Model summary**					**Parameters estimates**		
	R^2	F	df1	df2	Sig.	Constant	b1	b2
Linear	0.28	18.75	1	48	0.00	2.11	0.02	
Quadratic	0.38	14.65	2	47	0.00	16.98	-0.09	0.00

Table 5. Compared samples of SWL at assumed equal temperatures

		Existing Secondary	**Present Model**
Sample		6	6
Mean		16.34	6.10
Standard deviation		6.40	1.29
Standard error mean		2.61	0.53
t		6.25	11.56
df		5	5
Significance (2 – tailed)		0.00	0.00
Mean difference		16.34	6.10
95% Confidence interval of the difference	Lower	9.62	4.74
	Upper	23.06	7.46

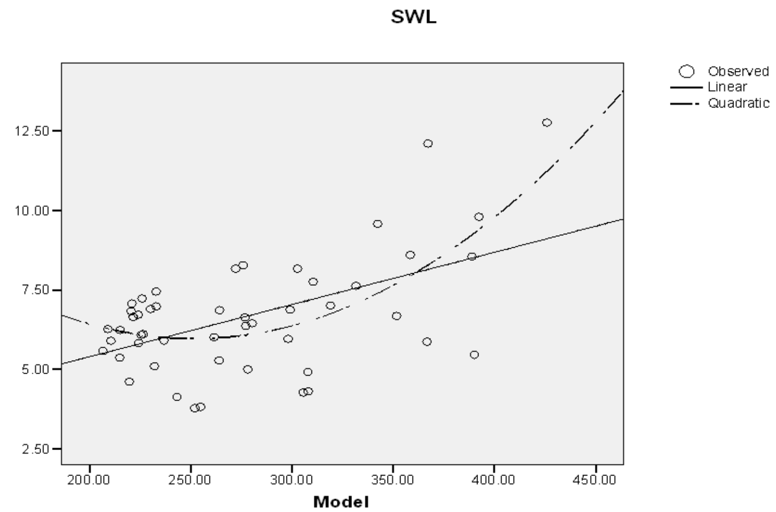

Figure 1. Safe Weight Lift relationships effect on Safe Weight of Lift with a Temperature model

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4. Discussion

Table 1 presents normative data of the selected 50 masculine construction workers. The age (years) factor with corresponding multiplier factor (AG), gender (GN) factor, temperature (^oC) factor with corresponding multiplier factor (TF), frequency of lifts (lifts/min) with corresponding multiplier factor (FM), physical-body weight (m_b), vertebrae length (L), and stature change (x) in metres and safe weight of lift (SWL) results for each worker's characteristics, which ranged between 3.78 and 12.77 kg. Table 2 shows results of independent characteristic factors of fifty males' construction worker interaction (physical body-weight, age, change in stature, length of the spine, and lifts frequency) and workplace temperature. The independent factors interactions gave coefficient of determination of 0.94, which explained 94% total variance in the SWLwT model and they were statistically significant at $p<0.05$. Maiti and Bagchi (2006) reported coefficient of determination of 0.10 for mutual interaction of RNLE parameters at $p<0.05$, thereby explaining 10% total variance of the RNLE model. SWLwT model selected factors mutual interaction shows weak positive relationship between age (β =0.23), temperature (β =0.25), frequency of lifts (β =0.14) and SWL, while spine length (β = -0.18) indicated weak negative relationship. The male bricklayers' weight (β =0.69) showed moderate positive relationship, while stature change (β =0.86) showed strong positive relationship with the SWL. Table 3 displays result of the model's Analysis of Variance (ANOVA) at alpha level of 0.05. The result shows that factors considered were statistically significant at $p<0.05$. The F-test = 404.53 means that the model selected factors and environmental-temperature estimated good reliability characteristics as factors in the prediction of safe weight of lift and safety management of male manual lifting workers considered in this study. Table 4 presents the model summary and parameter estimates of the sample data used as input into the regression curve estimation to determine relationship between the SWL and developed model-independent factors by considering linear and quadratic equations for its relationship. The quadratic equation predicted much better relationship between the SWLwT and developed model independent factors, which gave coefficient of determination (R^2) of 0.38 compared to linear equation's coefficient of determination (R^2) 0.28. Table 5 shows results of compared means test of the SWL of this present model and existing secondary SWL. Six existing secondary SWL values were selected at the temperature range of 27.00 – 32.00°C and six values of the SWL of the present model at temperature ranges of 26.00 – 27.90, 28.00 – 29.90, 30.00 – 31.90, 32.00 – 33.90, 34.00 – 35.90 and 36.00 – 37.00°C for the comparison of the model result with the existing secondary SWL. The compared mean test revealed that the existing secondary SWL mean of 16.34±6.40 was higher than the present model SWL of 6.10±1.29, and both were significantly different as the alpha level was less than 0.05. This could be attributed to a possible difference in the workplace temperature at which the existing secondary SWL were obtained compared to the model. It can be deduced from compared means test results that this present model can be used as a decision-making tool in the safety management of male labourers involved in manual load handling to estimate safe weight lift that can be lifted for 8 hours daily without increasing the threat of developing low back pain. Figure 1 shows that non-linear relationship existed between the SWL and the Safe Weight of Lift with Temperature model that comprised physical body-weight, age, spinal shrinkage, gender, length of the spine, lift frequency and surrounding temperature. However, [5] reported improved performance of RNLE after the introduction of human ergonomic characteristic factors to the NIOSH equation. The result collaborated suggestion of [1] that weight lift equation should not be only task based but must consider worker characteristics.

4.1 Limitation

The development of the model did not give consideration to the life style of the manual workers selected, and age range should not be above sixty years, female manual lifting workers data characteristic has not been measured to calculate weight safe to lift. The masculine manual workers measured were lifting individually, the model cannot be adopted where environmental temperature is above 40°C and lift frequency beyond 16 lifts/min.

5. Conclusions

A safe weight lift with a varying workplace temperature (SWLwT) model has been developed by considering six-individual distinct variables and varying thermal level of the workplace. The created model gave a good estimate of the safe lift weight at a construction site. The statistically significant contribution of the considered factors when at mutual interaction and SWL result in this present study using the developed model has shown that the model can determine safe weight of lift for unaided human lifting jobs in industries or organisations if adopted. It can be used as a decision-making tool to safely manage manual lifting labourers to limit occurrence of low back pain.

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