Effect of Anthropometry on Maximum Acceptable Weight of Lift

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Abstract

Manual material handling (MMH) and lifting activities are believed to contribute to the risk of low back pain (LBP). It has been found that as many as 50% of all back pains may be related to manual lifting activities. Revised NIOSH lifting equation (RNLE) was designed to reduce the incidence of LBP by recommending safe load limits, called the recommended load limit (RWL). While, an effect of worker characteristics like age, gender, weight and ethnicity, on load lifting task has been seen, the RNLE considers the effect of task demands only for establishing the RWLs. Thus, the present study investigates the role of worker anthropometry in a manual lifting task. The findings have been discussed in the light of the RNLE. A psychophysical methodology was adopted to arrive at the maximum acceptable weight limits (MAWLs). 50 industrial workers (25 males and 25 females) participated in the study. ANCOVA for gender using acromial height and wrist circumference as covariates showed that while acromial height and wrist circumference had a statistically significant effect on MAWL, gender did not. Further, it was observed that the using psychophysical criteria of 75% capable females (as per the RNLE guidelines), resulted in a MAWL of 22.2. kgs, which is comparable to the recommended weight limit (RWL) of 23 kg as obtained by the RNLE.

Keywords
Manual material handling, Manual lifting, Revised NIOSH lifting equation, Anthropometry

1. Introduction
Low back pain (LBP) is pervasive in modern society, with a global lifetime prevalence of approximately 40% (Coenen et al., 2014). According to Hoy et al. it is the greatest contributor to global disability in terms of years lived with disability (Hoy et al., 2014). Though LBP is an issue in both occupational and non-occupational settings, its consequences are severe in the occupational setting. Besides, human suffering, economic consequences of LBP include productivity-loss at work, sickness absence and disability.
A review of literature spanning 10 years (1997-2007), placed the estimated LBP cost between $84.1 to $624.8 billion (Dagenais et al., 2008).MMH tasks have often been associated with low-back pain (LBP), one of the costliest injuries with occupational origins. Statistical findings suggest that about 50% of all back pain are related to manual lifting (Afshari et al., 2017a). According to a report by national institute for occupational safety and health (NIOSH), about 60% of compensations arising from physical damages are related to the activity of manual load lifting (Afshari et al., 2017b).

Lifting involves the various human joints in a complex manner. The external force applied by the load to be lifted is shared primarily by the low back, hip and knee joints. The relative proportions of their sharing are also influenced by human factors (age, sex, body dimensions, strength of various involved muscles etc.), task factors (load, posture awkwardness, location of load, lift frequency, speed of lifting, size of container, coupling etc.), and environmental factors (temperature, humidity, ventilation, noise etc.).

Due to the well-established effect of lifting on LBP, an ad hoc NIOSH committee developed an equation to predict safe lifting limits on the basis of expert opinion and literature available at that time and expert opinion. The equation was later revised in 1991 and came to be known as the revised NIOSH lifting equation (RNLE).
The RNLE is one of the most widely used tools to identify the increased risk of LBP. It comprises of a load constant and six task related multipliers that together yield the recommended weight limit (RWL). It is believed that loads less than the RWL may be lifted by almost all healthy workers without any increased risk of LBP.
Parameters in RNLE are based on fundamental assumptions of safe tolerances for biomechanical, physiological, psychophysical and epidemiological limits of the western population. It is however being used worldwide, without taking into consideration the well documented effect of ethnicity on factors like anthropometry, strength, pain sensitivity etc., which form the basis for some of the RNLE multipliers (Christian et al., 2016; Fox et al., 2016). For example, Mexican population had smaller anthropometric measures, and Hispanic Americans were less tolerant to pain and discomfort as compared to the US population (Christian et al., 2016). Indian women were found to have a lower aerobic power than that used in the development of the RNLE equation (Maiti & Ray, 2004). Chinese participants were found to have a smaller maximum acceptable weight limit (MAWL) as compared to their Caucasian counterparts (Kim & Zhang, 2017), with a sharper decline with increase in frequency (Potvin, 2014). Lower percentage decrease in MAWL, with asymmetry for Chinese participants as compared to their Occidental counterparts has also been reported (Christian et al., 2016)(Fox et al., 2016). RNLE under-estimated the risk of low back pain in Korean population and proper modifications in the equation were recommended to account for racial difference (S.-Pi. Wu, 2000). A revision of the load constant and frequency multiplier of the RNLE for use in Chinese population was suggested (S. P. Wu, 1997) . Other studies however reported contradictory results. No significant difference was reported in MAWLs of Indonesian and Chinese inexperienced workers for a lifting task carried out at a frequency of one lift every 5 min(Afshari et al., 2018). Load constant of the RNLE was found to be valid for young, healthy, male Korean population (Behjati & Arjmand, 2019; Lavender et al., 2009). MAWLs of adult Indian women were found comparable to the RWL of RNLE (Maiti & Ray, 2004).

