Advances in Industrial Ergonomics and Safety VI
Edited by F. Aghazadeh
Taylor & Francis, 1994

MULTIPLE-TASK ANALYSIS USING REVISED NIOSH EQUATION FOR MANUAL LIFTING

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The paper describes the recommended procedure to analyze multi-task jobs. Other alternatives considered for multi-task analysis are also discussed. It is concluded that the recommended method, though a little complex, is based on sound ergonomic principles and offers a reasonable approach to multi-task problems.

INTRODUCTION

In the Revised NIOSH Equation for Manual Lifting, a task is defined by weight of the load to be lifted or lowered and six variables (Water et al., 1993). These include horizontal location of the hands (H), vertical location of the hands (V), travel distance (D), asymmetric angle (A), couplings (C) and frequency (F). A job is defined as a complex job or a multiple task when a worker performs two or more lifting/lowering tasks (Waters et al., 1994). In other words, one or more task variables are significantly different when a worker performs lifting tasks.

The primary objective of this paper is to describe the rationale for the multi-task analysis procedure used in the Revised NIOSH Equation for Manual Lifting. A secondary objective is to describe the other options that were considered for multiple-task analysis.

Multi-task lifting jobs are difficult to analyze because the Revised NIOSH Equation is based on multiple criteria (biomechanical, physiological, psychophysical and epidemiological). Secondly, it is not exactly clear how does the performance of several different lifting tasks affect biomechanical and psychophysical criteria.

APPROACHES CONSIDERED FOR MULTI-TASK ANALYSIS

A number of different approaches were considered for multi-task analyses. These were (i) worst task, (ii) frequency weighted average for each task variable, (iii) frequency weighted average for each recommended weight limit, and (iv) recommended procedure.

Worst task analysis

Under this procedure only the worst task, as defined by Lifting Index (LI), is considered and all other tasks are ignored. There are two options under this procedure. Under the first option, only the worst task is analyzed and it is assumed that the performance of other tasks has no effect on workers' ability to perform the entire job safely. Thus, the LI for the entire job will be equal to the LI for the worst task. In this regard, Herrin et al. (1986) showed that a single task in a job that produces excessive compressive force on the low back or requires excessive strength would increase the risk of back injuries. However, this approach would underestimate the physical stresses to the worker. This is especially true when the differences between different tasks are not large or the major problem with the job is physical fatigue rather than compressive force or strength. A second option is to use all other task variables except frequency for the worst task and use frequency for the entire job to determine Recommended Weighty Limit (RWL) and Lifting Index (LI). This assumes each task in the job is as bad as the worst task. Obviously, this would substantially overestimate the physical stresses from the job, in particular, when the physical demands of tasks are very different.

Frequency weighted average for task variables

The 1981 Work Practices Guide for Manual Lifting (U.S. Department of Health and Human Services, 1981) recommended that to determine the collective effect of all tasks, (i) a frequency weighted average for each task variable should be derived, (ii) frequency weighted average variables should be used to determine the four factors, the AL and the MPL, and (iii) the frequency weighted average weight should be compared with the AL and the MPL. In general, the approach worked well. The averaging approach, however, can mask the effects of hazardous task variables, resulting in an underestimation of the lifting hazard (Waters, 1991). Further, in extreme situations, the averaging of task variables can cancel out the effects of extreme task variables. For example, consider a multi-task job consisting of two separate tasks, each with a frequency of 1 lift/min., vertical heights (V) of 0 and 60 inches, horizontal locations (H) of 6 and 24 inches, and travel distances (D) of 30 inches. The frequency weighted H, V, and D are 15, 30 and 30 inches. The frequency weighted V of 30 inches is the ideal location for lifting while each task has one worst value for V. Secondly, this approach assumes a linear relationship between task variables and factors. Some factors such as horizontal factor, have non-linear relationships with task variables. The ALs for task 1 and task 2 are 46.4 and 11.7 lbs, respectively. The AL for the entire job is 23.9 lbs. Thus, frequency weighted averaging on task variables may produce higher AL for the entire job than AL for the individual task.

