Risk Analysis of Manual Lifting

by Professor N. Krishnamurthy[1]

1. INTRODUCTION

The problem arising from manual lifting of loads has been with mankind from time immemorial. It causes untold human misery and considerable financial loss in many industries including construction, manufacturing, food services and health care, both in terms of frequency and severity of its occurrence.

This topic takes on a special importance now that the Singapore Ministry of Manpower (MOM) has implemented the new Workplace Safety and Health Act (WSHA) which came into effect from 1 March 2006. All stakeholders along the work process chain in all workplaces must be more aware than before of possible hazards – and more accountable.

Addressing this problem in their guidelines for the logistics industry, MOM cites [Ref. 1], "not adopting the proper lifting methods" as an example of unsafe acts by employees.

Unsafe conditions also contribute to workplace hazards, and the management must:

(a) Determine situations, equipment, and procedures that can cause hazards,
(b) Provide equipment, safeguards, PPE etc., to eliminate or mitigate hazards, and,
(c) Train workers to use equipment and procedures correctly and consistently.

This paper presents the major considerations in the causes and consequences of manual lifting, and discusses techniques to evaluate the hazards arising from bad manual lifting practices. Author discusses a lifting equation commonly used to compute the maximum load a worker can carry, and illustrates the principles mentioned by a worked example.

2. MECHANISM OF BACK PAIN

Structurally, the human body bears most of the loads we carry through its bone skeleton as shown in Fig. 1, arms omitted in the upright image for clarity. The skull and hip bone masses are connected by the spine which is basically a chain of 24 bone rings with rubber-like cushions ("intervertebral discs") between them. The spinal cord goes through a hole passing through them connects to nerves leading to various limbs and organs.

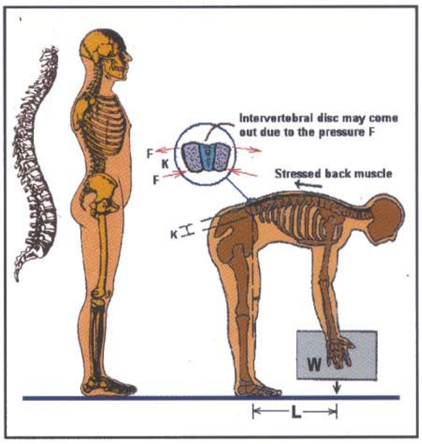

Fig. 1 Forces on vertebra bending down

2.1. Effect of Bending on the Spine

When a person bends and picks up a load the thin articulated tube of our spine is subjected to heavy bending moment, axial force, and shear force. For a load *W* lifted at a distance *L* from the worst affected vertebra near the base, the moment $M = W.L$. This moment is resisted as compression and tension forces *F* at the vertebra, of average diameter (about 4 cm) marked *K*. Then, as $W.L = M = F.K$, we get: $F = W(L/K)$. Thus if we lift a 10 kgf load half a metre away from our legs, $F = 10(50/4) = 125$ kgf

2.2. Comparison with Squat-Lift

The essential difference between bend-lift and squat-lift may be understood from Fig. 2.

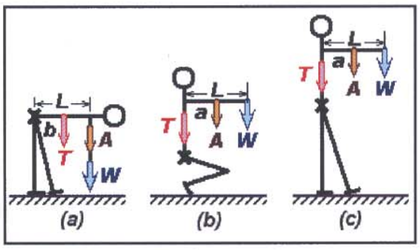

Fig. 2. Lifting Mode Schematics

The loads acting on the lower back vertebra (marked X) are the weight *T* of the upper torso and head, the weight *A* of the arm, and the load *W* lifted, at horizontal distances *b*, *a*, and *L*, as marked in the figure.

Typical values for adults are: $T = 32$ kgf, $A = 6$ kgf, and *b* and *a* are approximately half of *L* the arm length, which can be a maximum of about 40 cm. [Ref. 2.]

It may be noted that in bend-lift, $a = L$, and in squat-lift, $b = 0$.