Gender and age have a significant effect on lifting capacity (Matheson et al., 2014). Psychophysical rating of lift was found to be related to the strength and gender of the lifter(Jackson & Sekula, 1999). An association between seeking care for low back pain and demographic factors like age, gender and BMI was observed (Garg et al., 2014). It has been reported that MAWL of women is approximately 53% of their male counterparts (Ciriello et al., 2011)and their chances of experiencing high physical exertion are 8-9 times higher (Andersen et al., 2018). During isometric lifting tasks, a gender specific muscle activation pattern was found (Nimbarte, 2014). Females tended to apply more hip flexion while males flexed their lumbar spine during lifting tasks (Marras et al., 2003). Differences in inter-joint coordination between women and men performing a lifting task have been documented (Lindbeck & Kjellberg, 2001; Plamondon et al., 2014). However, no difference in lifting techniques between men and women is observed when load is adjusted to the subject's strength (Plamondon et al., 2014, 2017; Sadler et al., 2013; Sheppard et al., 2016).
Anthropometry has been implicated for variations in MAWL. For MMH tasks, spinal moments were found to increase with increase in subject's height and weight (Harari et al., 2017). Anthropometric characteristics of chest circumference, acromial height and wrist circumference accounted for 56.2% to 83.4% variance of MAWL (Chen & Ho, 2016). It was reported that 86-91% variance in MAWL was the result of modified composite strength (MCS), chest circumference, and acromial height (Lee & Chen, 1996). Muslim et al. (2013) highlighted the need for adjustments in the RNLE to account for the differences in anthropometry of Indonesians (Muslim et al., 2013).

1.1 Objectives
The present study attempts to explore the relationship between the various worker characteristics viz. gender, acromial height and wrist circumference and MAWL. Such a relationship, if established, may allow us to modulate the RNLE values to make the equation valid for populations with demographics different from the west.

2. Methods
Experimental investigations were carried out to establish the effect of acromial height, gender age and BMI on maximum acceptable weight limit. 50 industrial workers (25 men and 25 women), mainly involved in manual labor, participated in the study. The subjects were healthy with no history of back pain in 6 months preceding the study.
For the present study, a wooden box (40 cm*34 cm*20 cm) was fabricated based on optimal container dimensions proposed by Waters et.al. (Waters et al., 1994). In order to avoid visual cues, the box contained a false bottom that could hold up to 8 kg of load. Similar types of containers have been used by many earlier researchers (Banks &

Caldwell, 2019; Ciriello, 2007; S. P. Wu, 1997; S.-Pi. Wu, 2000). Handles, 2 cm in diameter, 12 cm long with a with a 6.5 cm clearance and a smooth, non-slip surface ensured a coupling multiplier of 1 (Waters et al., 1994) .
The start and finish position of the lift were measured between the ground and the middle of the handle. All lift parameters were chosen to maintain all RNLE multiplier values at 1. Thus, two shelves were mounted so as to ensure a vertical height of 75cm at origin of lift and 100 cm at the final position. Subjects were instructed to start the lift with their feet touching a small vertical barrier, on the floor, to ensure a horizontal distance of less than 25 cm.

Figure 1. Subject performing the experimental task

Before starting the experiment, the subjects were informed about the procedure and possible risks involved and their consent was obtained. For arriving at the MAWL, a psychophysical method was adopted. The experimental task involved lifting a box of unknown weight from the lower shelf and placing it on the higher one at a frequency of 0.2 lifts/minute. Subjects were instructed to adjust the weight of the box to one that they could potentially lift for an entire workday, without getting exhausted or out of breath. To indicate the start of a lift a buzzer was used. After every lift, subjects were encouraged to increase/decrease the load, so as to arrive at a comfortable load.
Every experiment comprised of 2 lifting sessions of 40 minutes each, with a break of 40 minutes between the two sessions. At the beginning of each session the subject started with an unknown weight. They adjusted the load, to one that they felt they could lift for an entire workday. Thus, two weights were obtained in the two sessions. If they were within 15% of each other, the average of the two reading was noted down as the MAWL. If the difference between them was higher, the set was discarded and the entire experimental run was repeated. A similar methodology has been used by many researchers in the past(Banks & Caldwell, 2019; Ciriello, 2003, 2005, 2007; Ciriello et al., 2011; S. P. Wu, 1997; S. P. Wu & Chen, 2003)

