PHYSICAL FATIGUE AND STRESSES IN WAREHOUSE OPERATIONS

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CONTENTS

Abstract ii

List of Illustrations v

List of Tables vii

Acknowledgement viii

Chapter 1: PHYSIOLOGICAL BASIS FOR JOB EVALUATION 1

Introduction 1
Motion and Time Study and Predetermined Motion-Time Systems 3
Metabolic Energy Expenditure and Heart Rate 4
Work Capacity Limits Based on Energy Expenditure 5
Working Time Prediction 10
Heart Rate Criteria 11
Heart Rate Recovery Criteria 16

Chapter 2: PHYSIOLOGICAL EVALUATION 17

Job of a Dry Grocery Order Selector 17
Subjects 18
Method 20
Results 29
Discussion 62
Conclusion 65

Chapter 3: BIOMECHANICAL AND ERGONOMIC EVALUATION 65

Biomechanical Evaluation 65
Ergonomic Evaluation 70

Chapter 4: SUMMARY OF RESULTS AND RECOMMENDATIONS 85

Conclusions 85
Recommendations 87

References 91

Appendix 96

ABSTRACT

The objective of this research was to study the physiological and biomechanical stresses to grocery order selectors. In particular, the objectives were to (i) determine the metabolic energy expenditure rate and heart rate at 100 percent performance level as established by traditional work measurement techniques, (ii) identify stressful work postures and motions, and (iii) perform a biomechanical analysis of selected task elements.

Sixty-three male and six female workers from three different warehouses participated in the study. Oxygen uptake and heart rate were continuously recorded while the subjects performed their routine work. The duration of the experiment ranged from 12 to 64.6 min (average duration = 34 min) depending upon the size of the order and pace of the worker. The major findings were:

* The average performance levels (allowed time per order/actual time per order *100) of male workers in warehouses 1, 2 and 3 were 118.8, 111.3 and 97.6% and the corresponding average metabolic rates were 6.16, 5.96 and 8.35 Kcal/min and the average heart rates were 110, 122 and 133 beats/min in warehouses 1, 2 and 3, respectively.
* 14, 25 and 54% of the male workers in warehouses 1, 2 and 3, respectively, reached a peak heart rate of 154 to 181 beats/min.
* Heart rate recovery curves showed that 24, 70 and 86% of the male workers in warehouses 1, 2 and 3 experienced excessive fatigue.
* The average energy expenditure and heart rate for six female workers from the three different warehouses were significantly higher than the acceptable limits. Heart rate

recovery data showed that all six females experienced excessive fatigue.

* 24, 30 and 64% of the male workers failed to meet the 100% performance index (standard output as determined by the traditional work measurement techniques) in warehouses 1, 2 and 3, respectively, while their average energy expenditure rates were 6.34, 5.44 and 8.37 Kcal/min and their average heart rates were 110, 115 and 133 beats/min. Similarly, 33% of the females failed to meet 100% performance while their average metabolic rate was 5.63 Kcal/min and the average heart rate was 161 beats/min.
* Biomechanical job evaluation showed that at least one out of three male industrial workers and three out of four female industrial workers do not have sufficient strength to perform certain tasks even occasionally without overexerting themselves. The estimated compressive force on the L5/S1 disc for the selected tasks ranged from 411 to 658 kg.
* Ergonomic evaluation showed that the racks were either too high or too low. The order selectors are required to lift heavy and bulky loads to a vertical height which exceeds the reach limit for most people and at a horizontal distance which is close to the functional reach limit.

Performance standards or time standards based on Time and Motion Study, Methods Time Measurement and Master Standard Data Systems were found to be physiologically unacceptable. There was no significant correlation between energy expenditure and performance index and heart rate and performance index in two out of the three warehouses studied. In terms of the physiological

cost of work there were inconsistencies within a warehouse and large differences between warehouses. It is believed that if the existing performance standards are enforced without providing significantly greater fatigue allowances, a significant number of workers may not be able to meet these standards as they might be working close to their maximal working capacity for this type of work. Physiological, biomechanical and ergonomic requirements of the order selector's job are discussed.

LIST OF ILLUSTRATIONS

Figure 1.1: Estimated Population Aerobic Capacities for U. S. Men and Women 6

Figure 1.2: Physical Work Capacity and Working Time 12

Figure 1.3: Relationship between Heart Rate During Work (Bicycle Ergometer) and Oxygen Uptake Expressed in Percentage of Subject's Maximal Aerobic Power 13

Figure 2.1: The New RPE (Rating Scale of Perceived Exertion) 22

Figure 2.2: Calibration of Oxylog against Beckman OM-11 26

Figure 2.3: Comparison of Expected Cases, Weight and Volume per Minute at 100% Performance from the Three Warehouses . . . 37

Figure 2.4: Relationship Between Energy Expenditure and Performance Index for the Sixty-three Male Workers Studied 50

Figure 2.5: Relationship Between Heart Rate and Performance Index for the Sixty-Three Male Workers Studied 51

Figure 2.6: Relationship Between Energy Expenditure and Heart Rate for the Sixty-Three Male Workers Studied 53

Figure 2.7: Comparison of Actual Cases, Weight and Volume Lifted per Minute by the Male Subjects from the Three Warehouses 55

Figure 2.8: Comparison of Performance Indices and Heart Rates of Male Workers from the Three Warehouses 57

Figure 2.9: Comparison of Energy Expenditure Rates of Male Workers from the Three Warehouses 58

Figure 2.10: Physical Difficulty of the Order Selector's Job as Perceived by the Male Subjects from the Three Warehouses 60

Figure 2.11: Heart Rate Against Time for a Typical Male Worker Working at Close to 100% Performance Level from the Three Warehouses 61

Figure 3.1: Examples of Picking a Load from a Walk In Slot (Left) and the Bottom Slot of a Two-Slot Configuration (Right) 72

Figure 3.2: Examples of Picking a Load from the Top Slot of a Three-Slot Configuration. Figure on the Right Shows a Step Used for Climbing 74

Figure 3.3: An Example of a Three-Slot Configuration (Top) and Body Posture Used to Pick Up a Load from the Bottom Slot (Bottom) 75

Figure 3.4: Examples of Picking a load from the Top Slot of a Two-Slot Configuration 77

Figure 3.5: Examples of Heavy Loads Stored Above Shoulder Height (Left) and Excessive Reaches Required (Right) 79

Figure 3.6: Examples of Over-Head Reach Required. Left: Picking a Load from the Top Slot of a Two-Slot Configuration. Right: Setting a Load on the Pallet Jack 80

Figure 3.7: Examples of Congestion in an Aisle. Left: A Worker has to Squeeze in Between the Racks and the Pallet Jack. Right: A Worker Waiting for the Selectors Ahead of him to Finish Picking 82

LIST OF TABLES

Table 1.1:	Heart Rates for Males at 50% Aerobic Work Capacity	15
Table 2.1:	Summary of Age, Body Weight and Height for Sixty-Nine Subjects Studied	19
Table 2.2:	Illumination Level, Dry Bulb, Wet Bulb Temperature and Relative Humidity in the Three Warehouses Studied . .	28
Table 2.3:	Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty Male Workers Studied in Warehouse 1	30
Table 2.4:	Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty Male Workers Studied in Warehouse 2	31
Table 2.5:	Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty-Two Male Workers Studied in Warehouse 3 . . .	32
Table 2.6:	Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from the Six Female Workers Studied in the Three Different Warehouses	33
Table 2.7:	Recovery Heart Rates for the Sixty-Three Male Workers Studied from the Three Different Warehouses	34
Table 2.8:	Recovery Heart Rates for the Six Female Workers Studied from the Three Different Warehouses	35
Table 2.9:	Recommended Additional Fatigue Allowances for the Three Warehouses	48
Table 3.1:	Biomechanical Analysis of Selected Order Selection Tasks	66
Table 3.2:	Maximum Voluntary Isometric Strength as a Function of Vertical and Horizontal Location of Hands	69

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CHAPTER 1

PHYSIOLOGICAL BASIS FOR JOB EVALUATION

INTRODUCTION

Manual materials handling is a major hazard to workers. In 1973, the state of California reported 27 percent of all compensable injury and illness was due to overexertion (National Safety Council, 1975). The state of Wisconsin reported that overexertion injury and illness claims have doubled in the last six years totaling 14,411 claims in 1977 (Workmen's Compensation Division, 1978). In an analysis of occupational injuries and illnesses for Wisconsin Grocery and Related Products - Wholesale Industry (1972-1976), the state of Wisconsin reported that 31 percent of the claims resulted in dislocation or hernia, strains and sprains to the back and trunk from lifting and lowering containers and boxes. These cases accounted for 33 percent of the compensation costs in the industry. The job category of warehousemen was the occupation most frequently cited with regard to these injuries. Thus, there is substantial evidence that overexertion in grocery warehouse operations is a significant problem.

To achieve higher productivity, many grocery companies with warehouse operations require workers to meet production or time standards. These standards are based on motion and time study or predetermined motion-time data systems. The objective of work study techniques is to eliminate waste and inefficiency. Improved work methods enable the worker to produce more with the same effort. Time standards let a worker know what a standard day's work is. However, most of the predetermined motion-time data systems were originally developed in the manufacturing sector for determining time standards for bench or assembly type of operations, i.e., for jobs which were highly repetitive and more sedentary in nature. On the other hand wholesale grocery operations, particularly the job of a grocery selector, are highly non-repetitive and physically demanding. Thus, there is some concern that the production standards based on traditional industrial engineering techniques may not be applicable to order selection.

For physical work, especially involving whole body exertion, several studies have demonstrated that work standards based on traditional time study techniques (motion and time study, predetermined motion-time data systems) are not always consistent with the physiological needs of the workers (Aquilano, 1968; Wyndhem et al., 1966; Moores 1970; Garg, 1979). Little research has been done to determine whether work loads based on traditional motion and time study techniques are appropriate for the kind of physically stressful work which exists in grocery warehouses. In connection with a dispute over a production standard system installed in a grocery warehouse in Denver, Colorado, Karnes (1979) concluded, from a review of the literature on the Methods Time Measurement System, that predetermined motion-time systems are neither scientific, accurate nor universally applicable. According to Davis et al. (1969): "It is practically impossible to estimate accurately the difficulty of a job by merely observing it. The number of task factors that have a bearing on task difficulty is very large. . . .The only practical approach is the measurement of the individual's physiological response to this specific complex of factors. . . .Perceptions about the difficulty of jobs or about the relative importance of components of jobs are frequently inaccurate." This is reflected in the following statement by Barnes (1980): "At the present time there is no satisfactory way of measuring fatigue. Physiological measurement promise to provide objective means of determining the time and duration of periods of work and rest during the day."

The primary objective of this study was to study the physiological and biomechanical stresses to the wholesale grocery order selectors. The following were the specific objectives:

(i) To determine the effects of daily work rates on cardiovascular responses and metabolic energy expenditure of order selectors.

(ii) To identify stressful work postures and motions by performing an ergonomic study of representative task elements of order selecting.

(iii) To perform a biomechanical analysis of selected task elements of order selecting to determine stresses to the musculoskeletal system and, in particular, low back.

MOTION AND TIME STUDY AND PREDETERMINED MOTION-TIME SYSTEMS

Conventionally, time standards for a job are set by determining a normal time through time study, predetermined motion-time data, or work sampling, etc. Allowances are added to normal time for personal time, fatigue, unavoidable delays and other factors to set standard time. The advantage of such an approach is that it is simple and can be understood and applied with minimal formal training.

However, the major problem with this method is that both the rating of the job and relaxation allowances are primarily subjective. As stated by Whitmore (1975), "The term 'work measurement' itself may be regarded as a misnomer, because in fact it is time which is measured rather than work in the mechanical or physiological sense. It may be better to regard work measurement as determining the time required to perform a task; the time being modified by the energy expenditure, which is compensated for by the addition of fatigue allowance."

Predetermined motion-time systems (PMTS) do not require analysts' ratings as they are performance rated using specific rating systems. However, there are several sources of error in PMTS essentially originating from two sources: the nature of the system, and the application of the system. Some of these sources include discreteness of data, assumption of flawless performance, unquantified variables, judgement of analyst, inappropriate application, etc. (Smith, 1978). Since each PMTS was developed in a specific context, there are certain tasks which are not suited to the system. Some systems may not be applicable to heavy work while others may not handle intricate, manipulative work well. Also, length of the cycle is important. Micro-data applied to long cycle activities will accumulate large errors (Smith, 1978).

METABOLIC ENERGY EXPENDITURE AND HEART RATE

During the performance of a work task, especially if it involves moderate to strenuous exertion, physiological changes take place within the body. Work physiology has as its premise that the measurement of certain of these changes provides indices of the level of stress imposed upon the worker. Alterations in work method, performance levels, or certain environmental factors, etc., are reflected in the stress levels of the worker and may be evaluated by physiological methods.

So far as physiological measurements made during manual materials handling tasks are concerned, the preponderance of available data in the literature pertains to steady state heart rate and/or metabolic energy expenditure rate responses. These are also the most widely accepted and reliable indicators of the level of physiological demands.

In repetitive lifting and load carrying, large muscle groups (the extensors of the legs and back) perform submaximal, dynamic contractions. During this type of work a subject's endurance is primarily limited by the capacity of the oxygen transporting and utilization systems-maximum aerobic power (Astrand and Rodahl, 1977; Chaffin, 1972). As reported by Bink (1962), Wyndham et al. (1966), Chaffin (1972), etc., by relating the energy expended in a task to the aerobic power of the individual for endurance effort, an objective assessment can be made of the work capacity of the worker for carrying out the industrial task in question without excessive fatigue.

WORK CAPACITY LIMITS BASED ON ENERGY EXPENDITURE

Figure 1.1 gives the aerobic capacity for American male and female workers as a function of age as estimated by Chaffin (1972). Cross-sectional population distributions summarized by Cummings (1967) conform to these data. A study by Rodahl and Issekutz (1962) of American policemen, however, indicates that persons having relatively sedentary jobs would have lower aerobic capacities than expected from Figure 1.1. As a result, Chaffin (1972) estimated that probably 80 percent or more of American men have an aerobic capacity below 16 Kcal/min. Kamon and Ramanathan (1974) estimated the maximum aerobic power for an average 35-year-old male worker to be less than 15 Kcal/min. According to the American Heart Association (1972), the maximal aerobic capacity for men of 30 to 39 years of age is 8 to 10.5 Kcal/min. for people in a fair cardiorespiratory fitness classification, 11 to 13.3

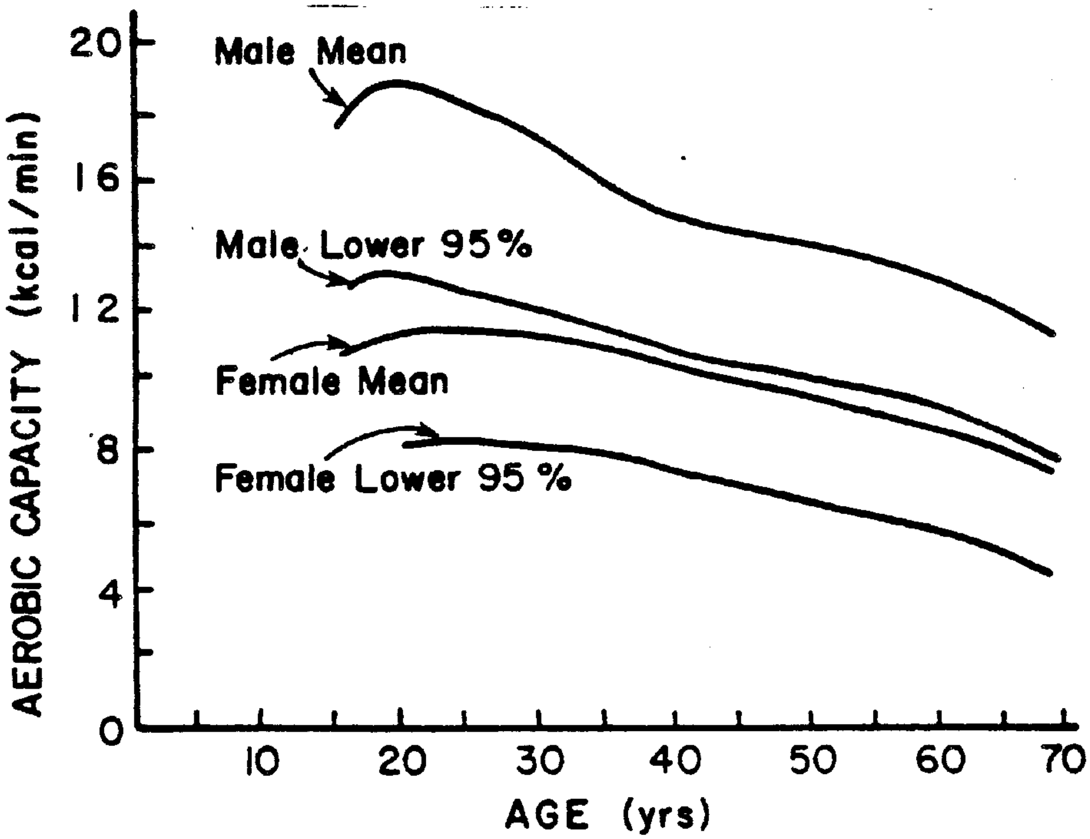

Figure 1.1: Estimated Population Aerobic Capacities for U.S. Men and Women (Chaffin, 1972).

