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Analysis of Main Effect of Independent Six-individual Characteristic Factors and Workplace Temperature on Safe Weight of Lift Model

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Abstract

This study analysed main effect of the independent six-individual characteristic gender based factors of age, body weight, spinal shrinkage, spine length, and frequency of lifts, and workplace temperature on safe weight of lift model. These six-individual characteristic factors and workplace temperature selected were based on biomechanical, physiological and psychophysical approaches. These were yet to be seen used together in any other studies. The human ergonomic factors and workplace temperature were compounded to develop a safe weight of lift (SWL) model using principle of strain energy to determine safe weight that can minimise threat of developing low back pain among manual workers. A subjective selection technique was used to select 50 practising male construction workers. The measurements of human ergonomic factors and workplace temperature were obtained using the ZT-160 scale, stadiometer, measuring tape, clock timer and Extech RH/Temperature pen device. The obtained data were inputted into the SPSS to analysis main effect of human ergonomic factors and workplace temperature on SWL model. Data were analysed using Multiple Linear Regression (MLR) and ANOVA at $\alpha_{0.05}$. The main effect analysis of the six-individual characteristic factors gave highest R^2 and β of 0.33 and 0.58 for the spinal shrinkage. The body weight and spinal shrinkage were statistically significant at $p<.05$. The ANOVA analysis results revealed that only body weight was significant at $p<.05$ with highest F-test = 3.47. Hence, the analyses of the human ergonomic factors and workplace temperature independently shown that body weight is the most significant factor of the developed model.

Keywords: Body weight; Ergonomic model; Low back pain; Spine shrinkage; Safe weight of lift.

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1. Introduction

Reference [2] developed a safe weight of lift (SWL) model using principle of strain energy by considering six-individual factors (gender, age, body weight, spinal shrinkage, spine length, and frequency of lifts) and workplace temperature to determine safe weight of lift that can minimise problem of low back ache in the midst of manual material handling labourers in Nigeria. They used purposive sampling technique to select 20 males' construction workers that lifted load weight between 20 and 22.50 kg, the computed safe weight lift using the model were between 3.78 and 13.63 kg, however, main, two-ways, and mutual interaction effect of the factors used to develop the model is yet to be carried out. The gender is the factor that allowed the use of the model to compute safe weight of lift for male or female labourers. The literature had established that male and female capability were different [17]. The age factor allowed the model to take to consideration the age factor multiplier, body weight is the consideration for the body mass of the manual worker adding to the weigh to be lifted, spinal shrinkage is the variation between the daybreak and nightfall height of the worker to determine the compression of the spine due to the weight lifted, spine length is the distance from the first thoracic to the last lumbar of the spine, frequency of lift is the number of load lifts per minute by the manual worker. The workplace temperature is the environmental temperature at which the manual worker was working. The use of compounded human ergonomic characteristic factors of gender, age, body weight, spinal shrinkage, spine length, frequency of lifts, and workplace temperature to develop a model to determine load weight to address the problem of low back pain had not been seen in the literature. The need to consider workers characteristic factors and temperature to address problem of low back ache had been suggested [1]. The developed safe weight of lift model consisted of compounded human ergonomic characteristic factors and workplace temperature to determine safe weight of lift to reduce low backaches. The developed model can be defined as the ratio of multiplied worker's spinal shrinkage and body weight to spine length, age, gender, lifts frequency factors and workplace temperature. The objective of this study is to analysis main effect of the independent six-individual characteristic factors and workplace temperature on the developed Safe Weight of Lift (SWL) model.

