INTERACTION EFFECT ANALYSIS OF SELECTED FACTORS ON SAFE WEIGHT MODEL

[1]Omotunde MUYIWA and [2]Olusegun AKANBI
[1]Ph.D, Department of Industrial and Production Engineering, University of Ibadan, Nigeria;
[2]Professor, Department of Industrial and Production Engineering, University of Ibadan, Nigeria
Email: {[1]folatunde2004@yahoo.com, [2]engrakanbi@yahoo.com*}*
Corresponding author: [1]folatunde2004@yahoo.com

Abstract

A mathematical model was developed by means of norm of strain energy to limit manual weight. The main effect interaction of the factors had been studied. However, Two-ways Interaction Effect (TIE) of the selected factors were not yet studied. Age, body-weight, stature-change, vertebra-length, lift-frequency, and varying workshop temperature were chosen factors on biomechanical, physiological and psychophysical basis. This study analysed TIE of the selected factors. The selected factors data were gotten by ZT-160 scale, stadiometer, tape-rule, stop-clock and RH/Temperature pen from fifty practising male manual construction workers selected using purposive sampling. The data were inputted into Excel and SPSS to analysis TIE through Multiple Linear Regression (MLR) and ANOVA at $\alpha_{0.05}$. The MLR investigation of TIE of the parameters shows that interactions between age and body-weight or stature-change, temperature and body-weight or stature-change, stature-change and lift-frequency or body-weight or vertebra-length, body-weight and lift-frequency or vertebra-length were significant (p=0.00), while between body-weight and stature-change gave highest R^2=0.81. ANOVA revealed that interactions between age and vertebra-length, temperature and vertebra-length, body-weight and stature-change remained significant p=0.02, 0.02, and 0.00 with F-test=2.80, 7.25 and 12.14, respectively. Hence, body-weight and stature-change interaction shows highest effect of the two-ways interaction of the selected factors.

Key Words – Body-weight and Stature-change, Low back pain, Manual lifting, Mathematical model, Two-ways interaction.

1. Introduction

[1] evaluated main and interaction effect of the parameters considered in developing National Institute for Occupational Health and Safety (NIOSH, 1991) lifting equation on the workers lifting index in a steel rolling in India. The outcome of the evaluation using ANOVA revealed that interactions between object weight and twisting angle, and object weight and lifting frequency were significant at p<0.05, while interactions among twisting angle and lifting frequency were less significant (p=0.061), while main effect analysis shows that load, twisting angle, and lifting frequency influence stressfulness of the task. The NIOSH lifting equation is a static equation for assessing recommended weight limit for manual lifting workers.

[2] introduced to National Institute for Occupational Safety and Health (NIOSH, 1991) lifting equation unique subjective multipliers to advance risk evaluation of the model. The researchers reported significant improvement in the NIOSH liftind equation model.

A mathematical model to limit weight of lift for bodily involved lifting was developed by [4]. The developed mathematical model was based on six-personal gender characteristic features and varying workshop temperature. The need to investigate the significance and effect of the various factors considered in the developed model has been suggested, which evaluation of main effects of the selected factors and workshop temperature was investigated and analysed by means of both Multiple Linear Regression and ANOVA [3]. The researchers found that among the considered factors (age, spine length, and spinal shrinkage, lift frequency, and body weight) and workshop temperature, only workers' weight and stature change were significant (p<0.05) independently. This led to the need to analyse the two-ways interactions effect of the selected compounded ergonomics human parameters and varying workshop temperature of the developed safe weight of lift model. This is to further establish the significance of the selected factors as it has been used to make model for safe weight lift. Therefore, this study set to analysis two-ways interaction effect of the selected six-personal gender involved distinguishing parameters and varying workshop temperature to make a model to limit weight lift with varying temperature (SWLwT).