Kcal/min. for people in an average classification and 13.6 to 16.8 Kcal/min. for people in a good classification. Work Practices Guide for Manual Lifting (U.S. Department of Health and Human Services, 1981) uses an aerobic power of 15 Kcal/min. The recommendations provided later in this report are based on an assumed aerobic capacity of 15 Kcal/min for men and 10.5 Kcal/min (70% of men) for women. These limits may be too high, however, for older workers.

Christensen (1955) proposed that work could be performed at 50 percent of the maximum aerobic power for an eight-hour workday. Serious doubts were expressed by Astrand (1960) that this was too high an expectation. She observed that at this rate the older subject would have incurred a heart rate increase of 30 beats/min in the first hour of work. As stated by Chaffin (1972), research by Brouha (1960) also lent credence to the theory that an eight-hour work capacity limit based on 50 percent of the maximum aerobic power of an individual was a fatigue-generating energy expenditure rate. Based on a recent study, Evans et al. (1980) concluded that 45% of maximal aerobic power appears to be the best predictor for self-paced hard work for <u>one to two hours</u> in duration. Astrand (1967), based on a study of bricklayers, carpenters, and laborers, suggested an average relative load of 40 percent of maximum aerobic power as the maximum work load that can be continuously performed without accumulating excessive amounts of fatigue. However, Lind and Petrofsky (1977) concluded that Astrand's estimate of 40% $\dot{V}O_{2max}$ may be an overestimate. Studies by Michael et al. (1961), Bink (1964) and Andrews (1969), etc., recommend 33 percent of the maximum aerobic power of a normal healthy person as the maximum energy expenditure rate that should be expended for an eight-hour workday. Assuming 15 Kcal/min for the maximum aerobic power, this translates into a physical work capacity limit of 5.0 Kcal/min for an eight-hour workday.

Recently, Petrofsky and Lind (1978) showed that each type of task has its own maximum aerobic capacity level. This is determined primarily by the number of muscles available for the work. These authors showed that the $\dot{V}O_{2max}$ for lifting (bent back method) was substantially lower than the $\dot{V}O_{2max}$ for bicycle ergometer. For example, the values of $\dot{V}O_{2max}$ for lifting 0.91, 6.82, 22.73 and 36.36 kg of loads were 54, 64, 75 and 80 percent, respectively, of that for bicycling. Thus, the average $\dot{V}O_{2max}$ for lifting was 68 percent of the $\dot{V}O_{2max}$ for bicycle ergometer. Similarly, at the maximal working capacitites during lifting, the highest heart rates were directly related to the weight being lifted. The highest heart rates for lifting 0.91, 6.82, 22.73 and 36.36 kg of loads were 144, 160, 164 and 182 beats/min, respectively, as compared to the maximum heart rate of 187 beats/min for bicycling.

Petrofsky and Lind (1978), based on the evidence from oxygen uptake, heart rate and arterial lactate, concluded that a work rate equivalent to 50 percent of maximum oxygen uptake for the given weight of the box could be maintained without incurring excessive fatigue. In other words, for lifting and lowering of loads, one may experience significant fatigue at levels as low as 27 percent of the $\dot{V}O_{2max}$ established on the bicycle ergometer to as high as 40 percent of $\dot{V}O_{2max}$ for bicycling, depending upon the weight of the load.

In industrial work there is the additional problem of static muscular effort (posture maintenance and holding of work loads) which reduces blood flow. This would indicate that aerobic capacities for this type of work would in general be lower compared to the dynamic capacities assumed in the above studies (Lind et al., 1979; Williams et al., 1980).

Based on a more recent study, Rodgers (1978) supported a 33 percent of maximum aerobic power in concluding: "We have observed that most people will select a level of effort that keeps them within the 33% of maximum capacity guideline and will also integrate other factors such as: biomechanical aspects, environmental characteristics, individual's physical fitness level, individual's skill level, individual's outside activities, etc."

Ergonomics Guides (AIHA Technical Committee, 1971) suggest 5.5 Kcal/min as an upper limit for an eight-hour shift. Studies by Lehmann (1958), Bink (1962, 1964), Barnes (1980) and Muller (1953) indicated that a work load of 5 Kcal/min is the maximum energy expenditure rate that should be expected for an eight-hour workday. Passmore and Durnin (1955) state that 5 Kcal/min probably represents the upper rates of energy expenditure that can be maintained regularly in heavy industry. Davis et al. (1969) and Aquilano (1968) used 5 Kcal/min as an acceptable physiological criterion to determine the physical difficulty of the job. Karger and Hancock (1982) recommend a value of 4.4 Kcal/min for 8 hours of continuous work. These authors suggest that if the energy expenditure for the job is greater than 4.4 Kcal/min, then a fatigue allowance should be given to the workers on the job.

Legwork at levels above 5.0 Kcal/min in well-trained individuals has been found to cause increased levels of blood lactate (Ekblom et al., 1968). This is further evidence to indicate that the metabolic demand for oxygen within the muscles is not completely fulfilled when the task is at higher levels than 5.0 Kcal/min. Additional support for using 5 Kcal/min is suggested by Snook and Irvine (1969) and Garg and Saxena (1979). Snook and Irvine (1969) reported that when healthy industrial men were allowed to choose the amount of repeated lifting acceptable for eight hours, they chose a level that resulted in an average metabolic energy expenditure rate of 4.9 Kcal/min. Similarly, Garg and Saxena (1979) reported an average value of 4.6 Kcal/min.

For the purpose of this report, a maximum allowable metabolic energy expenditure rate of 5 Kcal/min is assumed for an 8 hour work duration. However, this limit may be too high for some workers:

(1) There is a gradual decline in maximal aerobic power with age. The maximal aerobic power at age sixty is about 70% of the maximal aerobic power at age twenty (Astrand and Rodahl, 1977).

(2) The maximal aerobic power at any given age for women averages about 70% of that for men (Astrand and Rodahl, 1977).

(3) Industrial work requires static muscular effort (posture maintenance, handling of objects and pushing and pulling of objects with little movement). This would indicate that aerobic capacities for this type of work would in general be lower compared to the dynamic capacities stated earlier in this report.

WORKING TIME PREDICTION

With reference to a normal, healthy, 35-year old working man, three limitations in physical work capacity as a function of working time were proposed by Bink (1962) and Bonjer (1962):

(1) An upper energy work limit of 15 Kcal/min for a working time of four minutes (i.e., aerobic capacity)

(2) An 8-hour continuous work limit of 5.2 Kcal/min.

(3) A 24-hour performance limit of 2.85 Kcal/min based on dietary considerations.

A logarithmic relationship of working time to limiting physical working capacity was proposed by Bink (1962). This relationship, as modified by Chaffin (1972), is expressed by the formula:

$$PWC = \frac{\log 4400 - \log t}{0.187} \times \frac{\text{aerobic capacity}}{16} \qquad (1)$$

where: PWC = Physical work capacity (Kcal/min)

t = time duration (min)

This relationship between physical work capacity and working time for continuous work is shown in Figure 1.2. Acceptable limits for men and women are based on assumed aerobic capacities of 15 and 10.5 Kcal/min, respectively.

HEART RATE CRITERIA

Several investigators have attempted to define continuous work capacity in terms of a heart rate criterion. The heart rate is a function of individual physical fitness, demands of the work, and environmental stress such as due to heat. Although for an individual, heart rate, like metabolic rate, is linearly related to work load, inter-individual differences are larger for heart rate as compared to metabolic rate (Kamon, 1973; Astrand and Rodahl, 1977). Figure 1.3 shows the relationship between heart rate and oxygen uptake (percent of $\dot{V}O_{2max}$).

Morris and Chevalier (1961) stated that a working heart rate of over 130 beats/min was considered excessive. However, Suggs and Splinter (1961) considered 130 beats/min too high for industrial workers and recommended a maximum allowable heart rate of 110 beats/min. In a study relating heart rate

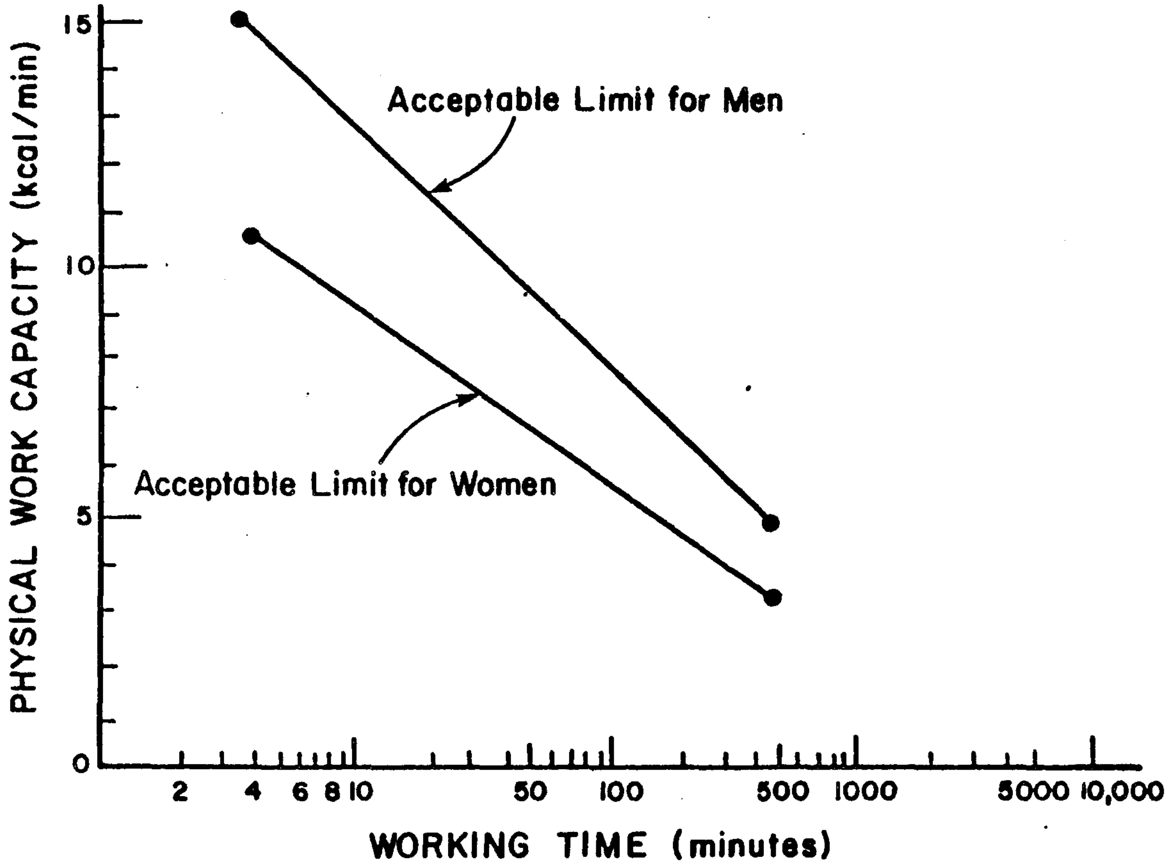

Figure 1.2: Physical Work Capacity and Working Time
(U. S. Department of Health and Human Services, 1981).

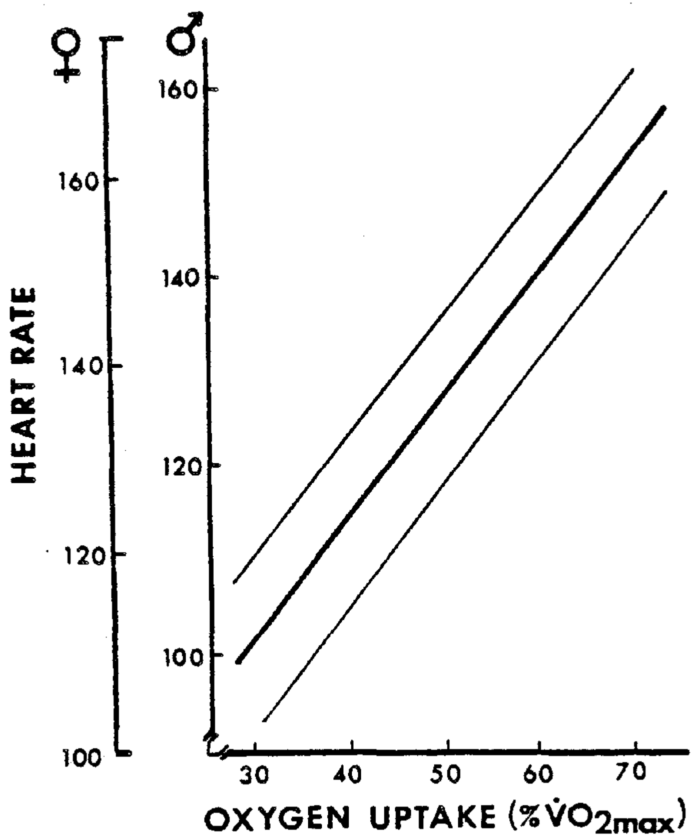

Figure 1.3: Relationship Between Heart Rate During Work (Bicycle Ergometer) and Oxygen Uptake Expressed in Percentage of Subject's Maximal Aerobic Power. Left of Ordinate, Heart Rates of Women; Right of Ordinate, Those of Men (Astrand and Rodahl, 1977).

to blood lactate concentration, Wells, Balke, and Van Fossan (1957) concluded that heart rates of up to 120 beats/min would not cause blood lactate to exceed the normal limits of rest values. However, Luongo (1964) claims that prolonged effort at 120 beats/min may fatigue the circulatory system. Astrand (1960) believes that age is an important variable. Heart rates for males of different ages at 50 percent of their maximum oxygen uptake are listed in Table 1.1.

According to Muller (1961), the limit of continuous performance for men is reached when the average working pulse is 30 beats/min above the resting pulse, both of these being measured in the same posture (for example, both standing up), so that the static loads are the same. This should correspond to a working heart rate of 100 to 110 beats/min, assuming a standing and resting heart rate of 70-80 beats/min. Based on the result of a psychophysical approach to lifting tasks, Snook and Irvine (1969) recommended that the mean heart rate should not exceed 112 beats/min for leg tasks and 99 beats/min for arm tasks. It is worth mentioning that the job of an order selector is a combination of leg and arm tasks.

At 33 percent of maximum aerobic power, heart rate is 105-110 beats/min (see Figure 1.2). Similarly, at 50 percent of maximum aerobic power, heart rate is 120-130 beats/min. According to the AIHA Technical Committee (1971), few men exhibit an average heart rate (including rest periods) higher than 110-120 beats/min during day-to-day employment. A more usual average rate for a physically active worker is 90-100 beats/min. A heart rate of 120-130 beats can be tolerated only for an hour or so, and 140-150 beats/min for ten minutes. According to Karger and Bayha (1977), "Tasks designed to stay within 110 beats/min average level are within the 'fair day's work' range. Also, the

Table 1.1

Heart Rates for Males at 50% Aerobic Work Capacity from Astrand (1960)

Age (yr.)	Number of Subjects	Heart Rate (Beats/Min)	
		Mean	σ
20-33	29	127	8.3
20-39	4	124	--
30-39	13	116	7.4
40-49	9	113	3.5
50-59	66	98	15.0
60-69	8	92	15.3

worker's complete overnight recovery from fatigue on such tasks is to be expected provided he is physically qualified for this level of work intensity."

For the purpose of this report a mean working pulse rate of 110 beats/min is assumed as an upper limit for an eight-hour workday. This may be excessive for older workers (age $>$ 40 years) as this would be close to 50 percent of their maximum aerobic power (see Table 1.1).

HEART RATE RECOVERY CRITERIA

Brouha recommended measuring heart rate while the worker is recovering from work to determine a safe stress level throughout the working shift. He suggested constructing heart rate recovery curves by determining the pulse rate at intervals of 0.5 to 1.0, 1.5 to 2.0, and 2.5 to 3.0 minutes following the cessation of work effort (Brouha, 1960). According to Brouha (1960), a safe stress level throughout the working shift is sustained provided (i) the first recorded pulse rate is 110 beats/min or less and (ii) the third recorded pulse rate is at least 10 beats per minute lower. In fact, he attached considerable significance to a one-minute recovery rate of no more than 110 beats per minute as a basis of separation between acceptable and unduly demanding tasks. Further, Brouha (1960) added that those heart rate recovery curves in which the difference between the first and the third minute pulse rates is less than 10 beats/min and in which the third reading remains above 90 beats/min represent no recovery. Normal recovery includes all cases in which the third minute pulse rate is at least 10 beats slower than the first, and those in which all three pulse rates are below 90 beats/min.

