A Review of Manual Load Lifting Models

Salami O. ISMAILA[1*] and Oliver E. CHARLES-OWABA[2]

[1] *Department of Mechanical Engineering, University of Agriculture P.M.B., 2240, Abeokuta, Ogun State, Nigeria.*
[2] *Department of Industrial and Production Engineering, University of Ibadan, Ibadan, Oyo State, Nigeria.*
E-mails: ismailasalami@yahoo.com, oeowaba@yahoo.com
[*] Corresponding author

Abstract

The paper reviewed the three main approaches for setting limits of load to be limited manually. In the analysis the strengths and the weaknesses were highlighted and a need for a new approach using spinal shrinkage and some anthropometric dimensions was advocated. The approach may probably lead to the development of a safe weight of lift that may be subject-specific. It is expected that such an approach may be more protective of workers that the approaches presently reported in the literature.

Keywords

Spinal Shrinkage; Spine; Manual Load; Strain Energy; Visco-Elasticity.

Introduction

The industrial losses and the human agony as a result of manual lifting of loads have necessitated the attention given to the determination of limits of loads to be manually lifted in the last few decades as reported by [1-4]. There has been quite a number of research works after the limits established by International Labour Organization (ILO) in 1962 to reduce injuries especially to the low back attributable to manual load lifting. It was however noted by [5] that no Occupational Safety and Health Agency (OSHA) regulations exist regarding what constitutes the maximum acceptable or safe weight of lift.

After this observation, several researchers have worked on the subject of manual load lifting using three main approaches namely: Physiological, Psychophysical and Biomechanical.

A review of the literature in this respect was carried out to evaluate the strengths and weaknesses of the literature and explore opportunities for further research.

Material and Method

The review of the literature was done under the three main types of manual load lifting approaches by consulting relevant literature and internet sources. The databases used in the research include Science Direct, and PubMed. The Goggle and Yahoo search engines were used to search the sources of the literature. The searching was done using the terms such as manual lifting, spinal load and spine. The results of the findings are presented.

The strengths and weaknesses of each approach are also presented. The strengths were taken to be capabilities of each approach while the weaknesses were the shortcomings and limitations of each approach.

Results and Discussion

The Physiological Approach

A group of researchers focused on the use of physiological approach, research by [6] and others such [7-10] readily belongs to this category.

The primary goal of this approach is to design tasks such that the physiological response of the body will be within acceptable limits as observed by [6]. The physiological variables as reported by [9] include pulmonary ventilation, oxygen uptake, energy expenditure and heart rate. Astrand and Rodahil [11] as well as [10] reported that for 20-year old conditioned male workers, the average maximum aerobic capacity was 20Kcal/min and that for a 55-year old female; the average maximum aerobic capacity was as low as 7.3Kcal/min. On the basis of this, energy expenditure limits were set for frequent lifting.

The Psychophysical Approach

Snook [12] advocated that psychophysics was the subjective rating of the physical effort or strain on the job, and postulated that there was an association between psychophysics and potential low back injury during manual lifting. The psychophysical approach was defined directly using measures of maximum acceptable weight of lift and indirectly by measuring isometric strength.

Snook and Irvine [13] had proposed the use of experimental procedures to determine the subject's preference for weight to be lifted under given task conditions based on monitoring the subject's feelings of exertion or fatigue, and call the subjectively chosen weights the maximum acceptable weight of lift (MAWL).

The work of [13] was actually to expand the work of [14]. Emanuel et al [14] had used the concept of allowing subjects to select loads that they felt were the maximum they could safely lift. Some years later, [15] gathered data on one- and two-handed lifting capabilities for three different vertical heights of lift for subjects who indicated they could lift 5, 10, or 20 lbs increments.

Snook and his co-researchers continued their research using the psychophysical approach as reported by [12] and [16] – [18] and were joined by others such as [19] – [22] using this approach.