Moment due to all three forces during bend-lift, Fig. 2(a),

$$M_b = T.b + A.L + W.L \approx 32(40/2) + 6x40 + W(40) = 880 + 40W \text{ kgf.cm}$$

Moment due to all three forces during squat-lift, Fig. 2(b),

$$M_s = T(0) + A.a + W.L \approx 32(0) + 6x(40/2) + W(40) = 120 + 40W \text{ kgf.cm}$$

This stays nearly constant as the worker stands up from squatting position, Fig. 2(c).

Upon equating the moment developed and the moment of resistance, namely *F.K*, as discussed in Section 2.1, the force *F* on the lower back vertebra is *(M/K)*, that is, *(M/4)*.

$$\text{For bend-lift, } F_b = (M_b/4) = 220+10W \text{ kgf}$$

$$\text{For squat-lift, } F_s = (M_s/4) = 30+10W \text{ kgf}$$

Even without carrying any load (*W*), the bending lift imposes an extra force of 190 kgf, the weight of two full-grown men, on the vertebra! Any additional load that we carry (including around the stomach) multiplies ten-fold. That is why for long term bending work, lower back trauma and hunchback-ism are common.

Needless to say, hugging the load close to our body would reduce *L* and *a* to about one-third of their extended values, leading to considerable reductions in moments.

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In addition to these forces arising from bending moment, we have the direct forces (*T*+*A*+*W*), that is (38+*W*) kgf, in a combination of axial and shear forces, which could be taken as direct compression conservatively, for a first approximation.

The maximum force on the vertebra would be of the order of (220+10*W*+38+*W*) or (258+11*W*) in bend-lift, and (30+10*W*+38+*W*) or (68+11*W*) in squat-lift. For *W* of 25 kg (a reasonable maximum for healthy adult men, somewhat lower for women) bend-lift imposes 533 kgf. Squat-lift imposes 343 kgf, less than two-thirds of the bend-lift strain.

Although the numbers used are crude overall estimates, the developed forces reaching the assessed normal vertebral strength of about 500 kgf must ring warning bells!

3. AVOIDANCE OF BACK STRAIN

3.1. Procedure for Squat-Lift

It is obvious that to avoid back trouble due to manual lifting, we must not bend and lift, but squat and lift. This has been practised globally for decades, with remarkable benefits. Figure 3, adapted from HSE's Guidebook on the subject [Ref. 3] illustrates the steps:

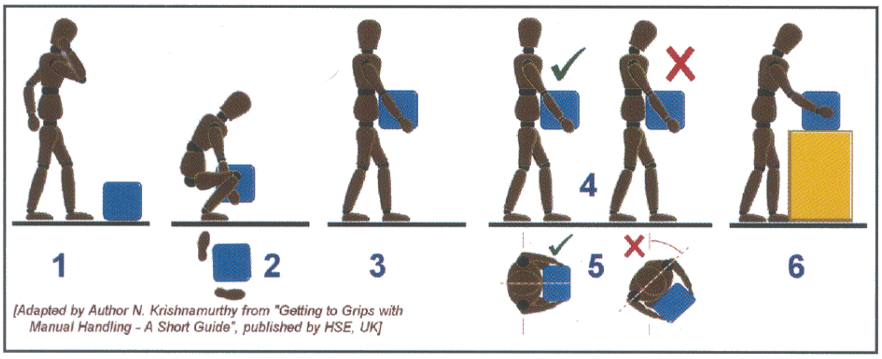


Fig. 3. Procedure for Manual Lift

1. Pause, study the situation, and plan. (Do not jump to the job without planning!)
2. Squat, with one foot on either side of the load, and steadily stand up.
3. Hold the load close to the body, arms relaxed and holding the load at bottom
4. Keep the head up, not bowed down
5. Hold load in front, not twisted to one side (by too large an angle)
6. Walk to the destination and unload on suitable platform; if to be lowered, squat.

3.2. Further Practical Considerations

More problems surface in actual practice than the analysis in the preceding segment suggests. It is not just the initial and final positions of the load that matters, but also the variation in horizontal and vertical movements, frequency of motion in repeated work, and even whether the load has convenient handles to hold or not.