CHAPTER 2

PHYSIOLOGICAL EVALUATION

JOB OF A DRY GROCERY ORDER SELECTOR

An order selector drives his electric pallet jack to a dispatching area. The order selector walks to the dispatcher window and receives a picking order for grocery selection. The picking order contains various items and quantities to be picked, the order for picking these items and their locations (aisle and slot numbers). The order selector drives to the empty pallet stacks, lifts or slides empty pallets and lowers them to the floor. Each empty pallet weighs approximately 36 kg (80 lbs). He then drives to the slot on the first picking label, walks to the grocery item to be picked, lifts the case from the slot, carries it to the pallet jack, lowers or lifts it on the pallet jack to build the load on the pallet jack, peels the label from the order and applies it to the case (item picked). He then walks to the same or next picking slot while moving the pallet jack or drives to the next aisle and picks up the next item on the order. After the entire order is picked, the order selector will tape or wrap a string around the stacked cases or bags (except in the third warehouse studied). He then drives to the loading dock area and places the loaded pallets in the loading dock area. The order selector drives to the dispatcher area, walks to the dispatcher window, and returns the end sticker of the order to the dispatcher. The dispatcher tells the order selector his performance and gives him another order to start again.

This is the job that an order selector does for the entire day ranging from eight to twelve hours/day depending upon overtime and five to six days per week. The job requires considerable lifting, lowering, pulling, pushing, bending, twisting, stooping, reaching, climbing and crawling. The average weight of a grocery item is approximately 15 kg (33 lbs) as estimated by the management, ranging from a few kg to 45.4 kg (100 lbs). It is common for a worker to reach or crawl inside a slot which is only 86.4 cm (34 inches) high and 112 cm (44 inches) deep or reach for an object which may be as high as 223 cm (88 inches). The details of layout and slot configuration are discussed under ergonomic evaluation.

SUBJECTS

Sixty-three males and six female workers from three different warehouses participated in the study. They were all volunteers and were employed as order selectors by their respective companies. Out of sixty-three male selectors, twenty-one were employed in the day shift, thirty-six in the evening shift (swing shift) and six in the night shift (grave yard shift). Out of six female selectors, five were employed in the day shift and one in the evening shift. Workers' age, body weight, height and number of subjects from each warehouse are summarized in Table 2.1. Analysis of variance showed that there were significant differences ($p < 0.05$) in age, body weight and height of the male subjects from the three warehouses. Duncan's multiple range test (Miller and Freund, 1977) revealed that the male subjects from warehouse 1 were significantly younger, heavier and taller than those from the other two warehouses ($p < 0.05$). There were no significant differences ($p \geq 0.05$) in age, body weight or height of the male subjects from warehouses 2 and 3.

A list of volunteers was prepared by the company and/or the union. Whenever the research team was ready for data collection, the management was informed and the first available volunteer was selected as a subject. No

TABLE 2.1

Summary of Age, Body Weight and Height for Sixty-Nine Subjects Studied

Variable	Sex	Warehouse 1			Warehouse 2			Warehouse 3		
		Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
No. of Subjects	M	21	--	--	20	--	--	22	--	--
Age (yr.)	M	28.4	7.2	20 - 47	37.3	8.5	23 - 51	33.8	6.5	22 - 44
Body Weght (kg)	M	89.1	11.4	68.2 - 111.4	79.7	12.5	61.4 - 102.3	80.2	15.8	65.9 - 126.8
Height (cm)	M	183.8	7.0	172.7 - 198.1	176.6	7.9	162.6 - 187.9	178.8	6.8	167.6 - 193.0
No. of Subjects	F	1	--	--	4	--	--	1	--	--
Age (yr.)	F	20	--	--	33.5	5.5	24 - 37	28	--	--
Body Weight (kg)	F	56.8	--	--	70.4	2.2	68.2 - 72.7	56.8	--	--
Height (cm)	F	160.0	--	--	168.9	7.3	157.5 -175.3	167.6	--	--

screening process was used to select the subjects for the study except if a worker was suffering from an illness, such as cold, flu, etc., or not feeling well, he was not allowed to participate in the study. Lack of constraints on the selection process allowed workers of different ages, body weights and heights to participate in the study. Also, no constraints were placed on the worker's past injury, illness or disciplinary experiences for participation in the study.

All the subjects were required to fill out and sign three different forms before any data were collected on them. These included: (i) subject 's consent to participate in the study, (ii) release of personnel and wage information concerning subject's employment with the company, and (iii) authorization for medical information. The subjects were paid by the company at their regular wage rate for participation in the study. Workers were not offered any incentive by the company, union or the research team to participate in the study.

All the analyses presented in this report are for male subjects only unless specifically stated. This is due to the small sample size of female subjects from warehouses 1 and 3.

METHOD

The subjects participated one at a time in the study. Date, time, shift and the subject's age, body weight, height and gender were recorded. The purpose of the study, equipment and the experimental protocol were explained to the subject. A questionnaire was used to determine (i) grocery items most difficult to pick, (ii) pain experienced in any part of the body from the job, (iii) known hazards in the workplace, and (iv) recommendations to prevent injury or fatigue on the job based on subjective impression. It was believed that this information might be useful in selecting tasks for biomechanical job evaluation and for general ergonomic evaluation of the workplace. The subjects were asked to rate the degree of perceived exertion using the rating of perceived exertion scale (RPE scale, Figure 2.1). When using the RPE scale the subjects were asked to state, "In general, how hard the work feels in terms of physical difficulty."

Exersentry cardiotachometer with three built in plastic electrodes was used to measure the heart rate. A Panasonic portable cassette tape recorder was attached to a belt and was connected to the cardiotachometer to continuously record heartbeat ("R wave"). After all the data were collected in the warehouse, the tape recorder was connected to an electronic counter in a laboratory and played back to determine minute by minute heart rate.

A portable Oxylog (18.5 x 8.2 x 21.5 cm) with a face mask from Ambulatory Monitoring, Inc., was used to measure oxygen consumption. Oxylog with the case weighs 2.6 kg and has a built in turbine type flowmeter attached to the face mask to measure inspiratory volume. Oxylog provides a total oxygen display and minute oxygen display or total and minute ventilation.

A photocopy of the order to be selected by the subject was obtained from the company. The face mask, Exersentry cardiotachometer, Oxylog and the portable cassette recorder were placed on the worker. The face mask was then checked for possible air leaks based on subjective impression of the subject. Explaining the procedure and equipment to the subject, signing the subject consent forms, obtaining anthropometric and other information, and putting the equipment on the subject took somewhere from 20 to 40 minutes per subject. Oxygen uptake and heart rate were measured while the subject assumed a relaxed

Scale for Rating of Perceived Exertion

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard

Figure 2.1: The New RPE (Rating Scale of Perceived Exertion) from Borg 1962.

standing posture. Total oxygen uptake and heart rate were continuously recorded while the worker selected the order. The first three minutes, approximately, were allowed as a warm up period. The Oxylog display was set to zero at the end of approximately the first three minutes. Actual time taken by the worker to complete the order and duration for oxygen uptake measurement were determined using a stopwatch. Standard time allowed for the order was provided by the company after the order was selected. The photocopy of the order included items to be picked, total number of pieces, and their weight and volume. The total number of pieces picked were counted while the worker selected the order. All lifts were divided into three categories: floor to knuckle height, knuckle to shoulder height and shoulder height to overhead reach. Photographs of critical elements were taken while the worker selected the order. After the completion of the order, (after being clocked out by the dispatcher), the worker was asked to stand in a relaxed standing posture. The recovery heart rate was recorded for three minutes after the cessation of work.

The duration of the experiment varied from worker to worker depending upon the size of the order and pace of the worker. The actual time taken by the worker to select the order ranged from 12 to 64.6 minutes. The average time was 23.1 minutes (δ = 4.81) for warehouse 1, 32.0 minutes (δ = 12.38) for warehouse 2, and 45.2 minutes (δ = 10.67) for warehouse 3.

It is worth mentioning that warehouses 1 and 2 used a single pallet jack while warehouse 3 used a double pallet jack. In warehouse 1 the size of the order was such that, in general, the workers were required to make only one trip per order. In warehouse 2 the workers sometimes made one trip per order, sometimes two trips per order and rarely three trips depending upon the size of the order. This may explain the differences in actual time per order among the three warehouses. Representatives from all three warehouses were informed that very short orders should be avoided as the physiological data may not be reflective of an 8-hour work day. Also, efforts were made to study orders from different sections of a warehouse based on the information provided by the company. For example, warehouse 3 was divided into four sections. There were 6, 4, 5 and 7 orders studied from the four different sections.

The order selectors were given the following instructions. They were asked to perform their routine work of order selecting in the warehouse. They were asked to use the same method or technique for selecting the order for this study that they used everyday. They were asked to work at a pace close to 100 percent or the standard pace as determined by the work measurement system used by the company. If a grocery item was missing, the worker pointed out the missing item to one of the members of the research team. The research team then informed a company representative of the missing grocery item. Normally, when an item is missing, the worker walks to a nearby phone at the end of an aisle, calls a fork lift operator to inform him about the missing item and then walks back to his pallet jack. Thus, in a routine order selection the worker will take more time when an item is missing than the time taken in the study.

The worker was followed by two to three members of the research team and at least one company representative. The research team did not interfere with the worker during order selection except to change the tape in the cassette tape recorder if needed and to occasionally take a look at the Oxylog reading to determine if the instrument was working properly. An estimate of these interferences showed that they accounted for less than 10 seconds during the entire order.

Dry bulb, wet bulb and illumination readings were taken in different aisles and at different times of the shift. Data for ergonomic evaluation of the workplace and biomechanical job evaluation of strenuous work elements were collected after all oxygen uptake and heart rate measurements were completed.

Equipment Calibration

Exersentry cardiotachometer was calibrated against a physiograph using a three lead configuration. The calibration showed that the heart rates measured from Exersentry cardiotachometer were within ± 3 beats of the heart rate obtained from physiograph with zero bias. Further, there was no difference between the heart rates obtained from Exersentry and physiograph for a heart rate less than 130 beats/min.

Oxylog was calibrated against Beckman OM-11 oxygen analyzer and Beckman LB-2 carbon dioxide analyzer using a Parkinson Cohan CD-4 gas meter. This calibration was performed both before and after the experiments. The post-experiment calibration is shown in Figure 2.2. The least square regression analysis resulted in the following equation:

$$\dot{V}O_{2Beckman} = 0.0698 + 0.94 * \dot{V}O_{2Oxylog}$$

where

$\dot{V}O_{2Beckman}$ = Oxygen uptake from Beckman instruments (liter/min) at STPD

$\dot{V}O_{2Oxylog}$ = Oxygen uptake from Oxylog (liter/min).

The correlation coefficient was 0.999 and the standard error was 0.036. The above equation was used to correct the measured values from the Oxylog. Only the corrected values are reported in this study.

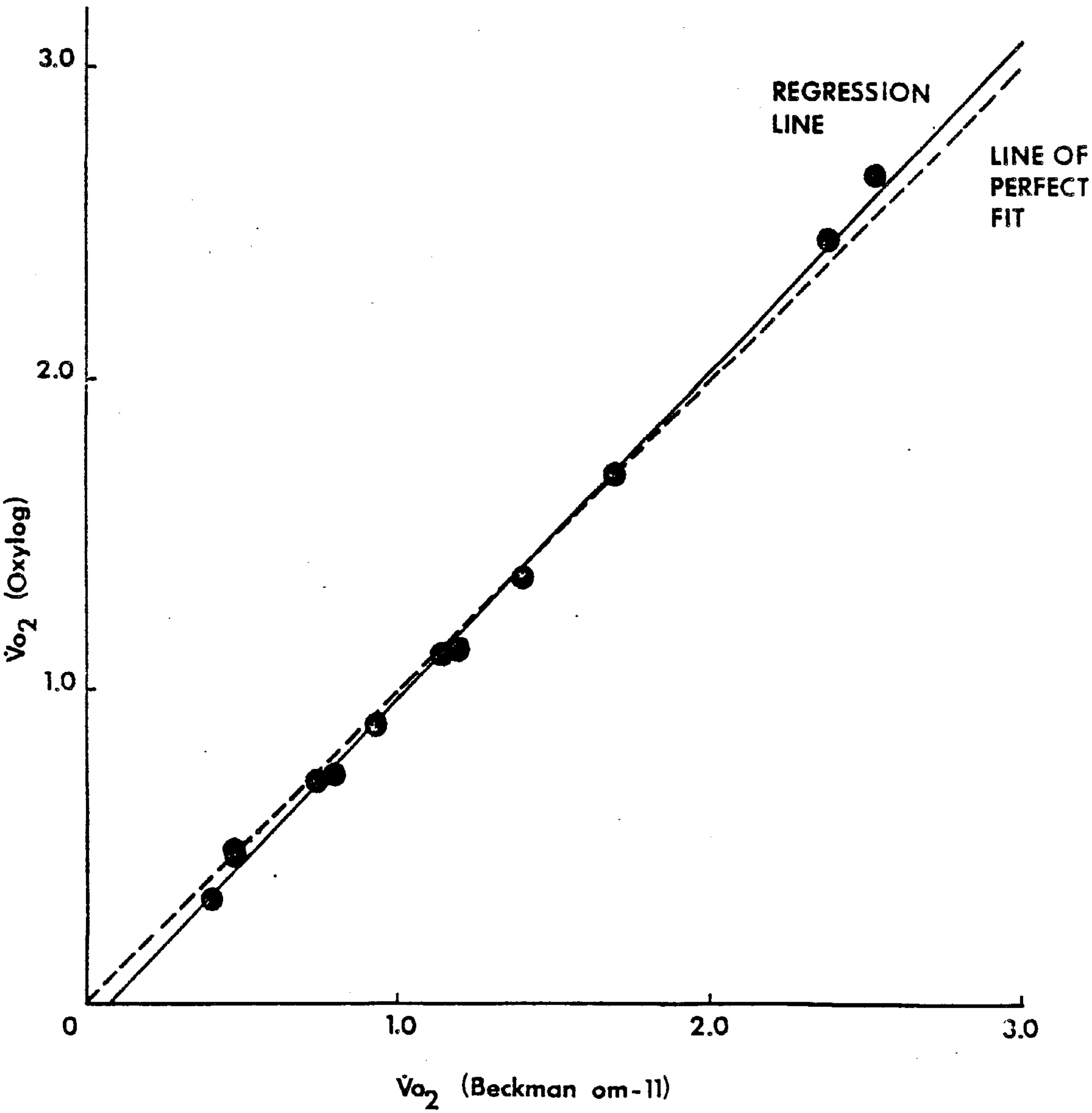

Figure 2.2: Calibration of Oxylog against Beckman OM-11.

Environmental Conditions

Illumination level, dry bulb, wet bulb temperature and relative humidity for the three warehouses are summarized in Table 2.2. There were approximately 50 observations per warehouse for illumination and 18 observations for dry bulb and wet bulb temperatures. Analysis of variance showed that there were significant differences ($p < 0.01$) in illumination levels in the three warehouses. Duncan's multiple range test revealed that all three illumination levels were significantly different from each other ($p < 0.01$). Similarly, there were significant differences ($p < 0.01$) in dry bulb temperature, wet bulb temperature and relative humidity in the three warehouses. The three dry bulb temperatures and relative humidities were significantly different from each other ($p < 0.05$). However, there was no significant difference in wet bulb temperatures measured in warehouses 1 and 2.

Illumination levels and temperatures were measured in the aisles at approximately waist height. The Illuminating Engineering Society (IES Lighting Handbook, 1981) recommends an illumination level of 15fc (range = 10 to 20 fc) for working spaces where visual tasks are only occasionally performed. Since the illumination level inside the slots would be much lower than that in the aisles, it is concluded that the illumination level in warehouses 2 and 3 is not sufficient and should be improved.

The thermal environment in warehouses 1 and 2 will probably be classified as moderate. On the other hand, the thermal environment in warehouse 3 (effective temperature = 23.3°C), though not excessive, may cause a little increase in deep body temperature, especially at high work intensity. Further, a relative humidity of 76% may reduce the effectiveness of heat loss by sweat evaporation.