The Biomechanical Approach

The other approach used to estimate the injury potential of material handling tasks is to assess the tasks from the biomechanical perspective as used by [4]. Biomechanics is the application of the principles of mechanics to the physical structure of human beings. The commonly used biomechanical measures include peak joint moment, peak compression force on the spine and peak shear force on the lumbar spine as noted by [23]. The goal of any criterion is to set limits on the physical stresses imposed during lifting and using the limits to determine the load that can be lifted. The most commonly used criteria are compression limits for the L4/L5 or L5/S1 Joints, and / or maximum joint torques. The compression limits for the L4/L5 or L5/S1 Joints are usually derived from cadaver studies of spinal failures while maximum joint torques are derived from the results of empirical studies in which the maximum voluntary contraction capability of joints are collected from a group of subjects as observed by [6].

The strength testing criterion was used by [24] and [25]. In fact [25] suggested a work limit of 40-50% of maximum lift strength for repetitive lifting and 70% for occasional lifting.

Jager and Luttmann [26-28] used the peak compressive force on the lumbar spine and found that lumbar vertebral units failed at compressive loads varying from 3,698N to 12,981N. Jager and Luttmann [28] confirmed that both age and gender have noticeable effects on compression tolerances.

The NIOSH Equations

The National Institute of Occupational and Safety Health (NIOSH) having recognised the growing problem of work-related back injuries published the Work Practises Guide for Manual Lifting in 1981. The lifting equation gained prominence among health practitioners since it provided an empirical method for computing a weight limit for manual lifting. This limit proved useful for identifying certain lifting jobs that posed a risk to the musculoskeletal system for developing lifting related low back pain as established by [29].

The NIOSH convened an ad hoc committee of experts in 1985 to review literature on lifting including the NIOSH Work Practices Guide of 1981. This revised edition became the 1991 lifting equation which reflected new findings and provide methods for evaluating asymmetrical lifting tasks, objects with less than optimal hand-container couplings and offers new procedures for evaluating a large range of work durations and lifting frequencies than the 1981 equation. The 1991 lifting equation as believed by NIOSH is more likely to protect most workers than the 1981 equation.

The reasons are that:

1. The 1991 equation is applicable to a wider variety of lifting jobs because of the addition of the asymmetric and coupling multipliers a
2. The recommended weight limits computed are generally lower than the Maximum Acceptable Weight Limits reported by [16].

However, [30] reported that the NIOSH Committee noted that due to uncertainties in the existing scientific studies and theoretical models, further research was needed to assess the magnitude of risk for lifting- related low back pain and its association with the lifting index. Table 1 shows the comparison between the 1981 and 1991 NIOSH equations.

Table1. Comparison between the 1981 and 1991 NIOSH Equations

Components	**1981 Equation**	**1991 Equation**
LC = Load Constant	40kg	23kg
HM =Horizontal Multiplier	15/H	25/H
VM = Vertical Multiplier	1-0.004(|V-75|)	1-0.003(|V – 75|)
DM = Distance Multiplier	0.7 + 7.5/D	0.82 + 4.5/D
AM = Asymmetric Multiplier	Not Available	1-0.0032A
FM = Frequency Multiplier	1-F/Fmax	From Table
CM = Coupling Multiplier	Not Available	From Table

H = Horizontal distance of hands from midpoint between the ankles (cm).
V = Vertical distance of the hands from the floor
D = Vertical travel distance between the origin and destination of the lift (cm).
A = Angle of asymmetry – angular displacement of the load from the sagittal plane.
F = Average Frequency rate of lifting measured in lifts/min.
1981 Equation (Action Limit): AL = LC × HM × VM × DM × FM - Eq(1)
1991 Equation (Recommended Weight Limit): RWL = LC × HM × VM × DM × AM × FM × CM - Eq(2)

The Maximum Acceptable Weight Limit (MAWL)

The Maximum Acceptable Weight Limit (MAWL) was based on the psychophysical approach.

Dempsey and Ayoub [2] stated that with the assumption that the biomechanical and physiological criteria are correct; the psychophysical approach provides limits that violate the biomechanical and physiological criteria at very low and high frequencies respectively.