2. Materials and methods

Reference [6] used regression analysis to investigate statistical significance of subjects' age, body weight, gender and spinal components (these were found to determine 42 – 74% variation in compressive strength of the lumbar spine) in the estimated spine compression tolerance limits equation developed for manual material handling workers and these factors were found to be statistically significant at $p<.05$ in setting spine loading compression limits for manual lifting workers. A biomechanical design of job algorithm was advised for redesigning of manual material handling activities in the workplace, which there tolerance limits can be set at ergonomical level of load damage in place of, fracture at loading, this is to reduce injury risk coming from manual material handling jobs. Reference [9] studied effect of body weight by studying obese and non-obese individual in a detailed multi-joint scalable model of thoracolumbal spine on spinal loading and risk of low back harm at five varying levels of 51, 68, 85, 102, and 119 kg of the body weight and a substantial increase at L5/S1 loadings with flexed body weight postures, and increased compression as body weight increased from 51 to 119 kg were observed. A remarkable body weight impact was observed on the computed spinal loads, which revealed a larger spinal shrinkage in obese individual compared to non-obese, this was attributed to larger spinal compressive loads in obese individuals. Reference [12] formulated a predictive model to determine safe weight of lift by considering intratruncal pressure, post – height shrinkage of the manual lifting worker and strain energy of the intervertebral disc, which was derived in terms of Young Modulus of elasticity, however, they suggested that body weight of manual lifting worker may not be a factor that may determine load to be lifted. Also, in a simulated fifty lifting operations performance involving moderate to large forward trunk flexion, the Recommended weight limit (RWL) generated $L_5 – S_1$ spine loads that exceeded the recommended limits and this was attributed to inadequacy in the NIOSH vertical multiplier. The RWL of the National Institute for Occupational Safety and Health equation (NLE) was seen to have generated L5/S1 spinal loadings exceeding recommended 3.40 kN and 1.00 kN for compression and shear force due to absence of some worker characteristic factors not included in the developed NLE [4]. An ergonomics of lifting of box job using Digital Human Model (DHM) were studied, by observing factors of box lifting while sitting or standing by the female and male manual workers. The multivariate analysis of variance (MANOVA) showed that worker's gender has vital role as it influence the Lattisiumus Dorsi (LD) muscle tension. The posture found less comfortable was standing position compared to sitting position for both males and females, also the box weight raised both muscle tension and Compression Force (CF). The CF on the lower back and the LD muscle tension were positively correlated at 0.94. This revealed that task could be performed by males with less risk than by females. However, females experience higher low back force and muscle stress than male for both standing and sitting position. The independent factors of posture and box weight were found to have significant influence on the L4/L5 by compression force and muscle tension at $p<.05$ [3]. Reference [7] investigated influence of factors of age (35 – 60 years), sex (male, female), body height (1.50 – 1.90 m) and body weight (50 – 120 kg) on spinal loads in a complete-factorial simulation that adopted a personalised kinematics driven musculoskeletal trunk finite element model. The researchers found that changes in body weight, height, and gender affected spinal loadings. The increased body weight from 50 to 120 kg approximately doubled compression forces at the L4/L5 and L5/S1 levels. In the area of gender, females experienced slightly larger compression and shear forces than males counterpart. The effects of body height and age on spinal loads were much smaller for females. The effect of personal factors considered ranged from; body weight to sex (gender) to body height and to age at 98.90, 0.70, 0.40, 0.47% for compression and 96.10, 2.10, 1.50, 8.70% for shear forces, respectively. Standardising load weight to individual back strength characteristics of male and female allow adoption of similar lifting technique [7, 16]. They predicted different disc compression forces for males (3.00 kN) and females (2.80 kN) instead of Revised NIOSH lifting equation (RNLE) of 3.40 kN for both genders. [10] interested in understanding if there is need to specify threshold for lifting operation and the lump sum beyond, which best revealed lumbar disk protrusion in the exists or total load considered, and therefore, recruited workers with various lifting exposures. The protrusion of disk was determined using magnetic resonance imaging. A sum of 252 men and 301 female were involved in the analysis. Men threshold for lifting were found to be 3.00 kN, which they suggested as optimal threshold to predict$L_4 – S_1$ disk protrusion, while women threshold was 2.80 kN as optimal. They observed that recommended weight limit threshold of NIOSH of 3.40 kN may not be the optimal, hence, it should not be generalised across different races and gender, also, different lifting threshold should be applied to male and female for workplace safety. [5] introduced novel multipliers (age, gender, body mass index and intervertebral disc) to the revised National Institute for Occupational Safety and Health (NIOSH) Lifting Equation (RNLE). The influence of the introduced novel multipliers were investigated based on individual and combination of factors using odds ratio. They observed that the incorporated intervertebral disc cross – sectional area muliplier to the RNLE gave a hopeful outcome, that could reduce LBP problem. Reference [8] studied influence of age on lifting capacity of a sampled size of 217 male construction workers, which were categorised into four ages quotas of 19 – 28, 29 – 38, 39 – 48, and 49 – 58 years using a progressive isoinerital lifting evaluation, and semi-squat method of lifting at two different styles of lifting reaching waist and shoulders, respectively. The researchers observed a marginal increase in lifting capacity between; 19 and 28, 29 and 38 years and after there was a linear decrease in load weight lifting capacity among the workers. [14] used wet bulb globe temperature (WBGT) proportion to estimate work capacity of workers by computing carefully chosen heat exposure and work for the classification of work intensity and they discovered that work capacity quickly reduced as the wet bulb globe temperature (WBGT) exceeded between 26 and 30°C. The work intensity had been classified into light, medium, heavy and very heavy, and categorised into different temperatures of 25 – 29°C, 30 – 34°C, and 35 – 39°C based on the WBGT and the require rest per hour (0.00 – 100%) for work done at these different temperatures.