2. Literature Review

[5] selected 52 employees of a metal industry through survey using a simple census method. The Washington Industrial Safety and Health Act (WISHA), Quick Exposure Check (QEC) and Nordic Musculoskeletal Questionnaire (NMDQ) were used to assess, evaluate and determine prevalence musculoskeletal disorder and SPSS was used to analysis data. It was found that 76.9% of the selected workers considered experienced

musculoskeletal disorder (MSD) within one year and major reported MSD was the lower back pain (73.07%), while 61.43% of the workers did not come to work due to pains experienced in various part of their body. The reported complains were identified to have been caused by repeated load lifting and over load weight lifted. [6] measured effect of load on the spine by assessing spinal shrinkage and individual age groups. The spinal shrinkage and age responses to compressive loading on the spine may influence musculoskeletal effects response resulting in stature loss. The responses of two different males' age groups were studied. Twenty male participants were categorised into two age groups of ten each, between 18 and 25years, and between 47 and 60 years. Each group completed two sets of 12 –station circuit of exercises where loading was based on the individual capabilities. It was seen that spinal shrinkage was greater in the age category of between 18 and 25years compared to aged group of between 47 and 60years. [7] related that female workers are distinct from males especially in the techniques of lifting (eg 15kg) boxes from the ground. The area of distinction identified were in task duration, knee and back postures, inter joint coordination and strength capabilities of the gender. [8] evaluated relationship between lifting frequency and Maximum Acceptable Weight of Lift (MAWL) using regression method. MAWL was generated for males and females from the frequency of lifts. [9] showed that percentage of persons that would see hard physical work (causes daily discomfort and fatigue) as excessive load increases with age to such a situation that it would require new assessment of individual capability of such work is recommended for persons over 40years. The researchers noted that approximately 40% men and women have their hard physical work constituted a load that exceeded 30% VO_2max. A model was developed by means of strain energy principle of the spine that include width and depth of the chest, the Young modulus of elasticity of circular cartilage, maximum permissible stature change, length of spine and leg of the students to determine safe back pack of 324 secondary students [10].

Construction was classified as one of the most hazardous industries with high manual labour, which involve greater health and safety risks [11]. The ANOVA was used to analyse influence of age, body mass index (BMI), lifting height and frequency on MAWL among Indian male construction workers. [11] research collaborated the importance of lift frequency, body weight and age in determine acceptable weight for manual lifting workers. In a task based factor analysis [13] observed that lifting weight and rate, and vertical distance were significant in determine safe limits during manual lifting.

Despite number of risk assessment tools that have been developed to assist practioners in the industry to confront the challenges of work involved low back pain, limitations have always been found, especially in the inability of consideration for individual variability in the lifting risk [14]. In a research carried out to evaluate risk of developing non-protracted and protracted low back pain (LBP) among 9,847 health care workers through questionnaire and data analysed using multi-adjusted logistic-regression, [16] found that frequently lifting and carrying low load mass (1.00-7.00kg) by bending back forward doubled the risk of developing protracted LBP. [17] found that increased lifting weight can increase musculoskeletal disorder (MSD) hazard and suggested the need to alleviate the challenge among manual lifting workers in the construction industry, the researchers suggested team lifting and use of adjustable lifting equipment, however, these suggestions may possibly increase cost for industry practioners. This current developed model is based on limiting weight lift to the individual capability before selected/returned to work. Reduction in lifting weight is not just the solution as found by [18, 19], but making load weight based on the capability and ability of the workers. Therefore, lifting weight should be reduced, which SWLwT model can be used to achieve by obtaining individual identified parameters and inputted into the model to evaluate lifting weight limit to the individual worker. [20] noted that epidemiological outcomes were not in agreement over the role of body weight in causing low back pain, however, they concluded in their findings that body-weight contributed to the effect of predicting spinal loading. In the review of [22] spinal loads with the accompanied hazard of back disorders as influenced by subject specific parameters were yet to be understood. This study contributed in understanding the effect of subjective based model to compute load weight limit safe for lifting.