Frequency weighted average for RWLs

An alternative to this approach was frequency weighted averaging of RWLs instead of task variables (Waters, 1992). Under this approach, instead of task variables, frequency independent RWLs (obtained by setting FM = 1) for each task were weighted according to task frequency. The Recommended Weight Limit for the entire job (collective effect of all tasks) was obtained by multiplying the frequency weighted RWL with a frequency multiplier corresponding to the sum of all task frequencies. The RWL for the entire job was compared with the frequency weighted average weight for tasks. Detailed analyses showed that this approach worked well in most cases. However, in certain situations LI for a single task was higher than the LI for the collective effect of all tasks. In other words, the analysis showed that in some situations, it is easier to perform the entire job than only part of it (i.e., one of the tasks).

As an example, consider two tasks: task 1 with H = 20, V = 0, D =30, A = 0, C = fair, F = 1 and weight = 25 lbs; and task 2 with H = 10, V = 30, D = 10, A = 0, C = fair, F = 3, and weight = 25 lbs. The Lifting Indexes for task 1 and task 2 are 2.0 and 0.89, respectively. The Lifting Index for the entire job is 1.31.

Recommended method

It became clear that there are major problems with averaging task variables or Recommended Weight Limits to determine the collective effect of different lifting tasks. Therefore, a new concept was introduced to analyze multiple tasks. This approach is based upon the following assumptions.

1. Performance of an additional lifting task results in an increase in Lifting Index (physical stress).
2. The increase in Lifting Index depends upon the characteristics of the additional lifting task.
3. The increase in Lifting Index is independent of the existing Lifting Index, i.e., Lifting Index due to tasks already being performed.

Obviously, the third assumption is questionable because it ignores potential interaction, if any, between two lifting tasks. However, the nature of this interaction is not known. It is assumed that this effect is minimal. While not perfect, this appears to be a reasonable approach to analyze collective effects of multiple tasks. Certainly, those who are interested in more precise analysis can use energy expenditure models, strength data and/or biomechanical models.

The new method is based on the concept that the Composite Lifting Index (CLI), which represents the collective demands of the job, is equal to the sum of the largest Single Task Lifting Index (STLI) and the incremental increases in the CLI as each subsequent task is added to the job. The incremental increase in the CLI for a specific task is defined as the difference between the LI for that at the cumulative frequency and the LI for that task at a frequency equal to cumulative frequency minus the task frequency.

As an example, first consider two identical tasks (A and B), each with a lifting frequency of 1 lift/min. Using this approach:

$$CLI = LI_{A,1} + (LI_{B,2} - LI_{B,1})$$

Since tasks A and B are identical, $LI_{A,1}$ and $LI_{B,1}$ cancel out and CLI = $LI_{B,2}$.

In other words, as expected, CLI for the entire job is the Lifting Index for the simple task being performed 2 times/min. Now, if the two tasks are different, then CLI = $LI_{A,1} + (LI_{B,2} - LI_{B,1})$. In this Lifting Indexes do not cancel out. $LI_{A,1}$ refers to the stress from performing task A. Addition of task B results in an increment of stress. This incremental stress is equal to the increase in stress when the frequency for task B is increased from 1 (corresponding to frequency for task A) to 2 (total frequency for all tasks).

MULTI-TASK PROCEDURE

Three different analyses are recommended for jobs with multiple tasks. These are:

(1) Frequency-Independent Recommended Weight Limit and Lifting Index (FIRWL and FILI) for each task.

(2) Single-Task Recommended Weight Limit and Lifting Index (STRWL and STLI) for each task.

(3) Composite Lifting Index (CLI) for the overall job.

FIRWL and FILI

FIRWL for each task is computed by using the respective task variables and setting the Frequency Multiplier (FM) to a value of 1.0. FIRWL reflects the compressive force and muscle strength demands from a single repetition of that task. The FILI is computed for each task by dividing the maximum weight (L) for that task by the corresponding FIRWL. Thus, FILI answers the question if it is safe to perform the task even once.