A safe weight of lift (SWL) model was developed with compounded human ergonomic factors of gender, age, body weight, spinal shrinkage, spine length, lift frequency, and workplace temperature using the principle of strain energy. The selected factors were observed during construction site visitations, which were selected based on biomechanical, physiological and psychophysical approaches of the workers to develop the model. The independent factors were the body weight, age, gender, spinal shrinkage, spine length and lifts frequency, and workplace temperature, while the SWL is the dependent factor.

2.1 Model presentation

Safe Weight of Lift (SWL) model, which was developed using the strain energy principle is expressed as:

$$S.E_b = S.E_T - S.E_l \tag{1}$$

$$S.E_b = \left[\frac{m_T g(D+V)}{sin\theta} + \frac{1}{2}m_T u^2\right] - \left[\frac{m_l g(D+V)}{sin\theta} + \frac{1}{2}m_l u^2\right] \tag{2}$$

Substituting $m_T = m_l + m_b$ in (2) gives:

$$S.E_b = \left[\frac{(m_l + m_b)g(D+V)}{sin\theta} + \frac{(m_l + m_b)u^2}{2}\right] - \left[\frac{m_l g(D+V)}{sin\theta} + \frac{m_l u^2}{2}\right] \tag{3}$$

Expanding and subtracting (3) gives:

$$S.E_b = \frac{m_b g(D+V)}{sin\theta} + \frac{m_b u^2}{2} \tag{4}$$

A rigidity measurement (a material property) called spring constant (k) presents for an axial force (F), which did not tension the material (spine) L when it is resting [13].

Since the spine is not tensioned:

$$\Delta L = L \tag{5}$$

Substituting (5) into (6) gives:

$$k = \frac{F}{\Delta L} = \frac{F}{L} = \frac{AE}{L} \tag{6}$$

Therefore,

$$k = F = AE \tag{7}$$

Body strain energy is expressed as:

$$S.E = \frac{1}{2}Fx \tag{8}$$

Putting (7) into (8) gives:

$$S.E = \frac{AEx}{2} \tag{9}$$

Therefore (4) and (9) yield:

$$\frac{m_b g(D+V)}{sin\theta} + \frac{m_b u^2}{2} = \frac{AEx}{2} \tag{10}$$

Factorising m_b (10) gives:

$$m_b\left[\frac{g(D+V)}{sin\theta} + \frac{u^2}{2}\right] = \frac{AEx}{2} \tag{11}$$

Cross multiplying and rearranging (11) gives:

$$\frac{2m_b}{x} = \frac{2AEsin\theta}{[2g(D+V) + u^2 sin\theta]} \tag{12}$$

Multiplying (12) with $1/2$ gives:

$$sin\theta = \left(\frac{D+V}{H}\right)cos\theta \tag{13}$$

$$\frac{m_b}{x} = \frac{AEsin\theta}{[2g(D+V) + u^2 sin\theta]} \tag{14}$$

Elliptical Truncal Area [8], [11] is expressed as.

$$A = \frac{\pi l_f l_s}{4} \tag{15}$$

Substituting (13) into (14) gives:

$$\frac{m_b}{x} = \frac{AE\left(\frac{(D+V)}{H}\right)cos\theta}{\left[2g(D+V) + u^2\left(\frac{(D+V)}{H}\right)cos\theta\right]} \tag{16}$$

Putting (15) into (16) gives:

$$\frac{m_b}{x} = \frac{\pi l_f l_s E\left(\frac{(D+V)}{H}\right)cos\theta}{4\left[2gD + u^2\left(\frac{(D+V)}{H}\right)cos\theta\right]} \tag{17}$$

$$m_l = \frac{\pi l_f l_s x^2}{4L}\left[\frac{E\left\{\frac{D+V}{H}\right\}cos\theta}{2gD + u^2\left\{\frac{D+V}{H}\right\}cos\theta}\right] \tag{18}$$

Comparing (17) with (18) gives:

The RHS (17) were part of factors considered in [11] model (18). The LHS (17) was substituted into RHS (18).

Therefore (17) and (18) give:

$$m_l = \frac{x^2}{L} \times \frac{m_b}{x} \tag{19}$$

Equation (19) is reduced to:

$$m_l = \frac{x}{L} \times m_b \tag{20}$$

Note: $m_l = SWLwT$ (21)

From (20)

$$SWLwT = \frac{x}{L} \times m_b \tag{22}$$

Equation (22) is the biomechanical outcome of the developed model comprising spinal shrinkage (x), body weight (m_b) and spine length (L). Other selected factors such as age (AG) and gender (GN) were based on physiological while temperature (TF) and frequency (FM) were based on psychophysical of the manual lifting workers.