The physiological criterion has been used because lifting especially if it is repetitive requires energy expenditure being a dynamic activity. Mital et al [31] observed that the criterion is more useful than the biomechanical criterion where high frequency of lifting is needed for the physiological design criterion. However, they identified two associated problems which are specifying the upper limit of oxygen consumption as a percentage of aerobic capacity that can be sustained without undue fatigue and deciding on what kind of aerobic capacity to be used to express that percentage. Dempsey [4] recently noted that measuring oxygen consumption in the field is not only expensive but also interferes with the performance of the task.

The psychophysical criterion has been extensively used in MMH research not only to determine the maximum acceptable weight of lift [32] but also the frequency of lifting [13]. The criterion is said to combine the physiological and biomechanical criterion. Snook [33] attested to the fact that the major disadvantage of the criterion is its subjectivity and stated that the method would be replaced when and if more objective methods become available. However, [8] noted that several investigators asserted that the criterion is an appropriate single criterion to use to determine lifting capacity. Ciriello et al [17] stated that psychophysical data collected in short periods are valid for task frequencies of up to 4.3 per min. One must therefore be careful if the criterion must be used for designting tasks with moderate to high frequencies.

Karwoski et al [34] postulated that at least one of the results of the classical psychophysical experiments, which are to indicate what is acceptable to the human subjects, might not be suitable as direct estimates for load limitation and for design purposes for lifting tasks. They opined that if the psychophysical approach is to be used for setting limits in manual lifting tasks, its experimental outcomes may need to be modified, the extent and magnitude of which must be based on the comprehensive studies across different sets of lifting task variables. They suggested the use of cognitive engineering approach. Jorgensen et al [4] observed that there was no association between spinal loading and changing the load weight prior to the next lift during the psychophysical method of determining an acceptable load. Davis et al [35] confirmed the conclusion of [4] when they used different subject of variables (muscle forces, heart rate and spinal loads). They concluded that if spinal loading is assumed to be a mechanism of injury as proposed by NIOSH, [36] and [37], then this lack of association in combination with high spinal loading at the Maximum Acceptable Weight Limit indicated that the psychophysical criterion may not be protective of low-back disc injuries. Also, the psychophysical approach does not seem to take the anthropometric dimensions of the lifter into consideration.

The biomechanical criterion provides a useful indication of the potential for the assessment of combination task risk. The primary biomechanical criteria are based upon peak joint moment, peak compression force on the lumbar and peak shear force on the lumbar spine. The primary biomechanical criteria used are based upon spinal compression and maximum voluntary torque capabilities of the various major joints involved in performing a Manual Materials Handling task. The probability of failure has been found to increase as the number of loadings increased by [38].

The mechanical properties of the intervertebral discs are dependent upon both the loading history and the applied load [39].

Dempsey [40] noted that some dynamic measures of capacity such as power, have been ignored by ergonomists, and these factors may prove to be effective predictors of Manual Materials Handling (MMH) capacity. Biomechanical variables have also been shown to be important determinants of structural failure as well as of increases in risk of low back disorders [4].

Kumar and Mital [41] observed that though pain is a physiological mechanism for ensuring system safety but every injury is a mechanical disorderliness or disturbance of normality associated with such episodes.

They stated that if biomechanical safety can be maintained for these spinal segments and elements, the problem of low back pain could be largely controlled. Chaffin and Andersson [42] earlier affirmed that greater workloads increase mechanical stress (and thus strain) to the cause of low back pain. Also, 'dynamic estimates of compression and strain rates were significantly better predictors of risk while lifting than static estimates of compression, dynamic estimates of shear forces and ligamentous strain rates' [43].

Based on the foregoing and the fact that the biomechanical approach is an objective method, it seems to be the best criterion to be considered for the determination of the limit of weight to be lifted manually.