TABLE 2.2

Illumination Level, Dry Bulb, Wet Bulb Temperature and Relative Humidity in the Three Warehouses Studied

Variable	Warehouse 1			Warehouse 2			Warehouse 3		
	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
Illumination (fc)	25.2	13.48	5.0 - 70.0	10.5	2.78	4.0 - 19.0	16.9	9.56	2.0 - 45.0
Dry Bulb (°C)	22.8	1.81	19.5 - 25.0	21.7	0.86	20.0 - 23.0	25.2	1.39	22.0 - 27.0
Wet Bulb (°C)	16.7	2.18	13.0 - 19.0	16.7	0.75	15.0 - 18.0	21.9	1.97	18.5 - 24.0
Relative Humidity (%)	55.2	6.17	44.0 - 63.0	60.9	4.44	55.0 - 70.0	75.9	7.82	60.0 - 87.0

Air temperature and relative humidity (RH) also have an effect on resting and working heart rates. For example, Brouha (1960) has reported an increase of 8 beats/min in resting heart rate (sitting in a chair) when the experimental conditions were changed from 15.5°C (41% RH) to 22.2°C (50% RH). The resting heart rate at the lower temperature was 70 beats/min (range = 55-89) and at the higher temperature 78 beats/min (range = 64-94). Further, there was a linear increase in working heart rate with the dry bulb temperature similar to the increase in the resting heart rate. Also, the average recovery time in the 22.2°C environment was 2.2 times as long as that observed at 15.5°C (Brouha, 1960).

RESULTS

The number of cases, weight and volume that the male subjects were required to handle per order and per minute to meet 100% performance are summarized in Tables 2.3 to 2.5. Resting heart rate, resting metabolic rate, rating of perceived exertion, performance index, average working metabolic rate, average working heart rate and peak heart rate are also summarized in Tables 2.3 to 2.5. Table 2.6 gives the same data for the six female workers studied in the three warehouses. Individual data are given in Tables A.1 to A.8 (Appendix A). Tables 2.7 and 2.8 list the recovery heart rates for the male and female subjects from the three warehouses.

Expected Workload/Order

An analysis of variance showed that there were significant differences ($p < 0.01$) in cases, weight, volume and allowed time/order from the three warehouses. Duncan's multiple range test showed that significantly greater cases, weight and volume per order were required by warehouse 3 than

Table 2.3

Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty-One Male Workers Studied in Warehouse 1

Variable	Unit	Mean	S.D.	Range
Total Cases/Order	Cases/Order	69.7	18.5	35 - 103
Total Weight/Order	Kg/Order	855.6	302.5	236.4 - 1247.3
Total Volume/Order	m^3/Order	1.57	0.23	0.69 - 1.94
Allowed Time/Order	Minutes	26.6	4.9	19.1 - 36.7
% of Cases/Order Picked From				
Floor to Knuckle Height	%	42.2	9.3	25.9 - 58.2
Knuckle to Shoulder Height	%	32.7	11.7	17.1 - 66.0
Shoulder, to Overhead	%	25.1	11.6	5.7 - 51.8
Expected Cases/min*	Cases/min	2.6	0.40	1.7 - 3.2
Expected Weight/min*	Kg/min	32.2	11.4	11.5 - 50.3
Expected Volume/min*	m^3/min	0.06	0.01	0.04 - 0.09
Resting Metabolic Rate**	--	--	--	--
Resting Heart Rate***	Beats/min	78.9	12.2	63 - 104
RPE	--	13.3	1.78	9 - 16
Performance Index	%	118.8	18.7	93.0 - 159.1
Working Metabolic Rate	Kcal/min	6.16	1.17	4.39 - 8.67
Working Heart Rate	Beats/min	110.1	18.9	71 - 149
Peak Heart Rate	Beats/min	123.8	20.6	91 - 168

* Total cases, weight or volume per order/allowed time per order
** Missing data
***Standing, relaxed

Table 2.4

Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty Male Workers Studied in Warehouse 2

Variable	Unit	Mean	S.D.	Range
Total Cases/Order	Cases/Order	117.8	54.2	58 - 216
Total Weight/Order	Kg/Order	1442.8	653.2	751.4 - 3100.0
Total Volume/Order	m^3/Order	2.75	1.16	1.13 - 5.80
Allowed Time/Order	Minutes	34.5	10.5	19.0 - 56.0
% of Cases/Order Picked From				
Floor to Knuckle Height	%	47.4	11.7	26.4 - 68.0
Knuckle to Shoulder Height	%	47.3	12.9	26.4 - 70.5
Shoulder to Overhead	%	5.3	5.6	0.0 - 23.0
Expected Cases/min*	Cases/min	3.4	0.85	1.8 - 4.4
Expected Weight/min*	Kg/min	41.2	9.1	19.4 - 55.4
Expected Volume/min*	m^3/min	0.08	0.02	0.05 - 0.14
Resting Metabolic Rate**	Kcal/min	1.73	0.28	1.30 - 2.25
Resting Heart Rate**	Beats/min	87.3	15.2	66 - 124
RPE	--	16.5	1.96	13 - 19
Performance Index	%	111.3	17.9	80.2 - 137.2
Working Metabolic Rate	Kcal/min	5.96	0.90	4.82 - 8.11
Working Heart Rate	Beats/min	121.9	18.6	84 - 158
Peak Heart Rate	Beats/min	136.4	18.9	104 - 171

* Total cases, weight or volume per order/allowed time
**Standing, relaxed

Table 2.5

Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from Twenty-Two Male Workers Studied in Warehouse 3

Variable	Unit	Mean	S.D.	Range
Total Cases/Order	Cases/Order	150.7	30.1	94 - 198
Total Weight/Order	Kg/Order	1918.6	508.2	1207.7 - 3100.0
Total Volume/Order	m^3/Order	3.92	0.33	2.73 - 4.59
Allowed Time/Order	Minutes	43.3	7.3	29.0 - 55.0
% of Cases/Order Picked From				
Floor to Knuckle Height	%	45.4	7.5	33.8 - 65.1
Knuckle to Shoulder Height	%	40.4	7.7	29.1 - 55.7
Shoulder to Overhead	%	14.2	7.1	0.8 - 25.1
Expected Cases/min*	Cases/min	3.5	0.43	2.7 - 4.3
Expected Weight/min*	Kg/min	45.9	17.3	26.3 - 98.4
Expected Volume/min*	cm^3/min	0.09	0.02	0.07 - 0.14
Resting Metabolic Rate**	Kcal/min	2.14	0.37	1.38 - 2.98
Resting Heart Rate**	Beats/min	86.4	13.8	65 - 110
RPE	--	15.9	2.02	13 - 19
Performance Index	%	97.6	11.6	78.8 - 120.5
Working Metabolic Rate	Kcal/min	8.35	1.67	5.74 - 11.51
Working Heart Rate	Beats/min	132.9	15.7	96 - 164
Peak Heart Rate	Beats/min	149.0	17.8	108 - 181

* Total cases, weight or volume per order/allowed time
**Standing, relaxed

Table 2.6

Summary of Number of Cases, Weight and Volume Selected, Performance Index, RPE, Metabolic Rate and Heart Rate from the Six Female Workers Studied in the Three Different Warehouses

Variable	Unit	Warehouse #			Intersubject Variability in Warehouse 2	
		1	3	2*	S.D.	Range
Total Cases/Order	Cases/Order	102	151	75.3	26.4	51 - 117
Total Weight/Order	Kg/Order	1178.2	2191.4	960.9	281.0	735.4 - 1425.5
Total Volume/Order	m^3/Order	1.67	4.0	2.02	1.01	1.10 - 3.71
Allowed Time/Order	Minutes	30.7	44.0	22.5	5.2	17 - 31
% of Cases/Order Picked From						
Floor to Knuckle Height	%	12.6	36.8	40.6	2.6	37.2 - 44.0
Knuckle to Shoulder Height	%	23.3	46.7	55.7	4.6	51.3 - 62.8
Shoulder to Overhead	%	64.1	16.4	3.7	2.3	0.0 - 4.1
Expected Cases/min**	Cases/min	3.30	3.4	3.3	0.51	2.6 - 3.8
Expected Weight/min**	Kg/min	38.4	49.8	42.9	8.5	35.0 - 55.4
Expected Volume/min**	m^3/min	0.05	0.09	0.08	0.02	0.05 - 0.11
Resting Metabolic Rate***	Kcal/min	--	1.80	1.65	0.07	1.57 - 1.75
Resting Heart Rate***	Beats/min	83	131	105.7	2.7	103 - 110
RPE	--	15.0	13.0	15.8	1.6	13 - 17
Performance Index	%	105.8	90.1	114.9	18.6	93.9 - 144.6
Working Metabolic Rate	Kcal/min	5.15	6.11	6.04	0.95	5.15 - 7.57
Working Heart Rate	Beats/min	129.0	169.0	147.2	12.3	129 - 162
Peak Heart Rate	Beats/min	142	179	163.5	17.5	136 - 181

* Mean of four subjects
** Total cases, weight or volume per order/allowed time per order
***Standing, relaxed

Table 2.7

Recovery Heart Rates for the Sixty-Three Male Workers Studied from the Three Different Warehouses

Subject No.	Recovery Heart Rate (Beats/min)								
	Warehouse 1			Warehouse 2			Warehouse 3		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
1	80	82	80	90	89	90	98	95	93*
2	75	72	72	132	131	130*	113	112	112*
3	105	102	100*	85	87	86*	103	107	101*
4	64	55	59	100	97	93*	143	139	137*
5	77	75	76	93	90	87	116	114	111*
6	--	--	--	94	94	91*	124	120	119*
7	106	102	98	97	93	94*	110	112	112*
8	65	52	52	125	125	119*	90	91	92*
9	74	78	82	121	112	110*	98	97	93*
10	91	85	82	138	123	121*	123	117	115*
11	70	68	72	90	90	89*	98	99	97*
12	134	124	119*	129	127	130*	120	117	115*
13	103	98	95*	82	81	79	98	100	98
14	101	98	98*	122	119	117*	138	131	134*
15	112	108	106*	100	97	97*	117	114	114*
16	104	94	94	60	59	63	101	93	83
17	71	71	70	101	96	90	112	110	108*
18	66	61	65	96	96	94*	77	76	73
19	77	73	73	80	81	82	103	101	97*
20	84	84	82	116	115	115*	116	110	104*
21	82	77	76	--	--	--	124	120	113*
22	--	--	--	--	--	--	95	94	94*

*Significant fatigue involved based on heart rate recovery criteria from Brouha (1960).

Table 2.8

Recovery Heart Rates for the Six Female Workers Studied from the Three Different Warehouses

Warehouse No.	Subject No.	Recovery Heart Rate (Beats/min) 1st	2nd	3rd
1	1	88	90	93*
2	1	132	120	116*
2	2	128	130	125*
2	3	133	118	112*
2	4	111	107	108*
3	1	150	147	140*

*Significant fatigue involved based on heart rate recovery criteria from Brouha (1960).

warehouse 2 and by warehouse 2 than warehouse 1 ($p < 0.01$). Similarly, all three allowed times were significantly different from each other ($p < 0.01$).

Expected Workload/Minute

A more objective analysis is to compare the cases, weight and volume that the male subjects were required to handle per minute to meet 100% performance because of significant differences in allowed time/order. The average cases/min that the subjects were required to pick in warehouses 1, 2 and 3 were 2.6, 3.4 and 3.5; the average weight/min was 32.2, 41.2 and 45.9 kg/min, and the average volume was 0.06, 0.08 and 0.09 m^3/min, respectively. Thus, all three requirements, i.e., number of cases/min, weight/min and volume/min that the subjects were required to handle to meet 100% performance, were the highest for warehouse 3 and the lowest for warehouse 1 (Figure 2.3). The number of cases/min, weight/min and volume/min varied considerably from order to order in a given warehouse. For example, in warehouse 3 one order required 4.3 cases/min with an average weight of 23 kg/case while another order required 2.7 cases/min with an average weight of 12.9 kg/case to meet 100% performance standards.

An analysis of variance showed that there were significant differences ($p < 0.01$) among the three warehouses. Duncan's multiple range test revealed that the subjects in warehouse 1 were required to lift significantly fewer (usually $p < 0.01$) cases, weight and volume/min than the subjects in warehouses 2 and 3. There were no significant differences ($p \geq 0.05$) in warehouse 2 and 3 for cases/min and weight/min. However, volume/min was significantly lower ($p < 0.05$) in warehouse 2 than in warehouse 3.

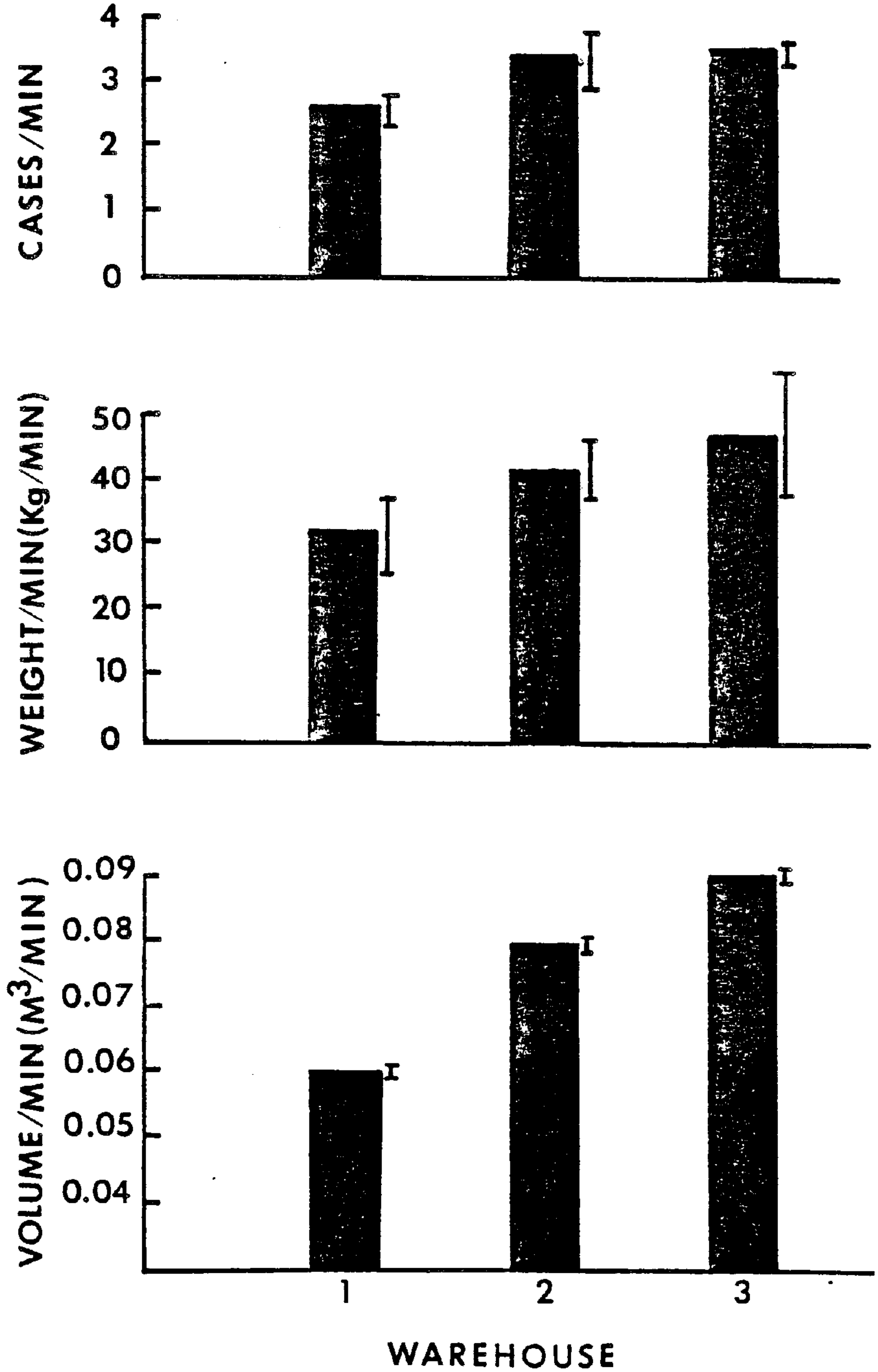

Figure 2.3: Comparison of Expected Cases, Weight and Volume per Minute at 100% Performance from the Three Warehouses. Based on Sixty-Three Male Subjects Studied.

Initial Height of a Grocery Item

In warehouses 1, 2 and 3, 42.2, 47.4 and 45.5% cases/order were located between floor and knuckle height; 32.8, 47.3 and 40.3% between knuckle and shoulder height; and 25.0, 5.3, and 14.2% between shoulder height and beyond overhead reach. An analysis of variance showed that there were significant differences ($p < 0.01$) among the three warehouses and the three height levels.

The initial height of the object may be misleading in determining the physical effort involved because after picking an object the subject had to carry it to the pallet on the jack and then lift or lower it to build the load on the pallet. For example, a subject may pick an object at elbow height but he/she may have to carry it and lift it to a height of 2.13m to set it on the pallet. Further, even picking an object between knuckle and shoulder height may require considerable physical effort as the slots were 1.12 m deep. However, the above mentioned statistics do show that 45% or approximately one out of two objects are picked from somewhere near floor level and 15% from a height above shoulder level.

