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Comparison of the Revised NIOSH Equation and Different Ergonomic Approaches to Determine the Maximum Weight of Lift
최대 허용작업중량의 결정에 대한 인간공학적 접근방법들의 비교 연구

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ABSTRACT

The purpose of this study was two-fold : (1) to investigate the difference between the lifting capacities based on three different ergonomic approaches; a) the biomechanical, b) the physiological, and c) the psychophysical approach, and the 1991 revised NIOSH Equation, and (2) to develop a comprehensive model for determining maximum weight of lift.

INTRODUCTION

Within the area of ergonomics, three approaches have been used extensively in the past to determine the safe or permissible load for occasional and repetitive lifting. These approaches are : (1) the biomechanical approach which utilizes the compressive forces on the spine as a criterion, (2) the physiological approach which utilizes the energy expenditure requirements as a criterion, and (3) the psychophysical approach which utilizes the perceived exertion by the subjects for determining the maximum weight to be lifted given certain job conditions.

Most of the proposed limits on lifting are based on a single criterion and consider only a single stress response of the worker to a manual lifting task. The biomechanical approach tends to minimize the stresses on the low-back by selecting smaller weight and more frequent rate of lifts. The physiological approach on the other hand tends to minimize the metabolic energy expenditure by selecting larger weight, less frequent rate of lifts.

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For infrequent lifting, the maximum acceptable weights of the load based on biomechanical criteria are generally higher than those based on the psychophysical criteria. For repetitive lifting, those based on psychophysical criteria are lower at low frequencies and higher at high frequencies than those based on physiological criteria(Karwowski, 1982). However, human performance depends on the intensity of physical work load with respect to several different responses simultaneously. It is important to consider the biomechanical stress, the physiological stress and the psychophysical perceived stress simultaneously in establishing load lifting limits(Kim, 1990).

The 1981 NIOSH Guidelines are based on two limits:an Action Limit(AL), and a Maximum Permissible Limit(MPL). The AL can be lifred by "almost everyange," with limits of 3.43kN, 3.5kcal/min. This is a limit at which "about 75% of women and 99% of men" of the population can perform safely. The MPL is the level that only a "few" can lift with limits of 6.37kN, 5.0kcal/min. This is a limit at which "about 25% of men and less than 1% of women" of the population are accommodated(NIOSH, 1981).

The 1991 NIOSH guide(Ayoub, through personal communication, 1992;Waters, 1993) has attempted to reduce discrepancies in safe limit between different approaches by modifying several factors in the 1981 guide. The most significant changes are in the ideal weight which is reduced from 40kg to 23kg, the frequency factor, and the horizontal factor. The 1991 guide provides new methods for evaluating asymmetrical lifting tasks, lifts of objects with less than optimal container couplings, and guidelines for a larger range of work durations and lifting frequencies than the 1981 guide.

The 1991 committee chose the simpler and older model to develop the biomechancal compressive force criterion, because of lacked data linking the predicted dynamic compressive force to the observed incidence of lifting-related low back pain.

In order to determine energy expenditure limits for repetitive lifting, the committee reduced the baseline aerobic capacity from the value of 10.5 kcal/min to 9.5kcal/min(90% of the 10.5kcal/min) to adjust for the difference between treadmill data and data collected from manual lifting studies. Petrofsky and Lind(1978a, b) indicated that the maximum aerobic capacity determined by lifting was 81% of the maximum aerobic capacity determined by the bicycle ergometer. The committee recommended a 30% reduction in the energy expenditure limit of 9.5kcal/min for lifting activities involving primarily the upper body(i.e. V>75cm). To adjust energy expenditure values for the aerobic demands posed by different durations of repetitive lifting tasks, the committee provided the choice of three percentages(50%, 40%, and 33%) of baseline maximum aerobic lifting capacity for lifting tasks lasting 1 hour, 1 to 2 hours, 2 to 8 hours, respectively(Waters, 1993).

Little research has been conducted to study the three different approaches simultaneously. When comparing the approaches, investigators usually made comparisons using the different studies carried out by different investigators. These studies used different subject samples, experimental procedures, environmental conditions, instruction, etc. Therefore, one may expect discrepancies when comparing the three different approaches. In establishing safe lifting limits, one possibility is to consider these apprcaches simultaneously and select the lowest weight recommendation from these approaches. Therefore, depending on the task variables, a certain design criterion(approach) can be limiting and therefore, should be used to determine the load limit(Kim, 1990).