3. Methods

A purposive sampling procedure was implemented to choose 50 men experienced in construction works lifting load-weight above 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, weight, stature change, vertebra length, lift frequency, and workshop temperature values were gotten**.** The weight, stature change, vertebra length, lift rate, and workshop temperature were recorded by means of weight-height scale machine, tailoring-rule, stop-clock, and pen-alike Extech RH/Temperature. The recorded data entered into Excel and SPSS were used to evaluate Two-ways Interaction Effects (TIE) of the ergonomics human characteristic factors and varying workshop temperature. Data were evaluated via Multiple Linear Regression (MLR) and ANOVA at $\alpha_{0.05}$. SWLwT model developed is: $SWLwT \times AG \times TF \times GN \times FM = x \times \frac{m_b}{L}$

Therefore,

$SWLwT = x \times \frac{m_b}{L \times AG \times TF \times GN \times FM}$ (Akanbi and Muyiwa, 2021)

such that

$S.E_T$ = strain energy aggregate

$S.E_l$ = lift load of the strain energy

$S.E_b$= strain energy of the higher part of the body

m_b = higher part of the body weight

m_l = lifting weight

m_T = higher part of the body and lifting load aggregate

F = Force applied on the spine

D = vertical dislocation of the load

V = vertical position of the load

u = lift velocity

g = gravitation acceleration

H = horizontal span of the load from the ankle

$\theta =$ Angle betwen hip and thigh for the period of lifting

A = cross – sectional area

E = Elasticity of the Young Modulus

L = length of vertebra involved

x = stature change

l_f = span of the chest

l_s = distance across chest

AG = Age parameter

TF = Temperature parameter

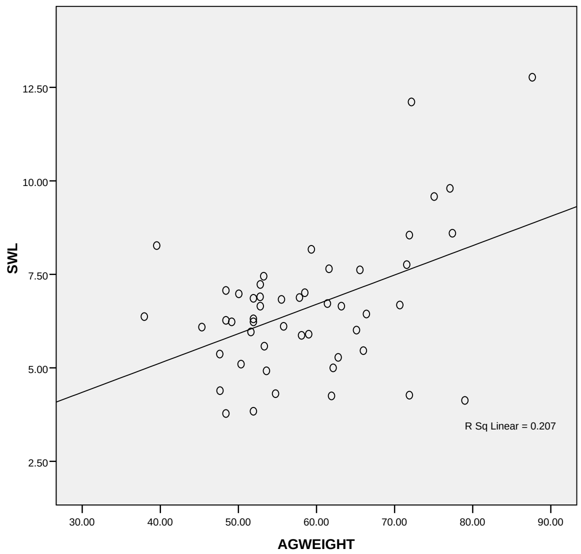

Figure 1. SWL vs AGWEIGHT

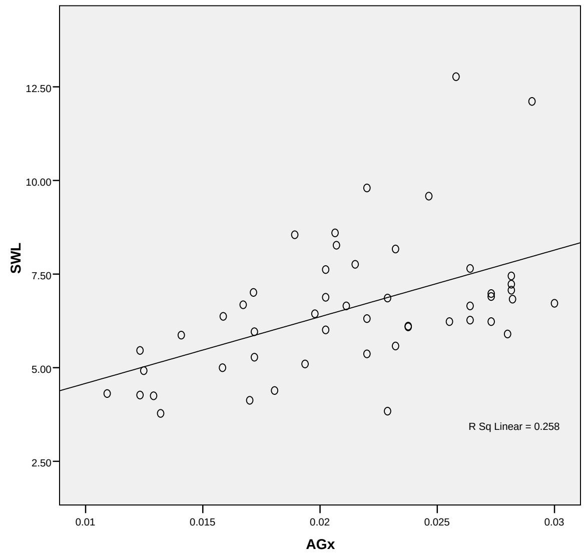