Rating of Perceived Exertion

The average rating of perceived exertion (RPE) for the order selecting job (and not the particular order selected) was 13.3, 16.5 and 15.9 in warehouses 1, 2 and 3, respectively. The overall RPE from the three warehouses was 15.2. In other words, on the average, the workers perceived the job of order selection between 'somewhat hard and hard' in warehouse 1 and between 'hard and very hard' in warehouses 2 and 3. An analysis of variance showed that there were significant differences ($p < 0.01$) among the three warehouses. Duncan's multiple range test revealed that the level of exertion perceived by the subjects in warehouse 1 was significantly lower ($p < 0.01$) than the exertion perceived by the subjects in warehouses 2 and 3. There were no significant differences ($p \geq 0.05$) between warehouse 2 and 3.

Performance Index

The performance index was computed by dividing the allowed time for an order by the actual time taken by the subject to complete that order. Thus, a performance index of 100% or higher indicates that a worker was able to meet the company's performance standard while an index of less than 100% indicates that the worker was unable to meet the company's performance standard.

The average performance index for male workers for warehouses 1, 2 and 3 was 118.8%, 111.3% and 97.6%. On the average, only the subjects in warehouse 3 failed to meet the 100% performance expected by the company. The performance of the workers ranged from 93.0% to 159.1% in warehouse 1, 80.2% to 137.2% in warehouse 2, and 78.8% to 120.5% in warehouse 3. Therefore, in addition to average performance, the top performance of a worker was the highest in warehouse 1 and the lowest in warehouse 3. Five out of twenty-one male workers in warehouse 1, five out of twenty male workers in warehouse 2 and fourteen out of twenty-two male workers in warehouse 3 failed to meet 100% performance standards set by the respective companies based on motion and time study or predetermined motion-time data systems. Thus, 23.8%, 25.0% and 63.6% of male order selectors studied were unable to meet company standards in warehouse 1, 2 and 3, respectively. Similarly, data on female workers showed that two out of six (one out of four in warehouse 2 and one out of one in warehouse 3) were unable to meet performance standards. A comparison of the workers' performances during the study with their respective performances over a four month period preceding the study showed that the workers, in general, worked much faster during the study. This may be due to the fact that they were being followed by a company representative and the members of the study team.

An analysis of variance showed that there were significant differences ($p < 0.01$) among the three warehouses. Duncan's multiple range test showed that the performance in warehouse 3 was significantly lower ($p < 0.01$) than the performance in the other two warehouses. There was no significant difference ($p \geq 0.05$) in warehouses 1 and 2. Significance tests (t-test for the hypothesis concerning one mean, Miller and Freund, 1965) showed that performance indices of 118.8% and 111.3% were significantly different from 100% ($p < 0.01$). However, a performance index of 97.6% was not significantly different from 100% ($p \geq 0.05$).

Metabolic Energy Expenditure Rate

The average metabolic energy expenditures for male subjects from warehouses 1, 2 and 3 were 6.16 (range = 4.39 to 8.67), 5.96 (range = 4.82 to 8.11) and 8.35 Kcal/min (range = 5.74 to 11.51), respectively. Seventeen out of twenty-one male subjects in warehouse 1, seventeen out of twenty male subjects in warehouse 2 and all twenty-two male subjects in warehouse 3 exceeded the acceptable standard of 5 Kcal/min (Tables A.5 to A.7). Similarly, all six female subjects from the three warehouses exceeded 5 Kcal/min (see Table A.8). The average metabolic rate for the six female subjects was 5.9 Kcal/min (range = 5.15 to 7.57).

An analysis of variance showed that there were significant differences in metabolic rates for male subjects from the three warehouses ($p < 0.01$). Duncan's multiple range test showed that the metabolic rates from warehouse 3 was significantly higher ($p < 0.01$) than the metabolic rates from warehouses

1 and 2. However, there was no significant difference in metabolic rates between warehouses 1 and 2.

To evaluate if the measured metabolic rates from the three warehouses were in agreement with the physiological fatigue criterion of 5 Kcal/min, t-statistics were calculated for each of the three warehouses. The t-tests showed that the measured metabolic rates were significantly different ($p < 0.01$) from 5 Kcal/min for all three warehouses.

Heart Rate

The average working heart rates for male subjects from warehouses 1, 2 and 3 were 110.1 (range = 71 to 149), 121.9 (range = 84 to 158) and 132.9 beats/min (range 96 to 164), respectively. The average heart rates for ten out of twenty-one male subjects in warehouse 1, fifteen out of twenty male subjects in warehouse 2, and twenty out of twenty-two male subjects in warehouse 3 were higher than the acceptable standard of 110 beats/min (Tables A.5 to A.7). Similarly, average working heart rates for all six female subjects were in excess of 110 beats/min. The average heart rate for the six female subjects was 147.8 beats/min (range = 129 to 169, Table A.8).

An analysis of variance showed that there were significant differences in heart rates for male subjects from the three warehouses ($p < 0.01$). Duncan's multiple range test revealed that the heart rates from the three warehouses were significantly different ($p < 0.05$) from each other.

To evaluate if the working heart rates from the three warehouses were in agreement with the physiological fatigue criterion of 110 beats/min, t-statistics were calculated for each of the three warehouses. The t-tests showed that the measured heart rates were significantly different ($p < 0.01$) from

110 beats/min for warehouses 2 and 3 while there was no significant difference ($p \geq 0.05$) for warehouse 1.

Peak Heart Rate

The average peak heart rates for male subjects from warehouses 1, 2 and 3 were 123.8 (range = 91 to 168), 136.4 (range = 104 to 171) and 149.0 beats/min (range = 108 to 181), respectively. As stated in Astrand and Rodahl (1977, p. 354) and by the American Heart Association (1972), the Scandinavian Committee on ECG Classification recommends that submaximal exercise testing be terminated at a certain predetermined heart rate: in the age group 20-29 years at 170 beats/ min, 30-39 years at 160 beats/min, 40-49 years at 150 beats/min, and 50-59 years at 140 beats/min. A comparison of individual peak heart rates with the above recommendations revealed that 5% of the male subjects in warehouse 1, 15% in warehouse 2 and 32% in warehouse 3 had their peak heart rate close to, or higher than the recommendations of the Scandinavian Committee on ECG classification for submaximal exercise termination. At maximal working capacity Petrofsky and Lind (1978) reported maximum heart rates of 144 to 164 beats/min for lifting up to 22.7 kg of load; and 14, 25 and 54% of the male subjects studied in warehouses 1, 2 and 3, respectively, had their peak heart rate close to or higher than 160 beats/ min. Similarly, four out of six female subjects studied had their peak heart rate in excess of 160 beats/min. This indicates that a significant number of workers might be working close to or at their maximal working capacity for this type of work.

An analysis of variance of peak heart rate for male subjects showed that there were significant differences ($p < 0.01$) among the three warehouses. Duncan's multiple range test revealed that all three warehouses were significantly different from each other ($p < 0.05$).

Heart Rate Recovery Curves

According to Brouha (1960), the heart rate recovery curve alone is sufficient to evaluate the physiological stress imposed by the work load and by the environment. The heart rate recovery curve indicates the rapidity with which the pulse returns to its resting level. Heart rate recovery data is given in Tables 2.7 and 2.8 for male and female subjects, respectively. The following criteria were used to determine onset of fatigue. For a safe stress level, the first recovery pulse rate should be 110 beats/min or lower and the third recovery pulse rate should be at least 10 beats/min lower than the first recorded pulse rate. However, if these conditions were not met but the recovery pulse rates were close to the resting pulse rate measured before the beginning of work, then it was regarded as a satisfactory recovery.

An analysis of heart rate recovery data showed that five out of twenty-one male workers in warehouse 1, fourteen out of twenty male workers in warehouse 2 and nineteen out of twenty-two male workers in warehouse 3 experienced excessive fatigue. Similarly, all six female subjects showed excessive fatigue based on heart rate recovery data (Table 2.8).

DISCUSSION

This study showed that the average metabolic rates of 6.16, 5.96 and 8.35 Kcal/min in the three warehouses studied were significantly higher than 5.0 Kcal/min. A comparison of these metabolic rates with Petrofsky and Lind (1978) data shows that these are equivalent to a work intensity of 51.8, 50.1 and 70.2% of $\dot{V}O_{2max}$ for lifting a 6.8 kg load and 44.2, 42.7 and 59.9% of $\dot{V}O_{2max}$ for lifting a 22.7 kg load. The average weight lifted in this study was 12.5 kg. Linear interpolation of the Petrofsky and Lind (1978) data for a

12.5 kg load showed that at 6.16, 5.96 and 8.35 Kcal/min the subjects were working at 49.1, 47.5 and 66.5% of $\dot{V}O_{2max}$ for lifting a 12.5 kg load. It is worth mentioning that these percentages are based on an average maximum aerobic capacity of 3.7 l/min on a bicycle ergometer which may be very high for most industrial workers.

Average heart rates of 121.9 and 132.9 beats/min observed in two out of the three warehouses were significantly higher than 110 beats/min. Comparison of these heart rates with the data on heart rate against $\%\dot{V}O_{2max}$ in Astrand and Rodahl (1977) shows that these heart rates are equivalent to work intensities of approximately 45% and 55% of maximum aerobic power on a bicycle ergometer. When age effect is included, these heart rates correspond to a work intensity level much higher than 50% of $\dot{V}O_{2max}$ (see Table 1.1). The observed heart rates of 121.9 and 132.9 beats/min are much higher than 98 to 102 beats/min reported by Astrand (1967) for bricklayers, carpenters and laborers and the upper limits of 99 and 112 beats/min recommended by Snook and Irvine (1969) for arm and leg tasks. Garg and Saxena (1981) reported 101 beats/min for lifting in the horizontal plane. Petrofsky and Lind (1978), based on five highly trained and physically fit male subjects, reported maximum heart rates of 144, 160 and 164 beats/min for lifting 0.9, 6.8 and 22.7 kg loads at maximum oxygen uptake rates. Thus, heart rates of 122.9 and 132.9 beats/min correspond to 76 and 82% of maximum heart rate for lifting tasks.

Peak heart rates of 5, 14 and 32% of male workers studied in the three warehouses and 83% of all female workers studied approached or exceeded the submaximal exercise testing termination limits set by the Scandinavian Committee on ECG classification. Also, peak heart rates of 14, 25 and 54% of male subjects in warehouses 1, 2 and 3, respectively, approached or exceeded

160 beats/min which is about the highest heart rate at the maximal working capacity for lifting of up to 22.7 kg loads (Petrofsky and Lind 1978). Heart rate recovery curves showed that 24, 70 and 86% of male subjects in warehouses 1, 2 and 3, respectively, and all six females experienced excessive fatigue.

Five out of twenty-one (24%) male workers in warehouse 1, six out of twenty (30%) in warehouse 2 and fourteen out of twenty-two (64%) in warehouse 3 failed to meet the 100% performance level. At the same time, all but two had metabolic rates in excess of 5.0 Kcal/min. The average energy expenditure rates for male workers who failed to meet 100% performance levels were 6.34 Kcal/min in warehouse 1, 5.44 Kcal/min in warehouse 2 and 8.37 Kcal/min in warehouse 3. The corresponding average heart rates were 110.0, 115.2 and 132.6 beats/min in warehouses 1, 2 and 3, respectively. Therefore, time standards which were developed by the companies using motion and time study or predetermined motion-time data systems are unacceptable from a physiological point of view. Physiological measurements show that the observed performance levels cannot be maintained by an average male or female worker for an eight-hour work day. This is further evidenced by the disciplinary actions taken against the workers for not meeting the performance standards and the high incidence of accidents in one of the three warehouses studied. In a period of six months, in one warehouse, there were 70 warning letters written to 56 different individuals, 48 one-day suspensions given to 42 separate individuals, 28 five-day suspensions to 28 individuals and 11 discharges for not meeting the 100% performance level. During the same period there were 102 separate accident reports involving dry grocery fillers which were filed with the Division of Workmen's Compensation. There are approximately 80 dry grocery fillers in this warehouse and the exact number could not be determined.

Fatigue Allowance

A fatigue allowance should be given if the energy output required to do the job over 8 hours exceeds the acceptable energy level (Karger and Hancock, 1981; AIHA Technical Committees, 1971; Chaffin, 1972; Lehmann, 1958, Spitzer, 1951; Murrell, 1965, etc.) The following assumptions are made to compute the fatigue allowances:

(i) A maximum aerobic capacity of 15 Kcal/min

(ii) A recommended physical work capacity (RPWC) of 5 Kcal/min for 8 hours, or a RPWC of 4.69 Kcal/min for 510 minutes including meal time, shift breaks and working time (see Chaffin, 1972). It is worth mentioning that a value of 5 Kcal/min for 8 hours or 4.69 Kcal/min for 510 minutes may be too high for female workers or a deconditioned aging work force. Then,

$$\frac{Tw * Mw + Tr * Mr}{510} = 4.69 \qquad (2)$$

and,

$$Tw + Tr = 510 \qquad (3)$$

where: Tw = Total working time (minutes)

Tr = Total resting time, including a meal break and shift breaks (minutes)

Mw = Metabolic rate of the job (Kcal/min)

Mr = Resting metabolic rate for a seated person = 1.5 Kcal/min (AIHA Technical Committee, 1971)

By substituting average working metabolic rates (6.16, 5.96 and 8.35 Kcal/min) from each of the three warehouses for Mw and 1.5 Kcal/min for Mr, equations (2) and (3) can be solved for maximum allowable working time (Tw) at the observed work rate and the corresponding resting time (Tr). These are shown in Table 2.9. However, Tw and Tr need to be adjusted for 100% performance. This is achieved by computing earned minutes in Table 2.9. For example, the observed work rate in warehouse 1 was 118.8%. Therefore, at this work rate, for each minute of work the workers are actually allowed 1.188 min. Resting time needed at 100% performance (no. 5 in Table 2.9) is computed by subtracting earned minutes from 510 (total shift time). By subtracting existing allowances for lunch and mid-shift breaks from the needed resting time, additional resting time needed can be computed so that the average metabolic rate over 510 minutes will not exceed 4.69 Kcal/min. The last row in Table 2.9 shows this additional resting time as a percentage of working time or what is generally known as fatigue allowances.

Table 2.9 shows that some additional fatigue allowances are needed in all three warehouses so that the physiological cost of work remains within the acceptable limits. In particular, additional fatigue allowances of 10.9, 13.3 and 93.7% of working time are needed in warehouses 1, 2 and 3, respectively, to maintain a reasonable level of energy expenditure over a work shift. A fatigue allowance of 93.7% at an average energy demand of 8.35 Kcal/min is in agreement with the statement in Lehmann (1958), "If, for instance, the work requires 8 Kcal/min (work - basal metabolism), he really should not work more than one-half of the whole working time." It is worth stressing that these recommendations are for healthy male workers with a maximum aerobic power of 15 Kcal/min or higher. Female workers who, in general, have significantly lower aerobic capacity than the male workers (Garg, 1983) will need significantly greater fatigue allowances than the above recommendations. For example, based on observed performance indices and metabolic rates for six

Table 2.9

Recommended Additional Fatigue Allowances for the Three Warehouses

		Warehouse		
No.	Variable	1	2	3
1.	Total Time/Day (min)	510	510	510
2.	Max. Allowable Working Time at Observed Work Rate, Tw (min)	349.1	364.8	237.5
3.	Resting Time Needed at Observed Work Rate, Tr (min)	160.9	145.2	272.5
4.	Earned Minutes (min) = (2) * Performance Index	414.7	406.0	237.5
5.	Resting Time Needed at 100% Performance (min) = (1) - (4)	95.3	104.0	272.5
6.	Existing Allowances (min)			
	Lunch	30.0	30.0	30.0
	2 Breaks of 10 min each	20.0	20.0	20.0
	TOTAL	50.0	50.0	50.0
7.	Additional Resting Time Needed at 100% Performance (min) = (5) - (6)	45.3	54.0	222.5
8.	Additional Fatigue Allowances as a % of Working Time at 100% Performance = (7) * 100/(4)	10.9	13.3	93.7

female workers and assuming an aerobic capacity of 10.5 Kcal/min (U.S. Department of Health and Human Services, 1981), the recommended additional fatigue allowances are 74.8, 100 and 167% of working time for warehouses 1, 2 and 3, respectively. Also, overtime is fairly common in some of the warehouses, ranging 2 to 4 hours/day. The aforementioned recommendations for fatigue allowances need to be adjusted to account for longer work shifts.

Relationship Between Performance Index, Metabolic Rate and Heart Rate.