METHODS

The comprehensive model, the ultimate goal of this study results from integrating the compressive force model, the energy expenditure model, and the psychophysical maximum acceptable weight of lift(MAWL) model. The load limit for lifting will be the minimum load weight among (1) the load weight given a compressive force limit, (2) the load weight given an energy expenditure limit, and (3) the load weight using the psychophysical approach at the given task variables of (a) frequency of lift, and (b) range of lift.

The height levels of lift selected for this study were:(1) Floor to Knuckle(FK), (2) Knuckle to Shoulder(KS), and Floor to Shoulder(FS). Six different levels of frequency;0.1, 0.25, 2, 5, 8, and 11 lifts/min were used. More detailed experimental procedure can be found in Kim(1990).

RESULTS AND DISCUSSION

Regression analyses showed that most of the variation in the oxygen consumption rate of a lifting activity can be explained by the first order interactions of body

Table 1. Prediction Equations for Estimating the Oxygen Consumption Rate, the Maximum Compressive Force on L5/S1, and the Psychophysical MAWL.

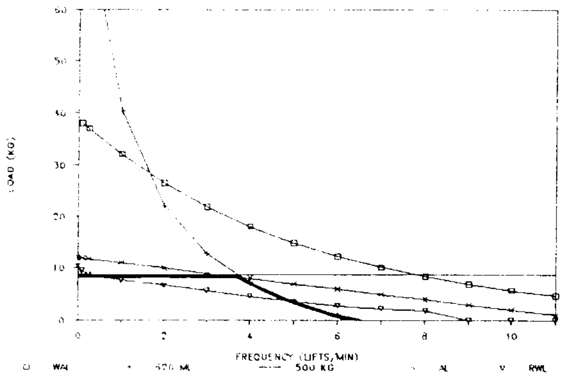
RANGE	VO2, COMP, and MAWL Models
FK	VO2 = 3.8941*B+0.5211*F*B+3.0072*L+3.0577*F*L COMP = 4.6153*B+12.2923*L MAWL =48.2582*EXP(-0.1586*F)
FS	VO2 = 5.7152*B+0.3087*F*B+0.1976*L+5.2392*F*L COMP = 4.8600*B+10.6654*L MAWL =43.2403*EXP(-0.1802*F)
KS	VO2 = 3.7471*B+0.1896*F*B+3.7880*L+3.1313*F*L COMP = 2.8119*B+14.6556*L MAWL =37.2841*EXP(-0.1454*F)
	VO2 = Oxygen Consumption Rate(ml/min) COMP = Maximum Compressive Force on L5/S1(kg) MAWL =Psychophysical MAWL(kg) B = Body Weight(kg) F = Frequency of lift(lifts/min) L = Weight of Load(kg)

weight and weight of load with the frequency of the task. Main effects themselves were found to be of little importance in explaining the variation in the oxygen consumption rate. However, the maximum compressive forces on L5/S1 can be explained by only two main effects, body weight and weight of the load. Prediction equations for estimating the oxygen consumption rate, the maximum compressive force, and psychophysical MAWL are shown in Table 1.

Using the developed equations and the 1991 NIOSH biomechanical and physiological RWL limits(3.43kN and 2.2~3.1kcal/min), the biomechanical limit of 3.43kN does not appear to be realistic for the range of FK and FS lifting. However, for the range of KS, the biomechanical RWL criterion(3.43kN) is limiting up to 2 lifts/min.

Actual oxygen consumption rate and the maximum compressive force on L5/S1 at MAWL were compared with the RWL criteria. With higher than 1.2, 0.7, and 0.25 lifts/min for the lifting range of FK, FS, and KS, respectively, the oxygen consumption rate was over the RWL criterion (3.1kcal/min for FK, FS, 2.2kcal/min for KS). However, all the compressive forces at the MAWL were higher than the RWL criterion(3.43kN). Because the psychophysical approach relies on self-reporting from subjects, the perceived 'maximum acceptable' limit, MAWL, may differ from the actual 'safe' limit, even though there is a relationship between the 'maximum acceptable' and the 'safe' limit.

It was reported that the estimated compressive force values for the dynamic models ranged from 19% to 200% greater than the static model predictions(references can be found in Waters, 1993). The average dynamic maximum compressive force ranged from 4 to 40% higher than the static maximum compressive force for the same task for this study.