Moreover, the fact that dynamic estimates of compression as a criterion of biomechanical approach has been used while that of strain was yet to be explored and the fact that some dynamic measures of capacity such as power (energy) have been ignored by ergonomists [40], a study based on these overlooked aspects may be worthwhile. Furthermore, it has been confirmed by [44] that the rate and magnitude of disc compression are caused by the loading and its temporal pattern. It is also a fact that people's spine shrink during the day and this varies between individuals probably due to different types of work undertaken [45]. Dolan et al [46] while conducting research on bending and compressive stresses acting on the spine during lifting activities concluded that "complex spinal loading during lifting tasks depend as much on the speed of movement, and the size and position of the object lifted, as on its mass".

Moreover, the Recommended Weight Limit (RWL) that was reported to combine the physiological, psychophysical and biomechanical approaches had some fundamental limitations. The limitations as reported by [30] are:

1. That a significant part of the equation is based on the 'psychophysical data that may reveal more about a worker's tolerance to stress than of impending low back pain'.
2. The physiological approach used 'does not address the potential risk associated with cumulative effects of repetitive lifting, which may be independent of the level of whole

body fatigue'

3. The three approaches if employed individually may probably not protect the workers.

Similarly, Elfeituri and Taboun [47] demonstrated the limitation of the revised NIOSH lifting equation especially as related to the design and analysis of realistic industrial jobs. When simulated in the laboratory, lifting tasks showed that NIOSH lifting index was very sensitive to horizontal location of load and frequency of lifting [48] at the expense of other task parameters. In fact, [49] observed that to define the RWL (Recommended Weight Limit), 'the technical measures that can be used as gold standard' for the NIOSH evaluation are not existing because of the complex nature of the multipliers employed.

It may therefore be necessary to consider establishing a relationship between strain energy, weight to be lifted and spinal shrinkage as well as some relevant anthropometric dimensions of human subjects. Moreover, the earlier models do not lay emphasis on the anthropometric dimensions of the lifters despite the fact that individuals differ anthropometrically.

Conclusions

A critical analysis of the three main approaches in setting manual weight lifting limits was done. This was undertaken to expose the approaches and provide an alternative way to determine the limits (and probably a safe weight of lift) of weight to be lifted manually. It is believed that if consideration is given to the inclusion of spinal shrinkage and some anthropometric dimensions in manual weight lifting limits, it would be more protective of the workers and would be subject-specific.

References

1. National Institute for Occupational Safety and Health (NIOSH), *Muscoskeletal Disorders and Work Factors*,Technical Report DHHS (NIOSH) Publication, 1997, p. 97-141 (Cincinnati, OH: NIOSH).

2. Dempsey P.G., Ayoub M.M., *The Psychophysical approach to Manual Materials Handling task design*, Ergonomics, 1999, 42(1), p. 17-31.
3. Potvin J.R., *Use of NIOSH equation inputs to calculate lumbosacral compression forces*, Ergonomics, 1997, 40(7), p. 691-707.
4. Jorgensen M.J., Davis K.G., Kirking B.C., Lewis K.E., Marras W.S., *Significance of Biomechanical and Physiological Variables during the determination of maximum acceptable weight of lift*, Ergonomics, 1999, 42(9), p. 1216-1232.
5. Karwoski W., 1982, *A fuzzy set based model on the interaction between stresses involved in manual lifting tasks*, PhD Dissertation Lubbock: Texas Tech University, 1982.
6. Dempsey P.G., *A critical review of biomechanical, epidemiological, physiological criteria for designing Manual Materials Handling tasks*, Ergonomics, 1998, 42(1), p. 73-88
7. Rodgers S.H., Yates J.W., Garg A., *The Physiological basis for manual lifting guidelines*, National Technical Information Service, Report Number 91-227-330, 1991.
8. Ayoub M.M., Selan J.J., Jiang B. C., *Manual Materials Handling in Handbook of Human Factors Engineering* Ed. Salvendy Gavriel, Chischester, New York, John Wiley, 1987.
9. Samanta A., Chartterjee B.B., *A Physiological Study of Manual Lifting of loads in Indians*, Ergonomics, 1981, 24(7), p. 557-664.
10. Coleman A.E., Burford C.L., *Aerobic Capacity in Sedentary adults participating in an adult fitness program*, American Corrective Therapy Journal, 1971, 25, p. 48-51
11. Astrand P.O., Rodahil K., *Textbook of Work Physiology*, New York, McGraw-Hill Inc., 1986.
12. Snook S.H., *The Design of Manual Material Handling Tasks*: *Ergonomics*, London, Taylor and Francis, 1978.
13. Snook S.H., Irvine C.H.C., *Maximum Acceptable Weight of Lift*, American Industrial Hygiene Association Journal, 1967, 28, p. 322-329.
14. Emanuel I., Chaffee J.W., Wing J., *A Study of Human Weight Lifting Capabilities for Loading Ammunition into the F-86H Aircraft*, WADC Technical Report 56-367, Wright Air Force Base, OH, 1956.