Performance Index vs Metabolic Rate and Heart Rate

Figures 2.4 and 2.5 give plots of metabolic rate and heart rate against percentage performance for the sixty-three male subjects from the three different warehouses. These figures show that there is no relationship between the performance index as determined by the traditional work measurement techniques (motion and time study or predetermined motion-time data systems) and metabolic energy expenditure rate (Figure 2.4) or heart rate (Figure 2.5). For example, a performance rate below 100% resulted in an energy expenditure level in excess of 11 Kcal/min while a performance rate above 100% resulted in a metabolic rate of less than 6 Kcal/min (Figure 2.4). Similarly, a heart rate in excess of 160 beats/min was observed at a performance level below 100% and less than 120 beats/min at a performance above 100% (Figure 2.5). The least squares regression analysis resulted in the following equations:

$$M = 8.71 - 0.0169 * PI \tag{4}$$

$$HR = 128.0 - 0.0567 * PI \tag{5}$$

where:

M = metabolic energy expenditure rate (Kcal/min)

HR = heart rate (beats/min)

PI = performance index (%)

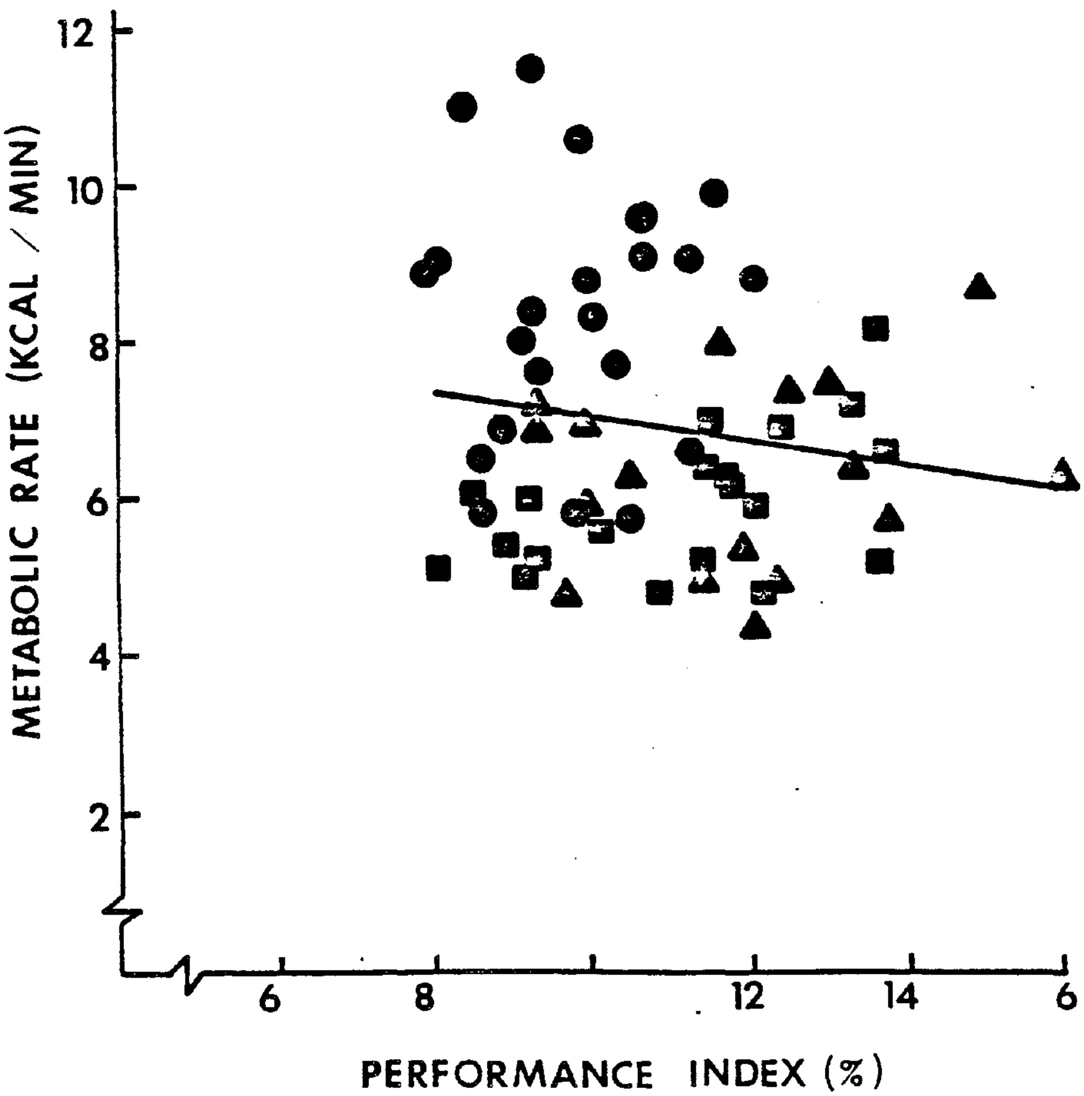

Figure 2.4: Relationship between Energy Expenditure and Performance Index for the Sixty-Three Male Workers Studied in Warehouse 1 (triangles), Warehouse 2 (squares) and Warehouse 3 (circles).

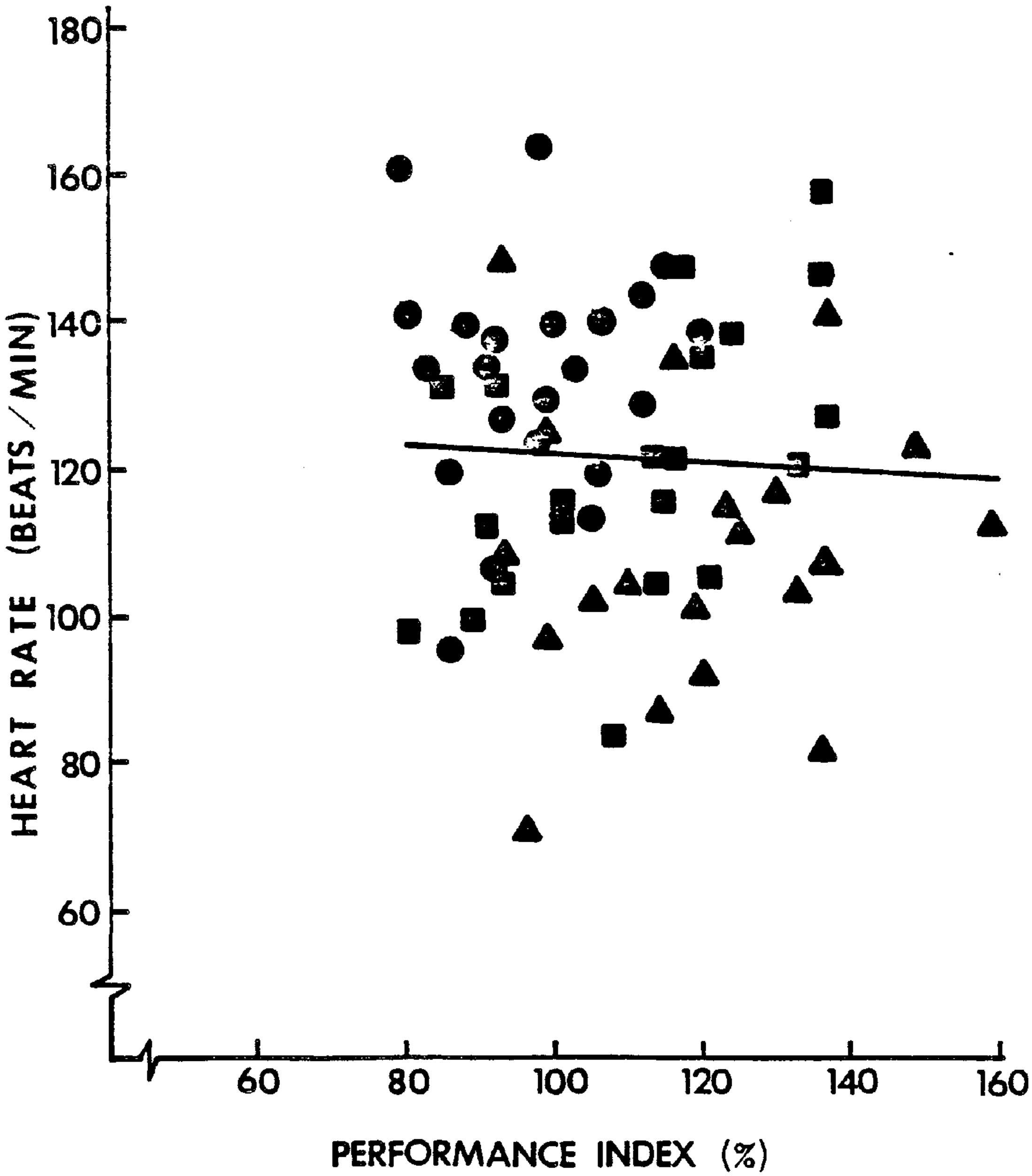

Figure 2.5: Relationship between Heart Rate and Performance Index for the Sixty-Three Male Workers Studied in Warehouse 1 (triangles), Warehouse 2 (squares) and Warehouse 3 (circles).

The correlation coefficient (r) and standard error (σ_e) were 0.18 and 1.67 for metabolic rate and 0.05 and 20.0 for heart rate. Further, regression analyses showed that as the performance index increased, both metabolic rate and heart rate decreased.

Separate regression analyses were performed for the three warehouses because of different work measurement systems used in these warehouses. The correlation coefficient and standard error for the regression of the metabolic rate against the performance index were 0.07 and 1.19 for warehouse 1, 0.53 and 0.78 for warehouse 2, and 0.02 and 1.71 for warehouse 3. Similarly, the correlation coefficient and standard error for the regression of heart rate against performance index were 0.08 and 19.3 for warehouse 1, 0.49 and 16.6 for warehouse 2, and 0.07 and 16.1 for warehouse 3. Thus, performance indices from warehouses 1 and 3 failed to explain any variation in metabolic rate or heart rate while the performance index from warehouse 2 accounted for approximately one-fourth of the variation in metabolic rate and heart rate.

Metabolic Rate vs Heart Rate

Figure 2.6 gives a plot of metabolic energy expenditure rate ($\dot{M}$, Kcal/min) against heart rate (HR, beats/min) for the sixty-three male subjects from the three different warehouses. The least squares regression analysis resulted in the following equation:

$$\dot{M} = 0.17 + 0.0549 * HR \qquad (6)$$

The correlation coefficient was 0.65 and the standard error was 1.29 Kcal/min. Heart rate accounted for 42% variation in metabolic rate.

Separate regression analyses for the three warehouses gave practically the same correlation coefficient but lower standard error. The correlation coefficients and standard errors from three separate regression analyses were

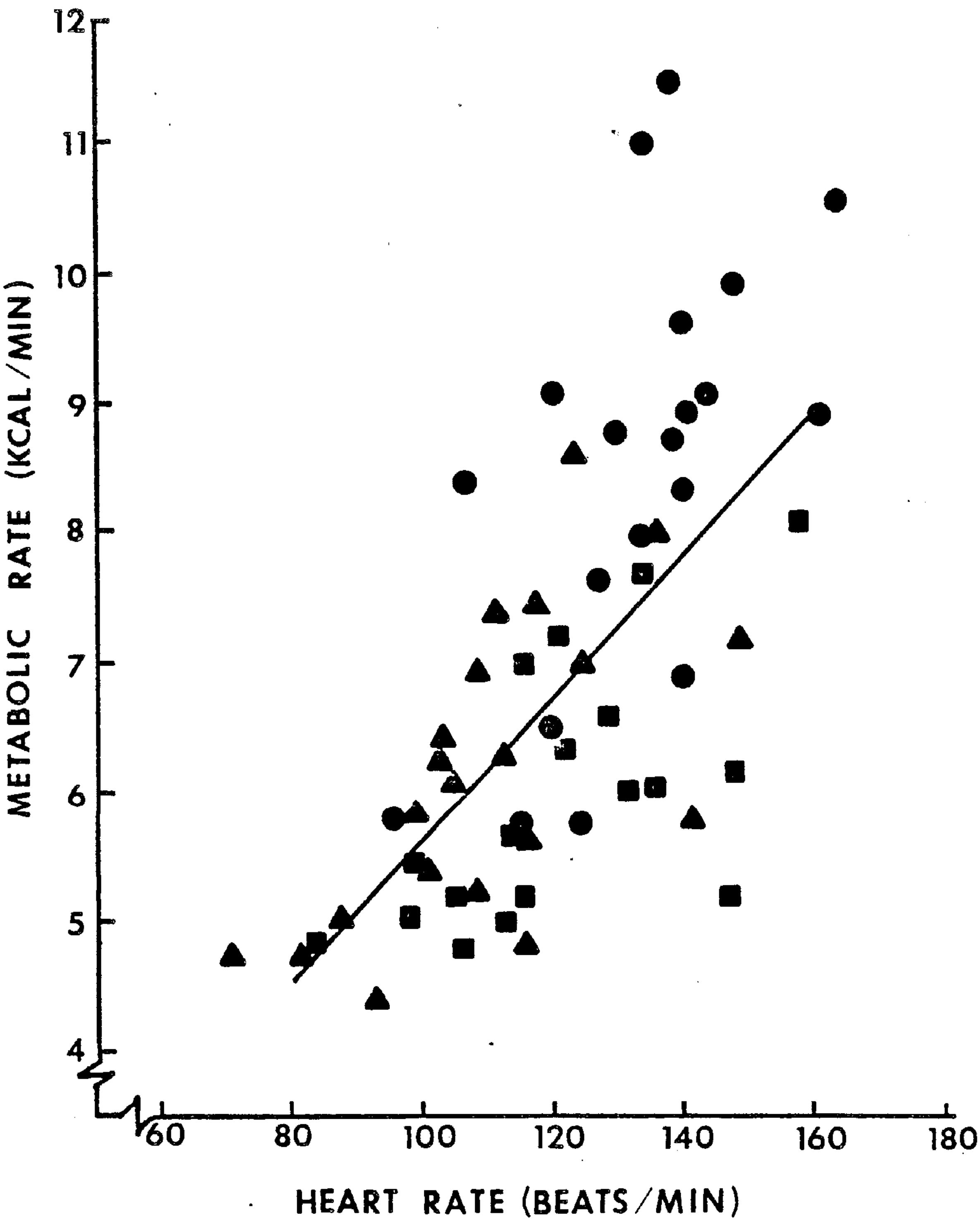

Figure 2.5: Relationship between Energy Expenditure and Heart Rate for the Sixty-Three Male Workers Studied in Warehouse 1 (triangles), Warehouse 2 (squares) and Warehouse 3 (circles).

0.64 and 0.93 for warehouse 1, 0.63 and 0.71 for warehouse 2, and 0.60 and 1.37 for warehouse 3.

The relationship between energy expenditure and heart rate is affected by several variables, such as nature of work, weights and forces involved, temperature and humidity, and workers' gender, training, physical fitness and emotional stress, etc. (Garg and Saxena, 1981; Astrand and Rodahl, 1977; Petrofsky and Lind, 1978; Burger, 1969). Since task environmental and personal variables varied considerably in this study, this may account for the somewhat lower correlation between metabolic rate and heart rate reported here.

Comparison of Warehouses

Figure 2.7 compares the actual cases, weight and volume lifted per minute by the male subjects from the three warehouses. Actual cases, weight and volume/min were computed by dividing total cases, weight and volume/order by the actual time taken by a subject to complete the order. Actual cases, weight and volume lifted per minute were the lowest for warehouse 1; actual weight and volume lifted per minute were the highest for warehouse 3, and the actual cases/min were the highest for warehouse 2. There were no significant differences ($p \geq 0.05$) between warehouses 2 and 3 for all three variables and there were no significant differences ($p \geq 0.01$) among the three warehouses for weight lifted per minute.