WAL = Weight of Load(kg) from the Psychophysical Model for RWL criterion(99% Male Population)

620ML = Weight of Load(kg) from the Physiological Model for RWL criterion for FK, and FS (3.1kcal/min)

500KG = Weight of Load(kg) from the Biomechanical Model for raised RWL criterion(4.90kN L5/S1 Compressive Force)

AL = Weight of Load(kg) from the 1981 NIOSH AL equation

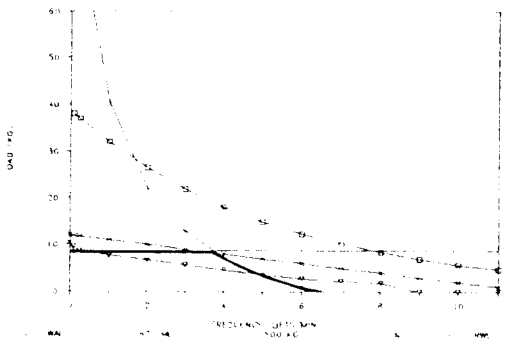
RWL = Weight of Load(kg) from the 1991 NIOSH RWL equation

Figure 1. Comprehensive Model for Maximum Weight of Load for FK Lifting.

For illustrative purposes, to include the effect of acceleration in dynamic lift, if the biomechanical RWL criteria were raised to 4.90kN(40% higher than 3.43kN), then the raised biomechanical RWL criterion would be limiting up to 4 lifts/min for the range of FK. The physiological approach would be limiting after 4 lifts/min. However, the maximum frequency suggested by this physiological approach would be 6.5 lifts/min(Figure 1).

With the raised biomechanical RWL criterion, the biomechanical approach would be limiting up to 2 lifts/min, and the physiological approach would be limiting above the 2 lifts/min for the range of FS. However, the maximum frequency suggested by the physiological approach would be 5 lifts/min, at which the body movement alone would require a metabolic energy rate of 3.1 kcal/min for the range of FS(Figure 2).

For the range of KS, the biomechanical criterion would be limiting up to 1 lift/min



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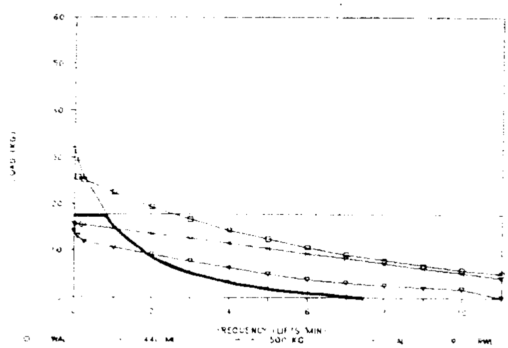
RWL =Weight of Load(kg) from the 1991 NIOSH RWL equation

Figure 2. Comprehensive Model for Maximum Weight of Load for FS Lifting.



WAL =Weight of Load(kg) from the Psychophysical Model for RWL criterion(99% Male Population)

620ML=Weight of Load(kg) from the Physiological Model for RWL criterion for FK, and FS (3.1kcal/min)

500KG=Weight of Load(kg) from the Biomechanical Model for raised RWL criterion(4.90kN L5/S1 Compressive Force)

AL =Weight of Load(kg) from the 1981 NIOSH AL equation

RWL =Weight of Load(kg) from the 1991 NIOSH RWL equation

Figure 3. Comprehensive Model for Maximum Weight of Load for FS Lifting.

after which the physiological approach would be limiting. However, the maximum frequency suggested by the physiological approach would be 7.5lifts/min(Figure 3).

CONCLUSIONS

The biomechanical approach is limiting at the frequency, 4, 2, 1 lifts/min, respectively, for the ragne of FK, FS, and KS. After then, the physiological approach is limiting for all the three different lifting ranges. The psychophysical approach is not limiting at all for the three different lifting ranges for this study. The psychophysical method in its present form may not be adequate for use in establishing lifting limits. However, more studies are needed to verify this conclusion.

Lifting is a task of an extremely complex nature, so it cannot be fully described or explained using only of one of the different approaches. All three, among others, are present in every lifting task and, as such, the need exists for a means of determining lifting limits which consider the three stresses simultaneously as well as all the significant interactive effects of the task variables(Kim, 1990).

Based on the results of this study, it appears that the 1991 NIOSH biomechanical criterion should be reexamined and the effects of dynamic lifting should be considered. It is also suggested that the physiological criterion of the 1991 NIOSH guide should include the effect of frequency of repetitive lifting tasks.

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