STRWL and STLI

STRWL for each task is computed by multiplying its FIRWL by its appropriate Frequency Multiplier (FM). The STRWL for a task reflects the overall demands of that task, assuming it was the only task being performed. The STLI is computed for each task by dividing the average weight (L) for that task by the corresponding STRWL. The STLI answers the question if it is safe to perform just this task, even if other tasks were not present in the job. The STLIs can be used to determine (i) which individual tasks in the job require excessive physical demands and (ii) to prioritize the individual tasks for ergonomic changes according to the magnitude of their physical stress.

Composite Lifting Index (CLI)

The CLI reflects the collective effects of all tasks. The CLI is computed as follows:

(i) The tasks are renumbered in order of decreasing physical stress, beginning with the task with the greatest STLI down to the task with the smallest STLI.

(ii) The CLI for the job is computed according to the following formula

$$CLI = STLI_1 + \sum \Delta LI \tag{1}$$

where

$$\sum \Delta LI = \left(FILI_2 \times \left(\frac{1}{FM_{1,2}} - \frac{1}{FM_1}\right)\right)$$
$$+ \left(FILI_3 \times \left(\frac{1}{FM_{1,2,3}} - \frac{1}{FM_{1,2}}\right)\right)$$
$$+ \left(FILI_4 \times \left(\frac{1}{FM_{1,2,3,4}} - \frac{1}{FM_{1,2,3}}\right)\right)$$
$$\vdots$$
$$+ \left(FILI_n \times \left(\frac{1}{FM_{1,2,3,4\ldots,n}} - \frac{1}{FM_{1,2,3,\ldots,(n-1)}}\right)\right)$$

Note that (1) the numbers in the subscripts refer to the new task numbers; and, (2) the FM values are determined based on the sum of the frequencies for the tasks listed in the subscripts.

Example

The following example from Waters et al. (1994) demonstrates the computation of CLI. Assume that an analysis of a job with three tasks provided the following results:

Task #	Object Weight (L)	Task Frequency (F)	FM	FIRWL	FILI	STRWL	STLI	New Task #
1	30	1	0.94	20	1.5	18.8	1.6	1
2	20	2	0.91	20	1.0	18.2	1.1	2
3	10	4	0.84	15	0.67	12.6	0.8	3

The tasks were renumbered based on STLI. In this case, the task numbers do not change. Then using the formula in equation (1):

$$CLI = 1.6 + 1.0\left(\frac{1}{0.88} - \frac{1}{0.94}\right) + 0.67\left(\frac{1}{0.70} - \frac{1}{0.88}\right)$$

$$= 1.6 + 0.07 + 0.20 = 1.9$$

where 0.88, 0.94 and 0.70 are the frequency multipliers corresponding to frequencies of 3, 1 and 7, respectively. The sum of frequencies for tasks 1 and 2 is 3 (or 1 + 2), and the sum of frequencies for tasks 1, 2, and 3 is 7 (or 1 + 2 + 4). To start with, the LI for the job is 1.6, which is the maximum STLI from the three tasks. The addition of task 2 increases the LI for the job by 0.07. The addition of task 3 to the job results in a further increase in the LI for the job of 0.20.

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ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY

ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY VI

Proceedings of the Annual International
Industrial Ergonomics and Safety Conference
held in San Antonio, Texas, USA, 7–10 June 1994

The Official Conference of the International Foundation
for Industrial Ergonomics and Safety Research

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Taylor & Francis
Publishers since 1798

UK	**Taylor & Francis Ltd, 4 John St, London WC1N 2ET**
USA	**Taylor & Francis Inc., 1900 Frost Road, Suite 101, Bristol, PA 19007**

A catalogue record for this book is available from the British Library

ISBN 0-7484-0085-0

Library of Congress Cataloging-in-Publication Data are available

Printed in Great Britain by Burgess Science Press, Basingstoke.