It is recognized that there are other variables such as workplace layout, distances, heights, etc., which determine the work intensity and some of these are difficult to quantify. However, if cases, weight and volume lifted per minute are indicative of work then the work intensity was the lowest in warehouse 1 and the highest in warehouses 2 and 3. On the other hand, there were significant differences in the performance indices from the three

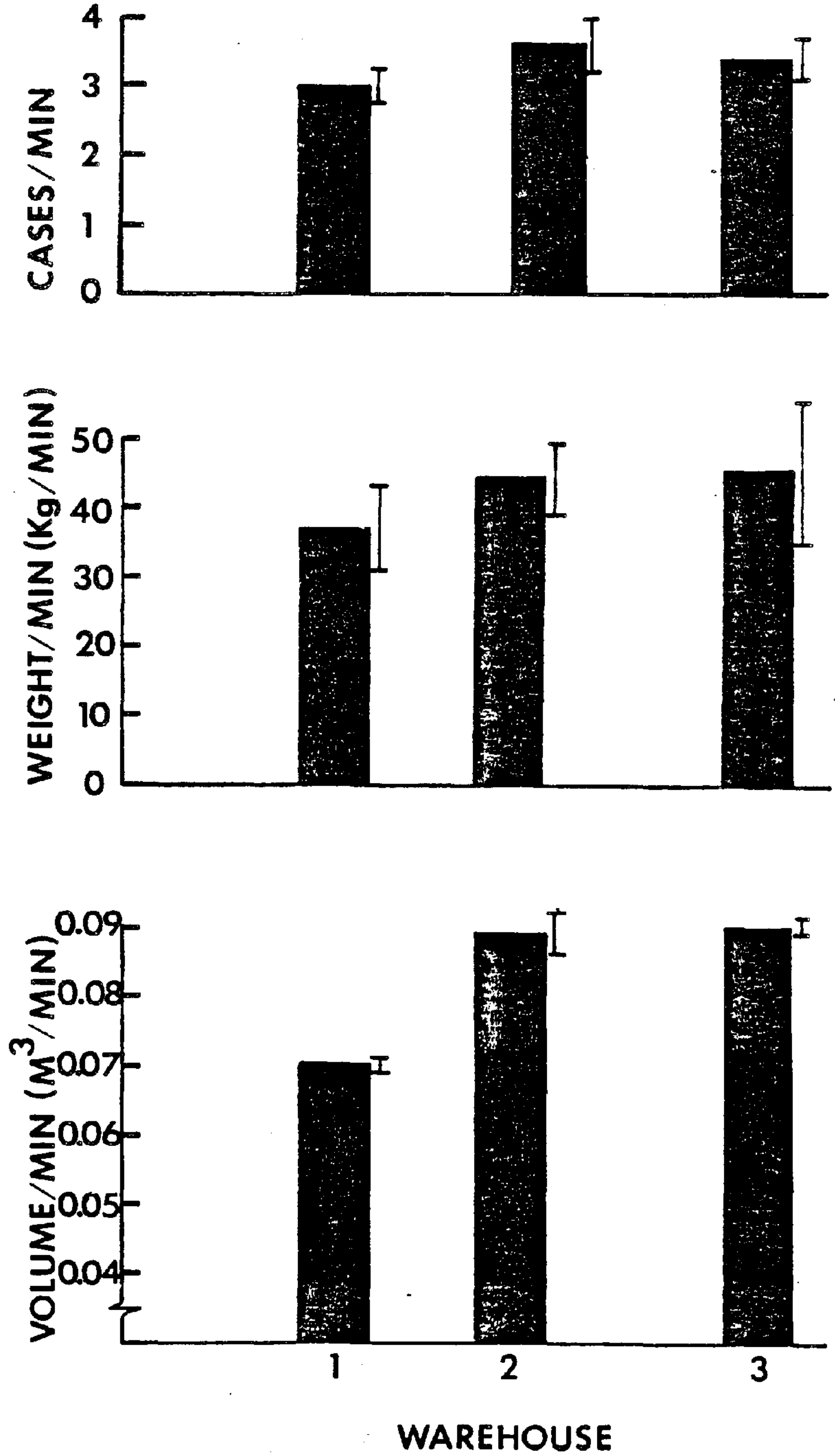

Figure 2.7: Comparison of Actual Cases, Weight and Volume Lifted per Minute by the Male Subjects from the Three Warehouses.

warehouses. Performance index as determined by the traditional work measurement techniques was the highest for warehouse 1 and the lowest for warehouse 3 (Figure 2.8). This shows discrepancies among the three different traditional work measurement techniques (Time and Motion Study, Methods--Time Measurement and Master Standard Data) used in the three different warehouses. Inconsistencies within a work measurement system as applied to order selectors in a given warehouse were mentioned earlier in this report.

Figure 2.8 shows that the performance index decreased from warehouse 1 to 3 while the heart rate significantly increased ($p < 0.05$) from warehouse 1 to 3. Thus, heart rate was inversely related to performance index from the three warehouses. Heart rate which is a measure of circulatory strain and physical work load indicates that the work intensity increased from warehouse 1 to 3. On the other hand, the performance index indicates that the subjects worked the fastest in warehouse 1 and the slowest in warehouse 3. This raises serious questions regarding the applicability of traditional work measurement techniques to physically demanding work. This also reinforces the statement from Davis et al. (1969) that "it is practically impossible to estimate accurately the difficulty of a job by merely observing it."

Figure 2.9 compares the metabolic energy expenditure rates from the three warehouses. The corresponding performance indices are also listed in Figure 2.9. Once again, metabolic rate was the highest for the warehouse with the lowest performance index (warehouse 3). The performance index for warehouse 1 was higher than that for warehouse 2, though not statistically significant ($p \geq 0.05$), while metabolic rates were practically the same.

The metabolic energy expenditure rate is a good indicator of the heaviness of the bodily work performed (Lehmann, 1958) and increases linearly with an increase in work load (Astrand and Rodahl, 1977). Energy expenditure shows

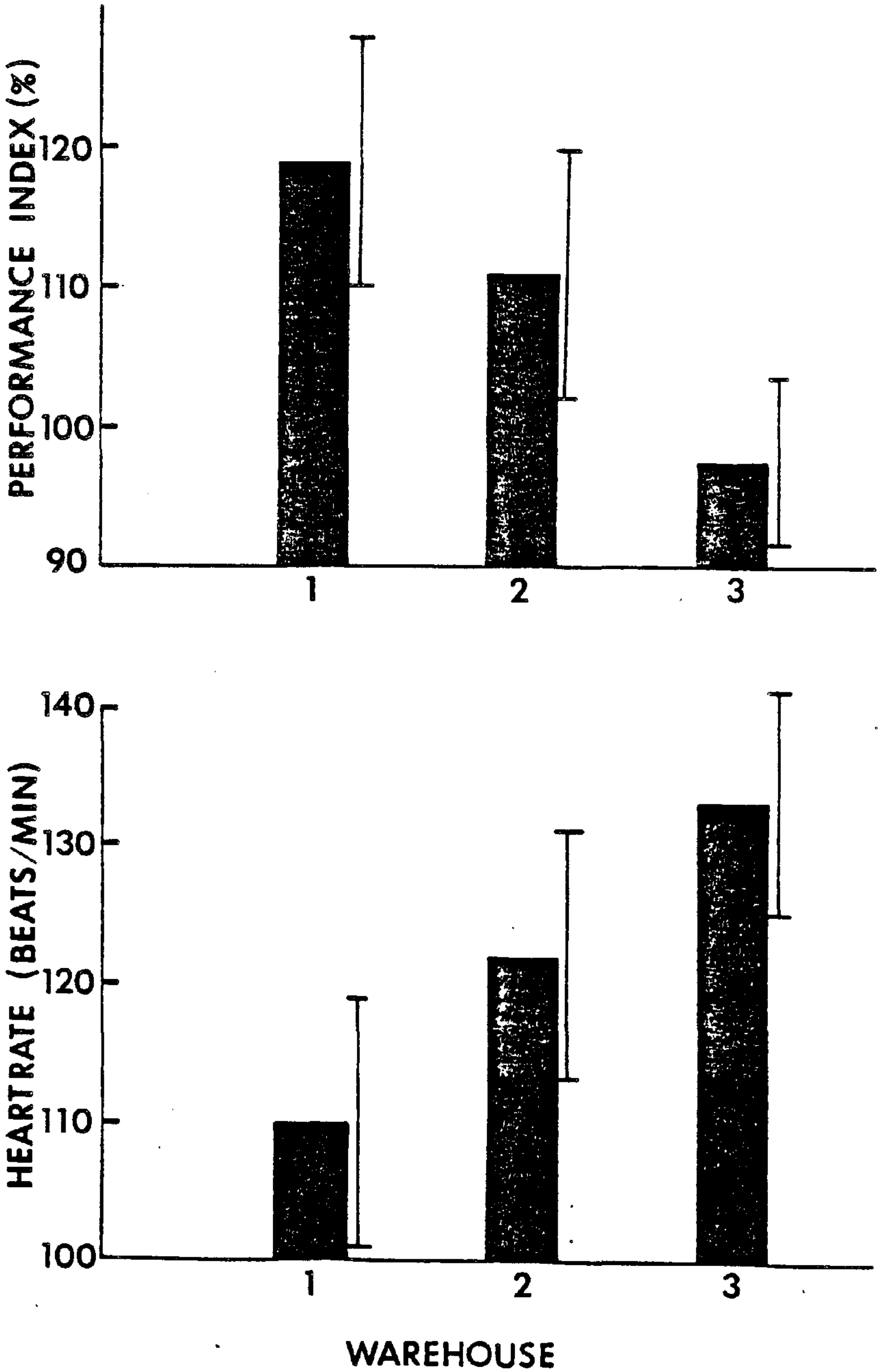

Figure 2.8: Comparison of Performance Indices and Heart Rates of Male Workers from the Three Warehouses.

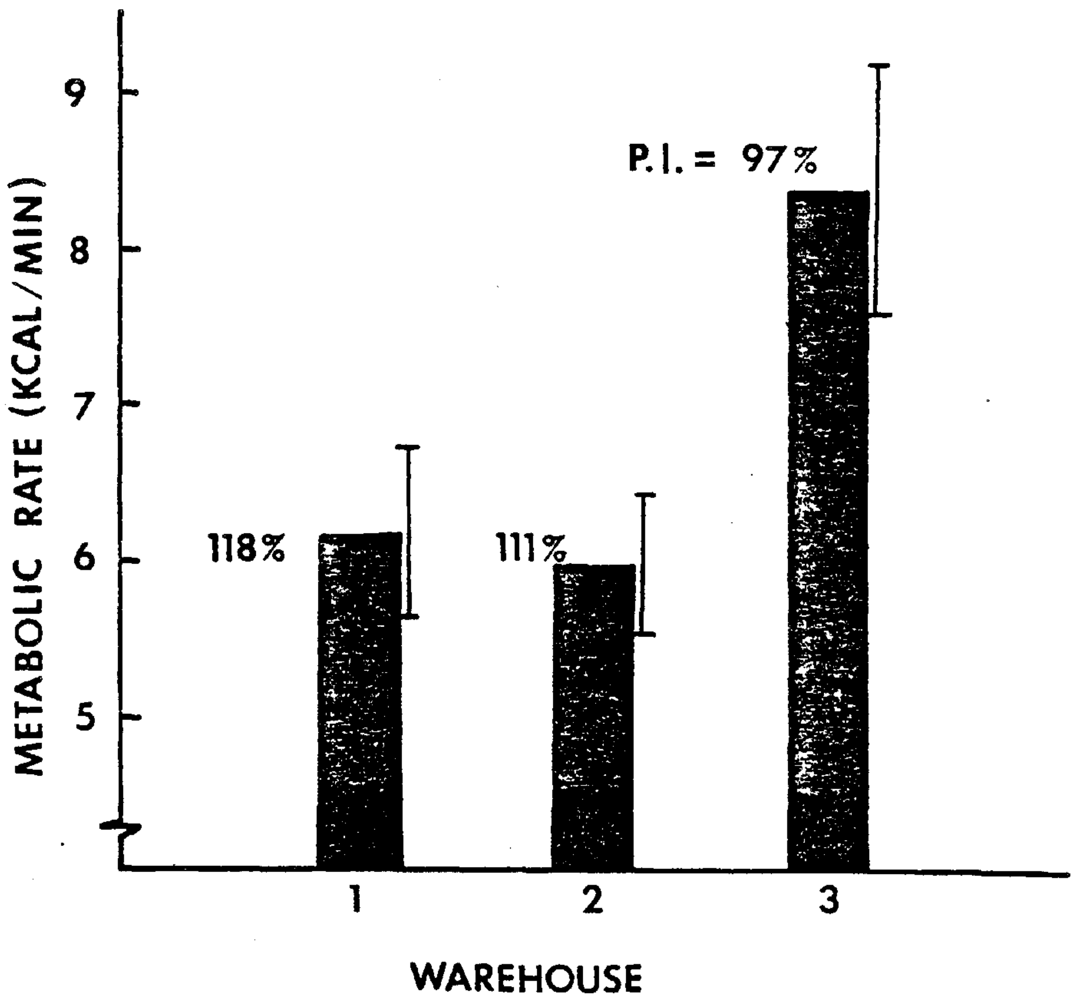

Figure 2.9: Comparison of Energy Expenditure Rates of Male Workers from the Three Warehouses.

that the subjects worked the hardest in warehouse 3 while the performance index indicates that the subjects' work intensity was the slowest in warehouse 3.

The subjects showed significantly higher heart rates in warehouse 2 than in warehouse 1 while their metabolic rates were the same. Since temperature and humidity in the two warehouses were about the same, it is reasonable to conclude that the subjects in warehouse 1 may be in better physical condition than the subjects in warehouse 2. Anthropometric data showed that the subjects in warehouse 1 were significantly younger (on the average by 9 years), taller (on the average by 7.2 cm) and heavier (on the average by 9.2 kg) than the subjects in warehouse 2. Also the physical difficulty of the job as perceived by the subjects was the most difficult in warehouse 2 and the least difficult in warehouse 1 (Figure 2.10). The rating of perceived exertion on the Borg scale was 13.3 (somewhat hard) for warehouse 1 and 16.5 (between hard and very hard) for warehouse 2.

Figure 2.11 gives a plot of heart rate against time from the three warehouses for a male subject working at about 100% performance level. This graph shows that the subjects do not work in a steady state during the course of an order selection: their heart rate and oxygen uptake (as observed by occasionally looking at Oxylog) vary considerably during order picking depending upon such factors as rate of handling cases, weight of the case and heights of slot and load on the pallet, etc. This graph also shows that the subjects consistently had the highest heart rate in warehouse 3 and the lowest in warehouse 1 during most of the working time while their work intensity as determined by the traditional work measurement systems was about the same.

Most warehouses recommend that the order selectors should walk close to the load, bend their knees and keep their backs straight when lifting and lowering a load. This recommendation is made with the expectation that the

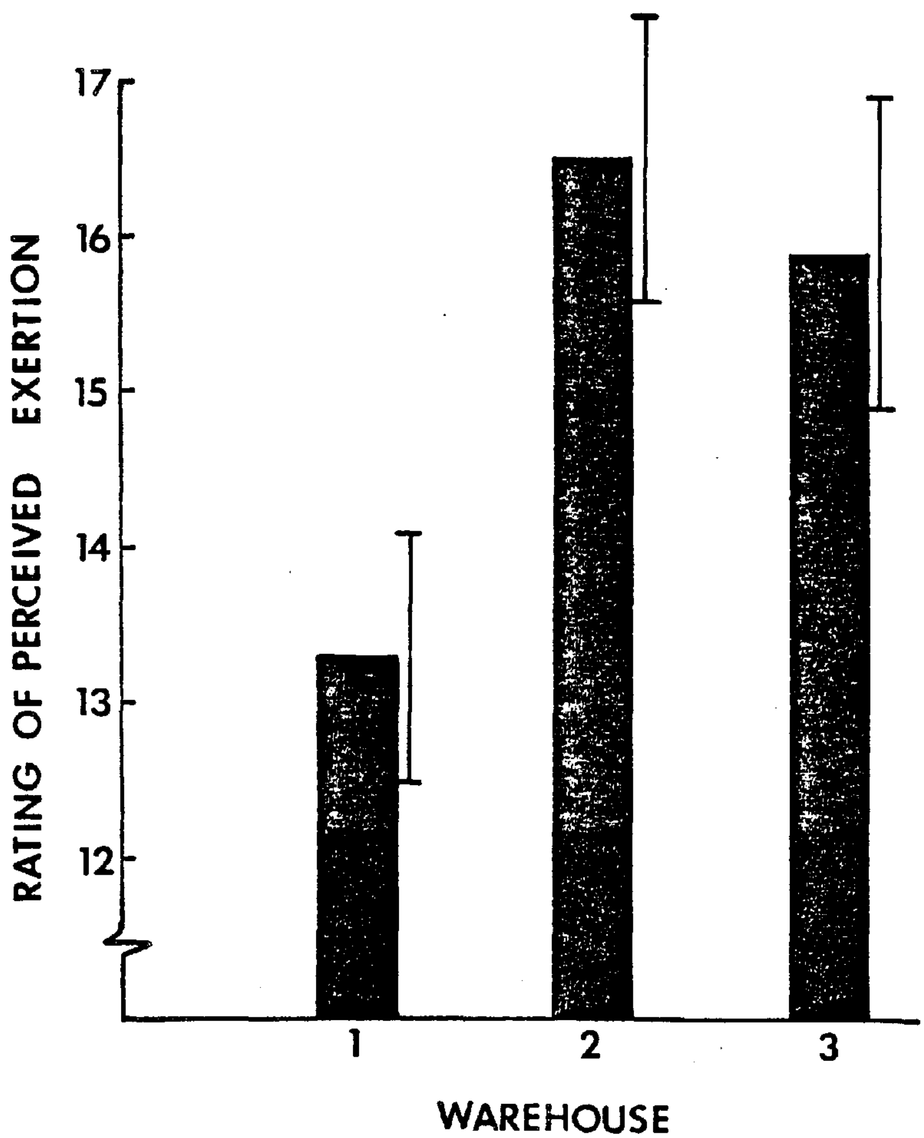

Figure 2.10: Physical Difficulty of the Order Selector's Job as Perceived by the Male Subjects from the Three Warehouses.