All these factors have been studied by numerous researchers for many years, and the conclusions have been published, tested, and accepted for use by many organisations. The U.S. National Institute for Occupational Safety and Health (NIOSH) has developed and has been continuously refining over the last 25 years an equation for manual lifting, known as the "NIOSH Lifting Equation for Recommended Weight Limit" (RWL) [Ref. 4] which has found wide, and least controversial, acceptance around the world. The Canadian Center for Occupational Health and Safety (CCOHS) has published on the internet, an on-line RWL calculator for the NIOSH-RWL. [Ref. 5.]

The equation is applicable only to two-handed lifting or lowering only. It does not apply to seated or kneeling workers, or to workers in restricted work space.

The parameters influencing RWL, and needed as inputs into the equation are marked in Fig. 4 and listed in Table 1, along with their quantitative influence on RWL in the form of corresponding multiplying factors, namely, *HM, VM, DM, AM, FM, and CM.*

Table 1. Values of Multipliers

No.	Parameter	Multiplier
1.	***H***, Horizontal distance from load to low back	***HM*** = 25/***H***
2.	***V***, Vertical location of load at beginning of lift	***VM*** = 1 – (0.003|***V***-75|)
3.	***D***, Vertical lifting distance	***DM*** = 0.82 + (4.5/***D***)
4.	***A***, Rotation of midline of the load during lift	***AM*** = 1 – 0.0032***A***
5.	***F***, Frequency of lifts, and duration of task	***FM***, From Fig. 5 (Left)
6.	***CM***, Quality of grasp and posture	***CM***, From Fig. 5 (Top)

The NIOSH "Lifting Equation" (revised in 1991), is:

RWL = LC.HM.VM.DM.AM.FM.CM

where, ***LC*** is the load constant, taken as 23 kgf, the standard value with which 90% of normal males and 70% of normal females are found to be comfortable.

Variations for *FM* and *CM* being more complex, the values are in tabular form, for a few specific values of the parameters for *FM*, the "Frequency Multiplier", and for certain qualitative variations for *CM*, the "Coupling Multiplier". Key tables are given in Fig. 5.

For most practical applications, values at such large intervals may be quite adequate. Further, more detailed data for smaller intervals are also available in the NIOSH Equation Applications Manual [Ref. 4].

For convenience of use, the author has fitted curves to the *FM* multiplier variations by regression analysis, shown superposed on the tabulated points confirming the close fit.

The spreadsheet program into which he incorporated these equations to compute *RWL* for any set of parametric values within their respective ranges may be accessed and downloaded from his website: *www.profkrishna.com.*

Asian body sizes and strengths being smaller than for Westerners, the author recommends that *LC* be reduced from 23 kg by about 10% to say, 21 kg. But Singapore MOM's guidelines for the logistics industry [Ref. 1] mention 25 kg as the upper limit for manual lifting. Author's program allows the user to modify *LC* between 21 and 25 kg.

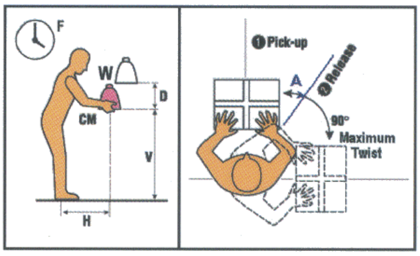
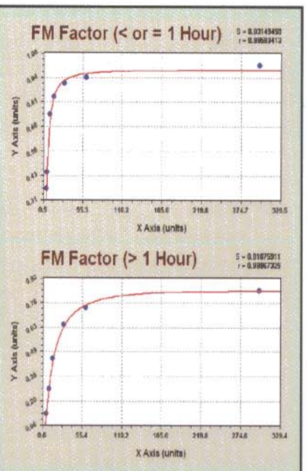


Fig. 4. Parameters in Lifting Equation

F = Time Between Lifts	FM Factor			
	Lifting While Standing		Lifting While Stooping	
	≤ 1 Hr.	> 1 Hr	≤ 1 Hr.	> 1 Hr
5 min	1.00	0.85	1.00	0.85
1 min	0.94	0.75	0.94	0.75
30 sec	0.91	0.65	0.91	0.65
15 sec	0.84	0.45	0.84	0.45
10 sec	0.75	0.27	0.75	0.27
6 sec	0.45	0.13	0.45	-
5 sec	0.37	-	0.37	-



C = Grasp	CM Factor:	
	Standing	Stooping
Good (handles)	1.00	1.00
Fair	1.00	0.95
Poor	0.90	0.90

Fig. 5. NIOSH Table and Author NK's Curve Fits for F (Left), and NIOSH Table for CM (Above)

Once RWL is determined, a "Lifting Index" may be found as: ***LI = W/RWL***
LI of 1.0 or less is obviously safe. The more it is above 1.0, the more unsafe it is.