15. Switzer S.A., *Weight-Lifting Capabilities of a selected sample of human subjects,* Technical Document Report No MRL-TDR-62-57, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, OH, 1962.
16. Snook S.H., Ciriello V.M., *The design of manual handling tasks: revised tables of maximum acceptable weights and forces*, Ergonomics, 1991, 34, p. 1197-1213.
17. Ciriello V.M., Snook S.H., Blich A.C., Wilkinson P.L., *The effects of task duration on psychophysically-determined maximum acceptable weights and forces*, Ergonomics, 1990, 33, p. 187-200.
18. Ciriello V.M., Snook S.H., Hughes G.J., *Further Studies of Psychophysically determined maximum acceptable weights and forces*, Human Factors, 1993, 35, p. 175-186.
19. Dempsey P.G., Ayoub M.M., *Manual Materials Handling Research: What we don't know* In Mital A., Krueger H., Kumar S., Menozzi M., Fernandez J.E. (eds), Advances in Occupational Ergonomics and Safety I (Amsterdam: 10s Press), pp. 303-308, 1996.
20. Yates J.W., Karwoski W., *Maximum acceptable lifted load during seated and standing work positions*, Applied Ergonomics, 1987, 18, p. 239-243.
21. Ayoub M.M., Bethea N., Deivanayagam S., Asfour S., Bakken G., Liles D., Selan J., Sherif M., *Determination and modeling of lifting capacity,* Final Report HEW (NIOSH) grant no 5R010H00545-02 NIOSH, Cincinati, OH, 1978.
22. Karwoski W., Yates J.W., *Reliability of the Psychophysical approach to manual lifting of liquids by females,* Ergonomics, 1986, 29, p. 237-248.
23. Straker L.M., Stevenson M.G., Twomey L.T., Smith L.M., *A Comparison of risk assessment of single and combination manual handling tasks: Biomechanical measures,* Ergonomics,1997, 40(7), p. 708-728.
24. Chaffin D.B., Herrin G.D., Keyserling W.M., Garg A., *A method for evaluating the biomechanical stresses resulting from manual materials handling jobs,* American Industrial Hygiene Association Journal, 1977, 38, p. 662-675.
25. Poulsen E., *Prediction of maximum loads in lifting from measurement of back muscle strength*, Progressive Physical Therapy, 1970, 1, p. 146-149.
26. Jager M., Luttmann A., *Biomechanical analysis and assessment of lumbar stress during load lifting using a dynamic 19-segment human model*, Ergonomics, 1989, 32, p. 93-112.

27. Jager M., Luttmann A., *Lumbosacral compression for uni- and bi-annual asymmetrical load lifting*. In S. Kumar (ed), Advances in Industrial Ergonomics and Safety IV, Denver, Taylor and Francis, p. 839-846, 1999.

28. Jager M., Luttmann A., *The load on the lumbar spine during asymmetrical bi-manual materials handling*, Ergonomics, 1999, 35, p. 783-805.

29. Liles D.H., Mahajan P., *Using NIOSH lifting guide decreases risks of back injuries*, Occupational Health and Safety, 1985, p. 57-60.