2.2 Developed model and other factors

Multiplying (22) LHS with multiplier factors give:

$$SWLwT \times AG \times TF \times GN \times FM = x \times \frac{m_b}{L} \tag{23}$$

Therefore,

$$SWLwT = x \times \frac{m_b}{L \times AG \times TF \times GN \times FM} \tag{24}$$

Equation (24) was safe weight of lift model developed by [2] to determine safe weight lift that cannot increase threat of developing low back pain among manual load handling workers.

where

$S.E_T$ = total strain energy

$S.E_l$ = weight of lift strain energy

$S.E_b$= strain energy of the upper body

m_b = upper body weight

m_l = lifted weight

m_T = sum of the upper body and lifted weight

F = Force on the spine

D = vertical displacement of the load

V = vertical location of the load

u = velocity of lift

g = gravitation acceleration

H = horizontal length of the load from the ankle

θ = Angle between hip and thigh during lifting

A = cross – sectional area

E = Young Modulus of elasticity

L = length of spine involved

x = spinal shrinkage

l_f = chest length

l_s = chest width

AG = Age factor

TF = Temperature factor

FM = Frequency of lift factor

GN = Gender factor.

π = 3.14

$SWLwT$ = Safe Weight Lift with Temperature

3. Data collection

A subjective sampling technique was adopted in the selection of 50 practising male construction workers who lift between 20.00 and 22.50 kg load weight for 8-hour daily at Arulogun, Ibadan. For each of the subjects, individual characteristic factors of age, body weight, spinal shrinkage, spine length, frequency of lifts, and workplace temperature measures were obtained**.** The body weight, spinal shrinkage, spine length, lift frequency, and workplace temperature were obtained using weight-height ZT-160 scale, measuring tape, clock timer and Extech RH/Temperature pen 445580 device. The obtained data were used as input into the model to estimate safe weight of lift (SWL). The obtained data and SWL results for each worker were used as input into the SPSS to analysis main effect of six-individual characteristic factors on the SWL model. Data were analysed using Multiple Linear Regression (MLR) and ANOVA at $\alpha_{0.05}$.

4. Results

Table 1: Main effect of human ergonomic factors and workplace temperature on Safe Weight Lift

Independent factors	Safe Weight Lift			
	R square	Beta	B	Sig. Level
Age (year)	0.01	0.08	0.02	.60
Body weight (kg)	0.26	0.51	0.08	.00
Spinal shrinkage (m)	0.33	0.58	191.54	.00
Temperature (°C)	0.06	0.25	0.18	.08
Spine length (m)	0.00	-0.06	-4.61	.66
Lifts frequency (lifts/min)	0.00	0.00	0.01	.98

Table 2: ANOVA results

	Sum of Squares	df	Mean Square	F	Sig.
SWL vs Age					
Between Groups	75.48	26	2.90	.64	.87
Within Groups	105.19	23	4.57		
Total	180.67	49			
SWL vs Body Weight					
Between Groups	166.77	38	4.39	3.47	.02
Within Groups	13.90	11	1.26		
Total	180.67	49			
SWL vs Spinal Shrinkage					
Between Groups	98.64	19	5.19	1.90	.06
Within Groups	82.03	30	2.73		
Total	180.67	49			
SWL vs Temperature					
Between Groups	136.35	32	4.26	1.63	.14
Within Groups	44.32	17	2.61		
Total	180.67	49			
SWL vs Spine length					
Between Groups	33.39	11	3.04	.78	.66
Within Groups	147.28	38	3.88		
Total	180.67	49			
SWL vs Lifts frequency					
Between Groups	.51	1	.51	.14	.71
Within Groups	180.15	48	3.75		
Total	180.67	49			

5. Constraints/limitations of the study

The developed *SWLwT* is a gender-based model, which can be applied to male or female labourer to determine safe weight of lift. However, in this present research, the model was applied to male labourers. Access to subjects that participated in this study were only possible at the construction sites, therefore, researchers always arrived to the construction site ahead of the workers and majority of early arrived workers were males. In addition, at the arrival of female labourers, the researchers observed that most female manual worker arrived carrying tools to be used on the site on their head or have toddler at their back.