3. Results and discussion

A correlation analysis was carried out on the observations gathered. The following results were obtained (Table 1):

Table 1: Correlation between gender, MAWL, height (Ht), acromial height (AH) and wrist circumference (WC)

		Gender	MAWL	WC	AH	Ht
Gender	Pearson Correlation	1	-.682**	-.694**	-.768**	-.772**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	50	50	50	50	50
MAWL	Pearson Correlation	-.682**	1	.758**	.761**	.715**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	50	50	50	50	50
WC	Pearson Correlation	-.694**	.758**	1	.722**	.717**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	50	50	50	50	50
AH	Pearson Correlation	-.768**	.761**	.722**	1	.975**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	50	50	50	50	50
Ht	Pearson Correlation	-.772**	.715**	.717**	.975**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	50	50	50	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

The observations were further analyzed using ANCOVA for gender using acromial height and wrist circumference as covariates. Owing to the high correlation between height and acromial height, only acromial height was chosen for ANCOVA as its Pearson correlation coefficient (0.761), with MAWL, was higher than that of height (0.715). Results obtained are shown in Table 2

Table 2. ANCOVA results for the effect of gender on MAWL using acromial height and wrist circumference as covariates

Tests of Between-Subjects Effects					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	1295.696a	3	431.899	31.152	.000
Intercept	97.757	1	97.757	7.051	.011
Acromial height	94.672	1	94.672	6.828	.012
Wrist Circumference	140.653	1	140.653	10.145	.003
Gender	8.634	1	8.634	.623	.434
Error	637.756	46	13.864		
Total	41873.876	50			
Corrected Total	1933.452	49			

a. R Squared = .670 (Adjusted R Squared = .649)

As evident from the table, both acromial height and wrist circumference had a statistically significant effect on MAWL. However, the effect of gender on the task undertaken in the present study was statistically non-significant.

Wrist circumference and acromial height had a statistically significant effect on MAWL. For both, the MAWL increased with increase in the value of both acromial height and wrist circumference (Figure 1, 2 and 3).

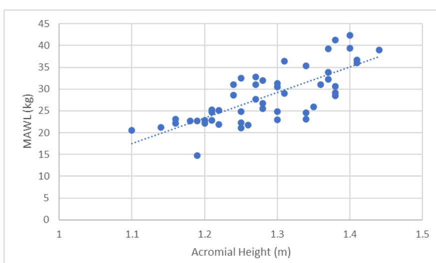

Figure 2: Effect of Acromial height on MAWL

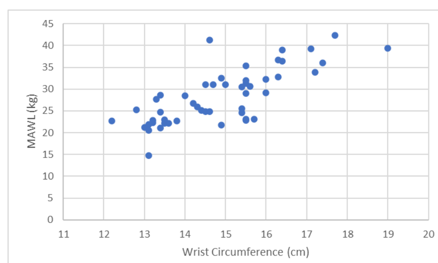

Figure 3: Effect of wrist circumference on MAWL

While gender showed a significant interaction with MAWL, when acromial height and wrist circumference were taken as covariates, its effect on MAWL was found to be statistically non-significant. Therefore, it appears that wrist circumference and acromial height have a more marked effect on MAWL as compared to gender. As seen from figs 2 and 3, MAWL increases with increase in acromial height and wrist circumference. It is possible that since women are in general shorter than men, they show lower acceptable load limits. Earlier researchers have concluded that when load is adjusted to a subjects' strength, no difference between lifting techniques of men and women were observed. Kranz et al. observed that, for lifting and pulling tasks, stature and strength are more important in determining kinematics and perceived workload than gender. The results of the present study indicate that it may be possible to use anthropometric parameters to modulate the load constant of the RNLE for different populations, thereby making the equation suitable for use worldwide.

For the task undertaken in the present study, all the multipliers of the RNLE had a value of 1 resulting in a RWL of 23kg. Using the psychophysical criteria of the RNLE, viz 75 percent women, the MAWL was found to be 22.2 kgs, which is comparable to the RWL. Similar results have been reported by Miti and Ray (2004)(Maiti & Ray, 2004).

4. Conclusions

The results of the present study indicate that while anthropometric characteristics of acromial height and wrist circumference had a significant effect on MAWL, gender did not have a statistically significant effect on it, when acromial height and wrist circumference were taken as covariates. Thus, it appears that acromial height and wrist circumference had a more marked effect on MAWL as compared to gender. The present research indicates that anthropometric variables may be used to determine safe loads for a given population.

It was noted that for the task undertaken in the study the MAWL, as per the RNLE criteria, is 22.2 kg which was comparable to the RWL of 23 kg as obtained from the RNLE. Thus, it appears that the RWL of RNLE is suitable for the Indian population

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