30. Waters T.R., Putz-Anderson V., Garg A., Fine L.J., *Revised NIOSH equation for the design and evaluation of Manual lifting tasks,* Ergonomics, 1993, 36, p. 749-776.

31. Mital A., Ayoub M.M., Asfour S.S., Bethem N.J., *Relationship between lifting capacity and injury in occupations requiring lifting*, In proceedings of the human Factors Society, 22nd Annual Meeting (Human Factors Society, Detroit), 1978, p. 469-473.

32. Snook S.H., Ciriello V.M., *The effects of heat stress on manual lifting tasks*, American Industrial Hygiene Association Journal, 1974, 35, p. 681-685.

33. Snook S.H., *Psychophysical acceptability as a constraint in Manual working capacity*, Ergonomics, 1985, 28, p. 331-335.

34. Karwowski W., Lee W., Jamaldin B., Gaddie P., Jang R., Alqesaimi, *Beyond Psychophysics: The need for a cognitive engineering approach to setting limits in manual lifting tasks.* Ergonomic, 1999, 42 (1), p. 40-60.

35. Davis K.G., Jorgensen M.J., Marras W.S., *An investigation of perceived exertion via whole body exertion and direct muscle force indicators during the determination of the maximum acceptable weight of lift*, Ergonomics, 2000, 43(2), p. 143-159.

36. Jager M., Luttman A., *Comprehensive strength of lumbar spine elements related to age, gender and other influences*, Journal of Electromyography and Kinesiology, 1991, 1, p. 291-294.

37. Mc Gill S.M., *The biomechanics of low back injury: implications on current practise in industry and the clinic*, Journal of Biomechanics, 1997, 30, p. 465-475.

38. Brinkmann P., Biggemann M., Hilweg D., Biggemann M., *Fatigue fractures of human lumbar vertebrae,* Clinical Biomechanics, 1987, 2(2), 94-96.

39. Adams M.A., McNally D.S., Dolan P., *Stress distributions inside intervertebral discs: the effects of age and degeneration*, Journal of Bone and Joint Surgery, 1996, 78-B, p. 965-972.

40. Dempsey P.G., *Power as a predictor of lifting capacity,* unpublished doctoral dissertation, Lubbock, TX , Texas Tech University, 1996.
41. Kumar S., Mital A., *Margin of Safety for the Human Back: A parable consensus based on Published Studies*, Ergonomics, 1992, 35(7/8), p. 769-781.
42. Chaffin D.B., Anderson G.B.J., *Occupational Biomechanics*, New York, John Wiley and Sons, 1991.
43. Granata K.P., Marras W.S., *Relation between spinal load factors and the high-risk probability of occupational low-back disorder*, Ergonomics 1999, 42(9), p. 1187-1199
44. Eklund J.A., Corlett H.E., *Shrinkage as a measure of the effect of load on the spine,* Spine, 1984, 9(2), p. 189-94
45. Dieen J.H. Van, Toussaint H.M., *Spinal shrinkage as a parameter of functional load of the human spine,* Spine, 1993, 18, p. 1504-1514.
46. Dolan P., *Bending and compressive stresses acting on the lumbar spine during lifting activities*, Journal of Biomechanics, 1994, 10, p. 1237-48.
47. Elfeituri F.E., Taboun S.M., *An Evaluation of the NIOSH Lifting Equation: A Psychophysical and Biomechanical Investigation,* International Journal of Occupational Safety and Ergonomics, 2002, 8(2), p. 243-258.
48. Dempsey P.G., Burdorf A., Fathallah F.A., Sorock G.S., Hashemi L., *Influence of measurement accuracy on the application of the 1991 NIOSH equation*, Applied Ergonomics, 2001, 32(1), p.91-99.
49. Takala E., Pehkonen I., Forsman M., Hansson G., Mathiassen S.E., Neumann W.P., Gisela Sjøgaard G., Kaj Bo Veiersted K.B.,Westgaard R.H., Winke J., *Systematic evaluation of observational methods assessing biomechanical exposures at work,* Scand J. Work Environ. Health, 2010, 36(1), p. 3-24.