6. Discussions

Table 1 showed the main effect result obtained using Multiple Linear Regression (MLR) as a tool of analysis, which comprised of coefficient of determinations (R-square), standardised coefficient (Beta, β), unstandardised coefficient (B) and significance level (p-values) of the observed selected factors of the manual lifting workers for the independent six-individual characteristic factors of the model. This showed results of the independent individual characteristic factors for the MLR main effect analysis. The main effect of 50 males' human ergonomic factors were considered, where age explained 1% of the total variance of Safe Weight Lift (SWL) and had a negligible positive relationship (β =.08) with the model. The age contributed insignificantly to the model (p>.05), body weight explained 26% of the total variance of the SWL and had a moderate positive relationship (β =.51) with the SWLwT. The body weight factor contributed significantly to the developed safe weight of the lift model (p<.05). Spinal shrinkage explained 33% of the total variance in the SWL and had a moderate positive relationship (β =.58) with the model, spinal shrinkage contributed significantly to the model (p<.05). Workplace temperature explained 6% of the total variance in the SWL and had a weak positive relationship (β=.25) with the safe weight lift model, and contributed insignificantly (p>.05) to the model. Spine length explained 0% of the total variance in the model and had a negligible negative relationship (β=.-06) with the model. The spine length contributed insignificantly to the SWL model (p>.05). The frequency of lift explained 0% of the total variance in the model and had a negligible positive relationship (β=.00) with the SWL model, contributed insignificantly to the model (p>.05). The highest coefficient of determinations (R^2) was 0.33 for spinal shrinkage, thereby explained 33% of the total variance in the SWL model, followed by the body weight, which its coefficient of determination (R^2) was 0.26 and explained 26% of the total variance in the SWL model, other factors such as lift frequency, spine length, age, and workplace temperature coefficient of determination (R^2) were 0.00, 0.00, 0.01, and 0.06, respectively. The body weight and spinal shrinkage were statistically significant at p<.05, meanwhile other factors such as age, temperature, spine length, and lifts frequency were not significant at p<.05.

Table 2 presented ANOVA results for the independent six-individual characteristic factors and workplace temperature for 50 males' human ergonomics characteristic factors. The result showed that age, body weight, spinal shrinkage, temperature, spine length, and lifts frequency gave F – test results of 0.64, 3.47, 1.90, 1.63, 0.78, and 0.14, respectively, while level of significance results were 0.87, 0.02, 0.06, 0.14, 0.66, and 0.71, respectively. This revealed that only independent factor of body weight was significant at p<.05 with highest F-test of 3.47 for the between groups of the considered six independent individual characteristics factors. [9, 7, 3]

found that changes in body weight affected spinal loadings. In this present study analysis of the main effect of independent six-individual characteristic factors and workplace temperature on the developed SWL model to minimise problem of low back pain among manual lifting workers showed that body weight is a significant factor influencing low back pain. This present study, therefore, collaborate result of findings in the literature.

6.1 Proposed Improvements

Future work should consider studying two-ways interaction and mutual interactions of the independent six-individual characteristic factors selected to further investigate importance of the factors considered to develop the safe weight of lift model. In addition, applicability of the model to female manual workers should be considered.

6.2 Validation

The main effect MLR analysis result shows that among the selected individual characteristic factors, body weight and spinal shrinkage were statistically significant at $p<.05$, while the ANOVA results showed that among the independent six-individual characteristic factors and workplace temperature, body weight was significant at $p<.05$ with highest F-test of 3.47. In the studies carried out by [9, 7, 3] found that changes in body weight affected spinal loadings. However, this present study outcome did not support finding of [12] where they suggested that body weight may not be a factor to determine load to be lifted.

7. Conclusion

This present study demonstrated main effect of the six-individual characteristic factors and workplace temperature of 50 males on the developed safe weight of lift model to determine safe weight of lift that capable of not increasing threat of developing low back pain among male manual workers that works in a construction site for 8-hours daily. Multiple Linear Regression (MLR) revealed that body weight and spinal shrinkage were significant at $p<.05$, while ANOVA analysis revealed that only body weight were significant at $p<.05$, $F=3.47$. These means that body weight and spinal shrinkage factors were very important in the model and contributed importantly to the model. Therefore, each of these two factors can be used independently to determine safe weight lift that can minimise the problem of low back pain among male manual workers. However, body weight and spinal shrinkage should not be the only factors that can be used to develop safe weight of lift model to compute safe load weight of lift for male manual labourers considered in this study because other factors had been identified in the literature to be contributing to problem of low back pain during manual load weight lifting. Therefore, statistical importance of two-ways interaction and mutual interactions of the human ergonomic factors and workplace temperature should be investigated.

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