Extensions and modifications of the formula for determination of *LI* for combinations of multiple lifting tasks, are available in the Manual, [Ref. 4].

3.3. Worked Example

Worker loads boxes weighing 15 kg on to a moving belt, at the rate of one every 30 seconds for durations of less than an hour at a time. His hands move from a height of 60 cm at start to 100 cm at the belt, at right angles, as shown in Fig. 6. With experience and under guidance, the worker positions himself with his feet lined so that he twists 45° one way and 45° the other way to turn the 90°. Horizontally, his hands move from 20 cm to 30 cm. He does not have to stoop during the task. The boxes do not have a good grip.

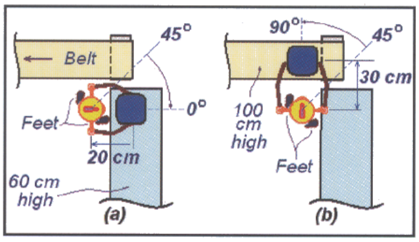


Fig. 6. Worker moving boxes

Data: *H* = Worst value 30 cm, *V* = 60 cm, *D* = 100 – 60 = 40 cm. *A* = 45°.
F = Every 15 sec. for less than an hour, and, *C* = Poor, standing, hence *CM* = 0.90

Analysis: Plugging into the formulas, we get,
$HM = 25/30 = 0.83$, $VM = 1 - (0.003|60-75|) = 1 - 0.003 \times 15 = 0.96$,
$DM = 0.82 + 4.5/40 = 0.93$, $AM = 1 - 0.0032 \times 45 = 0.86$, and,
For F = 15 sec., < 1 hr., from Fig. 5, $FM = 0.84$

Then, taking LC = 22 kg, $RWL = 22 \times 0.83 \times 0.96 \times 0.93 \times 0.86 \times 0.84 \times 0.90 = 10.60$ kg
Lifting Index = 15/10.60 = 1.42, > 1.0, hence the situation needs review.
If the basic data are input into the author's program, obviously, the first four multipliers will be exactly the values given here, but the *FM* factor appears to vary in the third decimal place, leading to *RWL* of 10.51 kg, and a *LI* of 1.43, a difference of less than 1%.

4. RISK ANALYSIS

4.1. Fundamental Principles

To encourage and assist local industries in improving workplace safety, MOM has published simple guidelines for risk management [Ref. 6]. The three important steps in risk management are: (a) Hazard Identification, (b) Risk Assessment, (c) Risk Control.

(a) Hazard Identification:

Hazards are potential dangers. It is well known and documented that manual lifting can be very hazardous, not only because of the weight lifted itself, but also on the manner it is handled. However, manual lifting is such a common, natural, and spontaneous activity that even professionals tend to take it for granted, or ignore it.

Hence it is very important that the particular job that is being analysed be looked at afresh, preferably by a colleague from a different activity or division, or by a safety consultant, and all potential dangers be identified and the available details documented. Unidentified hazards simply go unmanaged.

(b) Risk Assessment:

Risk assessment examines what might happen when hazards are realised. It involves the two components likelihood and severity.

In manual handling, the likelihood is very high in most industrial environments. It can be quantified very easily as frequency, by the number of times a task is done per hour.

Severity also has already been quantified in the Lifting Equation, as multiplication factors for *H, V, D, A, F* (Duration), and *C*. Thus *RWL* and *LI* values provide a good quantitative measure of the risk.

When *LI* is less than 1.0, the risk may be considered "Low". Assuming that nature provides roughly a factor of safety of 2 for the onset of the equivalent of "yield", meaning temporary and repairable damage, we may take it that when *LI* is above 2, the risk is "High" and hence unacceptable, unless something drastic is done to pull it down below 2. For *LI* between 1 and 2, risk may be considered tolerable, and mitigation measures and safeguards developed, to bring *LI* to 1.0 or below.