Figure 2. SWL vs AGX

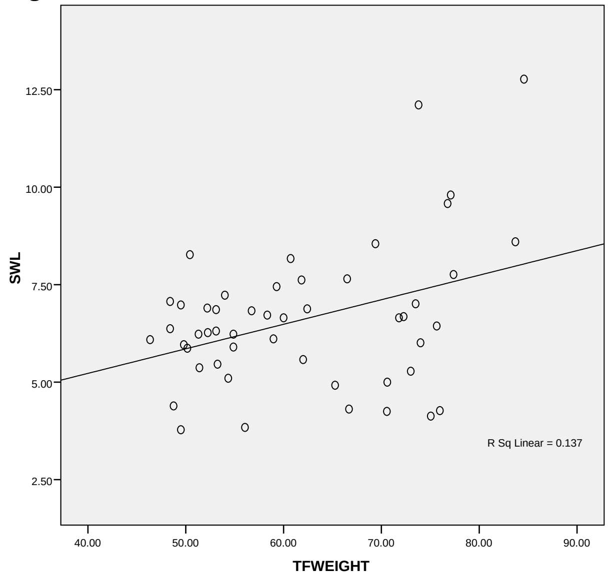

Figure 3. SWL vs TFWEIGHT

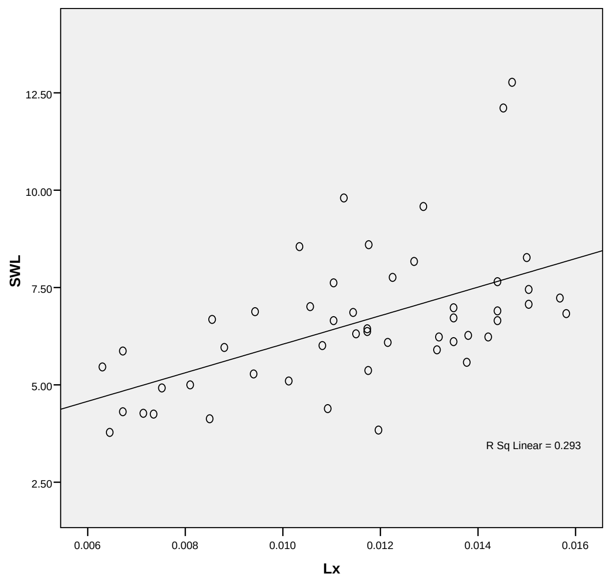

Figure 4. SWL vs LX

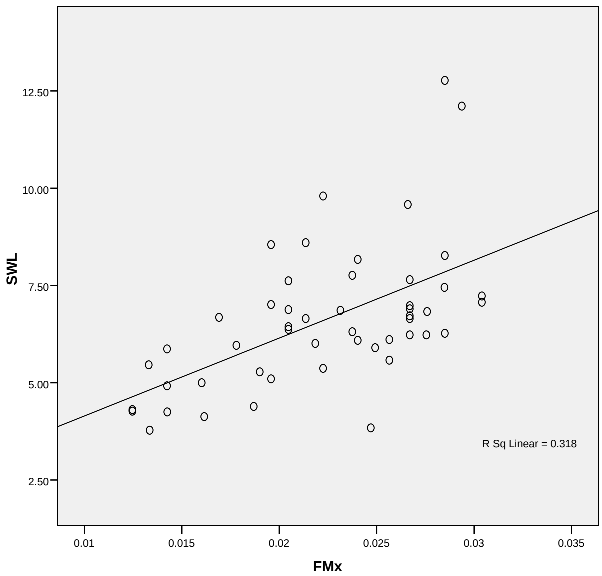

Figure 5. SWL vs FMX

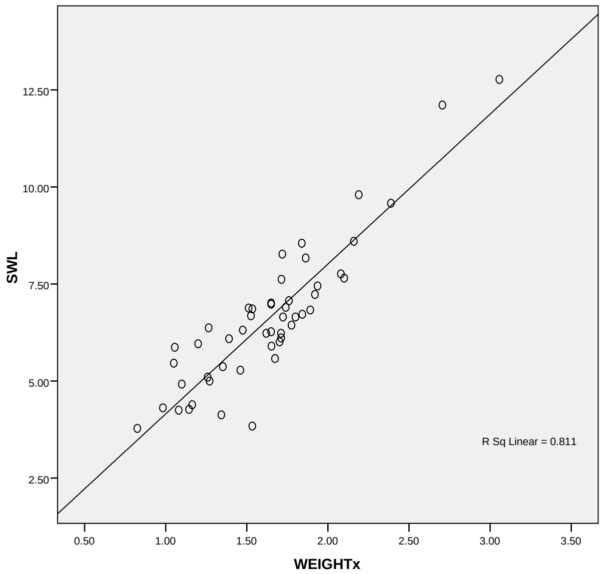

Figure 6. SWL vs WEIGHTX

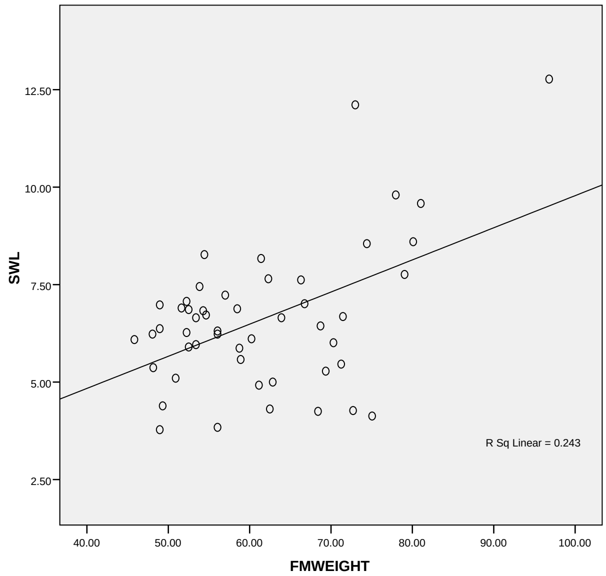

Figure 7. SWL vs FMWEIGHT

4. Results and Discussions

Table 1
Multiple Linear Regression output

Independent factors two-ways interaction	**Safe Weight of Lift (SWL)**			
	R square	Beta	B	p-value
AGTF	0.06	-0.24	-5.76	0.10
AGFM	0.01	-0.08	-2.46	0.61
AGWEIGHT	0.21	0.46	0.08	0.00
AGL	0.01	-0.12	-6.99	0.43
AGx	0.26	0.51	177.95	0.00
FMTF	0.06	-0.25	-7.54	0.08
TFWEIGHT	0.14	0.37	0.06	0.01
TFL	0.06	-0.24	-11.04	0.10
TFx	0.22	0.46	158.82	0.00
FML	0.00	-0.05	-3.02	0.74
FMx	0.32	0.56	200.14	0.00
WEIGHTx	0.81	0.90	3.86	0.00
Lx	0.29	0.54	366.61	0.00
FMWEIGHT	0.24	0.49	0.08	0.00
WEIGHTL	0.20	0.45	0.14	0.00