(c) Risk Control:

All six parameters identified in the Lifting Equation (*H, V, D, A, F,* and *C*) are potential candidates for risk control. Possible controls, according to the recommended hierarchy of control are as follows:

(i) Elimination: The task itself cannot generally be eliminated, but certain physical or procedural segments may be. For instance, the vertical distance *D* may be eliminated by rearranging the work surfaces.

(ii) Substitution: The more difficult manual portions of the task may be substituted with simple mechanical devices, or a heavy part substituted with its components. The worker may substitute upper body twist with whole body turning, avoiding the *A* effect. But psychologically this would be an unattractive solution, because it would be a burden to remember to turn the whole body every 30 seconds. The supervisor too cannot impose the requirement too rigidly because soon it would affect the smoothness of work as well as the working relationship.

(iii) Engineering Controls: Hardware solutions such as posture-related ergonomics, more efficient tools, reduction of weight *W*, distances *H, V*, and/or *D*, dimensions, etc. Provision of convenient grips, slings, or handles, to improve *CM*.

(iv) Administrative Controls: Warning notices and reminders, better training and motivation of workers.

(v) Personal Protective Equipment: Overalls, helmets, gloves, goggles, etc. While essential, these must not be counted upon as first line of defence to prevent injury or accident.

4.2. Example Problem (Continued)

For the example problem considered, *LI* of 1.42 is less than 2, and hence manageable.

Let us assume that the load *W*, vertical distances *V* and *D*, and frequency and duration *F*, are fixed for efficiency of production, and placing two workers is not economically viable.

That leaves the following factors, which may be modified as indicated below:

(a) Reduce *H* from 30 cm to 25 cm, by shifting the table closer to the belt.

(b) Eliminate twisting by providing a pallet on a swing arm at 100 cm height, and having stops at appropriate start and stop angles. Figure 7 shows one possibility, with the worker simply having to lift the box by 40 cm on to the pallet, and then, after swinging the arm to the belt position, slide the box on to the belt.

Any small sideways or twisting motion the worker does now will be with the load at the same level, and hence *D* = 0.

But why not make the arm itself lift the box by 40 cm? The high cost of motorization and electric supply will be a management option of "elimination".

(c) Provide suitable grips to the box with the load.
With these measures, the corresponding multipliers increase to 1.0 in all three cases, physically meaning that we have removed potential danger in regard to *H, A*, and *C*. Revised *RWL* = 22x1.0x0.96x0.93x1.0x0.84x1.0 = 16.50 kg, leading to a *LI* of 0.91, a definite improvement from 1.42 earlier.

5. CONCLUSION

The preceding is an over-simplified version of a very complex and critical situation very prevalent in construction and other industries. The author's application of mechanics principles to the spine forces problem is admittedly crude, although similar assumptions have been used in other complicated stress analysis areas such as welding.

Full-fledged hazard analysis and risk assessment in this matter will require more detailed collection of data, inclusion of certain other practical considerations, and sophisticated bio-mechanics, for which, adequate tools are available in the references cited.

In sum, the author is confident that the simplified treatment presented herein will help engineers in charge of erection and production understand the basic problems of manual lifting, and that it will give safety personnel usable guidance to identify manual lifting related hazards and fundamental approaches to handling them.

6. REFERENCES

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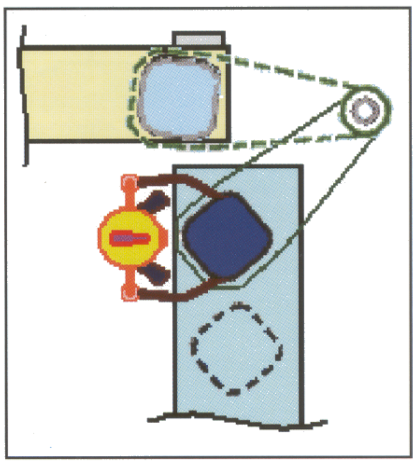

Fig. 7. Swing arm