Table 2
ANOVA output

	SS	df	MS	F	p-value
AGTF					
Between				0.49	.87
Groups	16.36	9	1.82		
Within Groups	148.50	40	3.71		
Total	164.86	49			
AGFM					
Between				1.17	0.45
Groups	144.24	42	3.43		
Within Groups	20.63	7	2.95		
Total	164.87	49			
AGWEIGHT					
Between				0.62	0.87
Groups	64.91	25	2.59		
Within Groups	99.95	24	4.16		
Total	164.86	49			
AGL					
Between				2.79	0.02
Groups	142.38	34	4.18		
Within Groups	22.47	15	1.49		
Total	164.85	49			
AGX					
Between				1.86	0.06
Groups	74.47	15	4.96		
Within Groups	90.39	34	2.65		
Total	164.86	49			
FMTF					
Between				2.54	0.18
Groups	159.29	45	3.54		
Within Groups	5.57	4	1.39		
Total	164.86	49			
TFWEIGHT					
Between				1.47	0.22
Groups	129.59	35	3.70		
Within Groups	35.27	14	2.52		
Total	164.86	49			
TFL					
Between				7.25	0.02
Groups	162.32	44	3.68		
Within Groups	2.54	5	0.51		
Total	164.86	49			
TFX					
Between				0.56	0.88
Groups	35.43	16	2.21		
Within Groups	129.42	33	3.92		
Total	164.85	49			
FML					
Between				1.79	0.08
Groups	119.10	9	4.10		
Within Groups	45.76	40	2.28		
Total	164.86	49			
FMX					
Between				2.12	0.29
Groups	159.59	46	3.47		
Within Groups	4.91	3	1.63		
Total	164.50	49			
WEIGHTX					
Between				2.12	0.29
Groups	162.63	42	3.87		
Within Groups	2.23	7	0.32		
Total	164.86	49			
LX					
Between				2.39	0.11
Groups	154.13	42	3.67		
Within Groups	10.73	7	1.53		
Total	164.86	49			
FMWEIGHT					
Between				1.10	0.65
Groups	161.81	48	3.37		
Within Groups	3.05	1	3.05		
Total	164.86	49			
WEIGHTL					
Between				0.86	0.62
Groups	64.93	21	3.09		
Within Groups	99.93	28	3.56		
Total	164.86	49			

Table 1 showed the Multiple Linear Regression analysis output of the two-ways interaction of the selected factors of the selected 50 experienced males construction workers in Ibadan, Nigeria. The results showed that interactions between age and body-weight (AGWEIGHT), age and stature-change (AGX), temperature and body-weight (TFWEIGHT), temperature and stature-change (TFX), lift-frequency and stature-change (FMX), workers' weight and stature-change (WEIGHTX), vertebra-length and stature-change (LX), and lift-frequency and body-weight

(FMWEIGHT) were statistically significant (*p*=0.00), and gave coefficient of determination of 0.21, 0.26, 0.14, 0.22, 0.32, 0.81, 0.29, 0.24, and 0.20, respectively. This means that AGWEIGHT, AGX, TFWEIGHT, TFX, FMX, WEIGHTX, LX, and FMWEIGHT interactions explained 21, 26, 14, 22, 32, 81, 29, 24, and 20% of the total variance in the developed model, respectively. Meanwhile interactions of WEIGHTX explained highest total variance (81%) of the developed model and was statistically significant ($p<0.05$). Also, standardised coefficient (β) shows that AGWEIGHT, AGX, TFWEIGHT, TFX, FMX, WEIGHTX, LX, and FMWEIGHT interactions shows positive relationship with the developed model as seen Fig. 1 to 7. However, interactions between body-weight and stature-change gave highest β=0.91 compared to other standardised coefficient (β) and statistically significant two-ways interaction factors. These findings supported [2] that ergonomics human characteristic factors are required to determine safe weight and to assess risk impact of the load weight on manual lifting workers.

The ANOVA output of the two-ways independent factors interaction were presented in Table 2 under the headings: sum of squares, degree of freedom (df), mean square, F-test, and p-value. The ANOVA output results shows that interactions between age and vertebra-length (AGL), temperature and vertebra-length (TFL), and body-weight and stature-change (WEIGHTX) were statistically significant ($p<0.05$) and produced F-test results of 2.80, 7.25, and 12.14, respectively. The ANOVA result revealed that interactions between body-weight and stature-change gave highest F-test result (12.14), which means the interaction of the two factors influence the model the most. Therefore, effect of WEIGHTX in the model is very important, as well means that body-weight and spinal-sprinkage are most important factors to be considered in determine safe weight of lift among manual lifting workers to reduce problem of low back pain. This effect was also supported by the MLR result. Hence, the model developed to determine safe weight of lift for manual lifting workers should not only be task-oriented but should also be subjective. The need to include human factor into task based model such as National Institute for Health and Safety lifting equation (NLE) has been suggested and researchers have demonstrated effect of such inclusion [15]; [2]. It is not yet known whether [10] had studied interactions effect of the parameters involved to develop their model. [11] revealed that interaction between frequency and age affected the lifting capacity of the manual lifting workers, however, this current study did not support this claim. [12] findings showed that lifting frequency is one of the major factors that influence manual lifting workers' heart beat rate, respiratory response and safety shoes discomfort. While in this present study MLR analysis shows that lifting frequency interaction influenced manual lifting workers' body-weight and stature-change significantly. This study support results of [20], where their findings showed importance of body-weight in assessing effect of spinal loading. [21] stated that due to NIOSH lifting equation (NLE) nature of risk parameters interaction, it is likely that limits values from NLE may not be accurate for all lifting tasks, therefore, they examined effect of the lifting parameters and its interactions. They found that main effect analysis of the parameters were significant, while its interaction effects contributed 10.01% of total variance of normalised working heart rate. The amount of variance found by [21] is lower to the amount of variance contributed by the two-ways interaction of this study, while in the main effects analysis of this study only two parameter were found to be significant (body weight and stature change). The main effects and analyses variance were methods implored by [22] to identify prominent parameters in a sensitivity analyses of a subject-specific trunk musculoskeletal model. The researchers arranged the effect of the parameters in decreasing order of significant: body weight, sex, body height, and age. These were some of the parameters selected and considered in the developed SWLwT model, which their two-ways interaction effects were been considered in this study. Some of these factors were found to be significant in interaction with other factors (AGWEIGHT, AGX, TFWEIGHT, TFX, FMX, WEIGHTX, LX, and FMWEIGHT). Setting load weight limits to depend only on body weight of manual lifting workers has been found not to be an appropriate and effective way of minimising low back pain problems [23], as it has been seen in this study that body weight is not the only considered factors of interaction rather the workers' weight has interacted significantly with other parameters of the developed model.

5. Conclusion

The developed safe weight of lift with varying temperature model (SWLwT) is a gender based subjective model that considered selected six-personal characteristic factors and varying workshop temperature to decide load weight limit to be lifted that will not increases hazard of rising low back pain among bodily load weight lifting workers. The developed SWLwT model is sex sensitive to decide load weight limit for male/female worker. The ANOVA analysis of the two-ways interaction of the selected factors showed that AGL, TFL, and WEIGHTX were significant, while MLR analysis showed that AGWEIGHT, AGX, TFWEIGHT, FMX, WEIGHTX, LX, and FMWEIGHT were significant. Furthermore, the ANOVA and MLR analyses agreed to the significant of the interactions between body-weight and spinal shrinkage (WEIGHTX).

The cost implication of implementation of the model is yet to be studied if adopted. Since it may require change in the load-weight to be lifted, also the time taken to collect require data of the chosen parameters from the bodily involved lifting workers and if need arise for replacement of any labourer that did not meet the expectation for the require manual work are the areas yet to be studied using the model.

There is also need to study mutual interaction effects of the selected factors of the developed SWLwT model.

The model can be applied in various industries and establishments where manual lifting is prevalent to reduce health expense on their workforce and absence at work due to impact of manual load weight lifting on their workers.

The model can serve as a pre-placement or return to work appraisal decision making to minimise challenge of low back pain in a manual load weight involved industries. The manual worker efficiency can be fully utilised if s/he lifts weights that falls within his/her lifting range.

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