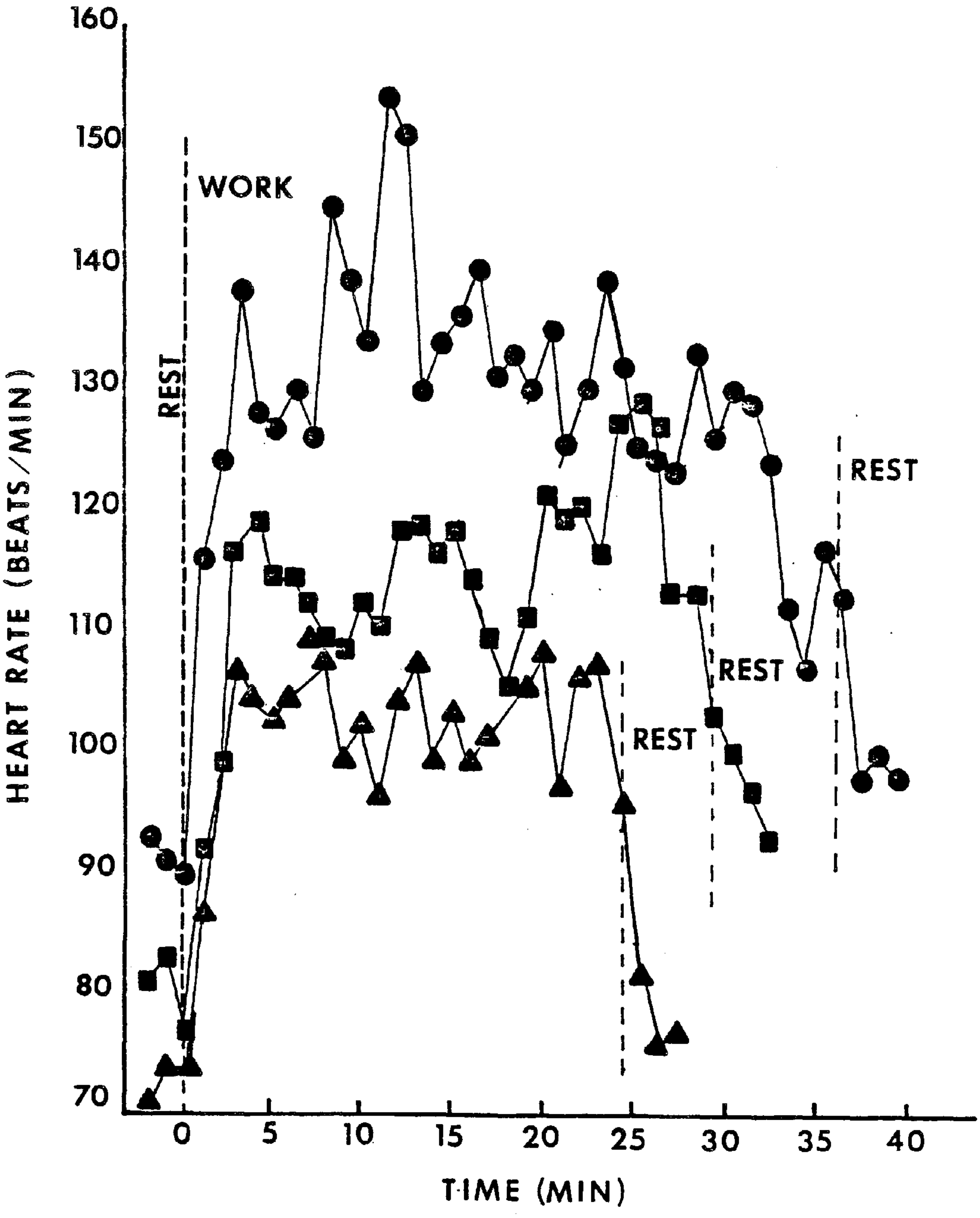

Figure 2.11: Heart Rate against Time for a Typical Male Worker Working at close to 100% Performance Level from Warehouse 1 (triangles), Warehouse 2 (squares) and Warehouse 3 (circles).

traditionally recommended squat method of lifting will reduce back injuries. It was observed that practically no order selector used the squat method of lifting in order to save time and energy.

A review of the literature (Garg and Saxena, 1979; Garg and Herrin, 1979; Brown, 1971) shows that the squat lifting technique is significantly more fatiguing than the commonly used stoop lifting method (bending the back and keeping the knees straight). In other words, it would be practically impossible for an order selector to use the squat method of lifting while maintaining a reasonable level of physiological stresses (heart rate and energy expenditure) if the existing standards are enforced.

CONCLUSION

(i) This study showed that the performance standards or time standards based on Time and Motion Study, Methods Time Measurement and Master Standard Data Systems are physiologically unacceptable. At the existing standards, additional fatigue allowances of 10.9, 13.3 and 93.7% of working time in warehouses 1, 2 and 3 are needed so that the stresses to the male workers are within physiologically acceptable limits. Female order selectors will need significantly greater fatigue allowances.

(ii) The average performance levels of male workers in warehouses 1, 2 and 3 were 118.8, 111.3 and 97.6% and the corresponding average metabolic rates were 6.16, 5.96 and 8.35 Kcal/min. Based on average energy demands, the job of an order selector is classified as very heavy in the first two warehouses and as extremely heavy in the third warehouse (Eastman Kodak Company, 1983).

(iii) Average heart rates of 110, 122 and 133 beats/min indicate that in two out of three warehouses subjects were working at a level close to or greater than 50% of their maximum aerobic power for bicycle ergometer. Average heart rates of 122 and 133 beats/min are very high compared to maximum heart rates of 144 to 164 beats/min reported by Petrofsky and Lind (1978) for lifting up to a 22.7 kg load.

(iv) 14, 25 and 54% of male workers in warehouses 1, 2 and 3, respectively, reached a peak heart rate of 154 to 181 beats/min. This indicates that for short spells a significant number of workers might be working close to or at maximal working capacity for this type of work.

(v) Heart rate recovery curves showed that 24, 70 and 86% of male workers in warehouses 1, 2 and 3 experienced excessive fatigue.

(vi) Average energy expenditure, heart rate and peak heart rate for six female workers were 5.9 Kcal/min, 148 beats/min and 163 beats/min while the average performance index was 109%. Heart rate recovery data showed that all six females experienced excessive fatigue.

(vii) 24, 30 and 64% of male workers failed to meet the 100% performance index in warehouses 1, 2 and 3, respectively, while their average energy expenditure rates were 6.34, 5.44 and 8.37 Kcal/min and their average heart rates were 110, 115 and 133 beats/min. Similarly, 33% of females failed to meet 100% performance while their average metabolic rate was 5.63 Kcal/min and the average heart rate was 161 beats/min.

(viii) A comparison of performance indexes from the three different warehouses with the physiological measurements showed that the heart rate during order selection was inversely related to the performance index. The average heart rates from the three warehouses were 110, 122 and 133 beats/min while the corresponding average performance indices were 118.9, 111.3 and 97.6%. Similarly, an energy expenditure of 8.35 Kcal/min in one warehouse was equivalent to a performance index of 97.6% while an energy expenditure of 6.16 Kcal/min in another warehouse was equivalent to a performance index of 118.8%.

There was no significant correlation between energy expenditure and performance index and heart rate and performance index in two out of three warehouses studied. On the other hand, the average correlation coefficient between energy expenditure and heart rate from the three warehouses was 0.65.

It is believed that if the existing performance standards are enforced without providing significantly greater fatigue allowances, a significant number of workers may not be able to meet these standards as they might be working close to their maximal working capacity for this type of work (lifting, lowering, carrying, etc.). This is especially true for the female and older work force. Other workers may accumulate excessive fatigue which may result in increased incidences of injury and illness. Disciplinary actions taken against the workers for not meeting 100% performance in one warehouse and accident statistics support this conclusion.

It is of importance to note that time standards are based so that "normal" performance should be achievable by practically all workers. The statement that is frequently made regarding time standards is that at least 95% of the healthy working population between the ages of 18 and 65 can achieve these standards (Karger and Hancock, 1982; Barnes, 1980). From a physiological point of view, it would be impossible for a large number of male workers and most female workers to maintain an average energy expenditure level over 8 Kcal/min and a heart rate of 133 beats/min over an 8-hour work day if the entire healthy working population between the ages of 18 and 65 is considered.

CHAPTER 3

BIOMECHANICAL AND ERGONOMIC EVALUATION

BIOMECHANICAL EVALUATION

Biomechanical criterion deals with force loadings on the musculoskeletal system as a predictor of tissue tolerance and muscle strain and sprain (including low-back pain). A selected number of tasks from the three warehouses were analyzed using the three-dimensional static strength biomechanical model (Garg and Chaffin, 1975; Chaffin, Herrin, Keyserling and Garg, 1977). A summary biomechanical analysis of some selected tasks is presented in Table 3.1.

Briefly, the three-dimensional static strength biomechanical model involves: (i) simulation of the task, (ii) computation of forces and moments (resultant moments) at various body joints, and (iii) comparison of these forces and moments with volitional forces and moments (muscle strength) to estimate the percentage of male and female populations that could be expected to perform the task occasionally without overexertion. The input to the model consists of either body joint angles or hand coordinates with reference to the center of the ankle joints, a gross body posture (such as stoop, squat, stand, lean, etc.), and the direction and magnitude of hand forces. The output from the model consists of the fraction of male and female populations capable of performing a given manual materials handling task, limiting muscle groups, and estimate of compressive force on the L5/S1 disc.

Maximum musculoskeletal stresses to an order selector occur while picking up an object from a slot or setting it on the pallet jack (origin and destination of lift, Park and Chaffin, 1974). Since the location of an object varies

Table 3.1

Biomechanical Analysis of Selected Order Selection Tasks

Task No.	Task	Body Posture	Object	Load (kg)	Hand Coordinates (cm) Right V	H	Left V	H	Percent Capable M	F	Compressive Force (kg)* M	F
1	Lift	Stoop	Rice Bag	45.4	20	33	20	20	90	42	639	566
2	Lift	Stoop	Burlap Rice	45.4	46	30	25	20	76	27	658	587
3	Lift	Stoop	Pinto Beans	45.4	38	25	51	38	67	10	564	514
4	Lift	Stoop	Wheat Flour	45.4	63	51	63	30	33	2	580	522
5	Lift	Stoop	Corn Starch	45.4	69	48	69	48	29	2	625	604
6	Lift	Stoop	Water Softener	36.4	66	58	66	58	34	1	634	675
7	Lift	Stand	Water Softener	36.4	173	38	152	23	81	13	457	401
8	Lift	Stoop	Sugar Bag	27.3	35	38	30	20	78	28	519	453
9	Lift	Stoop	Sugar Bag	27.3	51	53	43	33	82	32	615	437
10	Lift	Stoop	Rice Bag	27.3	53	61	46	33	84	34	635	570
11	Lift	Stand	Paper Bags	27.3	168	33	137	33	94	34	411	368
12	Lift	Stand	Bird Seeds	27.3	160	58	137	46	62	4	523	462
13	Lift	Stoop	Dog Food	22.7	38	48	38	48	79	29	561	490
14	Lift	Stoop	Dog Food	22.7	48	43	89	74	31	2	554	453
15	Lift	Stoop	Paper Box	22.7	46	68	68	68	19	1	499	492
16	Lift	Stand	Dog Chow	22.7	132	48	132	48	51	2	435	348
17	Lift	Stand	Charcoal	22.7	140	69	140	38	67	3	474	449
18	Lift	Stand	Johny Cut	22.7	172	51	155	41	96	21	439	336
19	Lift	Stand	Cat Food	21.8	213	25	213	25	Reach limit exceeded			
20	Lift	Stand	Dog Food	22.7	175	51	213	36	Reach limit exceeded			

V = Vertical distance of hand grip from floor
H = Horizontal distance of hand grip from ankles
*Estimated compressive force at the L5/S1 disc

considerably within a slot or on the pallet depending upon the size of the existing load, it could be easier or harder to manually lift an object than shown in Table 3.1. However, it is clear from Table 3.1 that most of the female workers and a significant number of male workers may not have sufficient strength to lift these objects. An analysis of Table 3.1 shows that less than 68% of the male workers and less than 25% of the female workers have sufficient strength to perform 9 and 11 tasks, respectively, out of 18 tasks analyzed in Table 3.1. In other words, it is estimated that at least one out of three male workers and three out of four female workers are not capable of occasionally lifting 50 and 61% of the objects, respectively, analyzed in Table 3.1 without overexerting themselves.

The estimated compressive force on the L5/S1 disc for the eighteen jobs ranged from 411 to 658 kg. The estimated compressive force was consistently higher than the recommended limit of 350 kg by the Work Practices Guide for Manual Lifting (U. S. Department of Health and Human Services, 1981). According to the above guide: "Jobs which place more than 650 kg compressive force on the low-back are hazardous to all but the healthiest of workers. In terms of a specification for design a much lower level of 350 kg or lower should be viewed as an upper limit." Based on an industrial study of 400 male workers, Chaffin and Park (1973) found that the observed incidence rates for low-back pain were related to predicted back compressive forces on the L5/S1 disc. Also, Brigham and Garg (1983) reported high predicted compressive forces on the L5/S1 disc for those jobs where back injuries occurred. The predicted compressive forces from this study may partially explain high incidence rates of low-back pain found among order selectors.

All six female workers and 70% of the male workers indicated that they experienced low-back pain because of work. Most of these workers indicated that they experienced pain frequently and a few indicated occasionally. Other body parts mentioned were feet and legs (35%), shoulder (17%) and wrist (8%).

Among several task factors which have an effect on a person's maximum voluntary isometric strength (MVIS), horizontal distance of the hands from the ankles is the most critical (Martin and Chaffin, 1972; U. S. Department of Health and Human Services, 1981). The MVIS at the horizontal distance of 51 cm is approximately 23 kg for the 50th percentile male population (Table 3.2). Since 12 out of 18 tasks in Table 3.1 required a horizontal distance for one of the hands of approximately 51 cm or greater while the weight of the load ranged from 22.7 to 45.4 kg it can be concluded that approximately half of the male workers may not have sufficient strength to perform these jobs without overexerting themselves. Similarly, a comparison of Tables 3.1 and 3.2 showed that for 13 out of 18 jobs analyzed in Table 3.1 job strength requirements exceeded the strength capability of the 90th percentile female population. Thus, the above comparison supports the findings based on the biomechanical analysis that the physical strength requirements for order selectors may be excessive for most female workers and a significant number of male workers.

A direct comparison between the action limits (AL) and the maximum permissible limits (MPL) recommended by the U. S. Department of Health and Human Services (1981) and the weight of the load may be misleading as the order selectors perform several other tasks such as lowering, pulling, walking, carrying, twisting, turning, etc., in addition to lifting loads from a slot. Also, the initial location of the load and travel distance vary considerably from object to object. Keeping these reservations in mind, AL and MPL were computed for an assumed horizontal distance of 51 cm, vertical

Table 3.2

Maximum Voluntary Isometric Strength as a Function of Vertical and Horizontal Location of Hands

Source	Hand Coordinates (cm)		Maximum Voluntary Isometric Strength (kg)									
			Males					Females				
			Population Percentile					Population Percentile				
	V	H	10	25	50	75	90	10	25	50	75	90
U. S. Dept. of Health & Human Services (1981)	38	38	26	34	45	60	77	13	17	24	33	44
Chaffin (1974)*	51	51	10	16	24	31	37	4	9	14	18	23
U. S. Dept. of Health & Human Services (1981)	152	25	35	44	55	66	76	16	22	29	36	42
U. S. Dept. of Health & Human Services (1981)	152	51	16	19	23	28	34	9	11	13	16	19

*Percentile strength estimated from mean and standard deviation assuming normal distribution distance of 38 cm, vertical travel distance of 51 cm and a frequency of 5.2 lifts/min (expected average frequency of 3.2 lifts/min from the three warehouses plus 2 lifts/min for additional lifting, lowering, pulling, carrying, walking, etc.). The resulting action limit and maximum permissible limit were 3.8 and 11.5 kg. Therefore, the average expected weight of 12.5 kg from the three warehouses was greater than MPL. In other words, only about 25% of the men and less than 1% of the women workers have the muscle strength to be capable of performing the work expected by the warehouses.

The maximum weight of an object was 45.4 kg (100 lbs) in warehouses 1 and 2 and 36.4 kg (80 lbs) in warehouse 3. There were several items which weighed approximately from 22.7 to 27.3 kg (50 to 60 lbs) in all three warehouses. Table 3.1 shows that the objects weighing from 22 to 45 kg are lifted from different heights ranging from near the floor level to as high as 213 cm. At the same time the horizontal distance of the left or the right hand from the ankles ranged from 20 to 74 cm. According to the Work Practices Guide (U. S. Department of Health and Human Services, 1981) the vertical reach for most people is 175 cm and the horizontal functional reach limit near the floor level is 80 cm. Thus, the order selectors are required to lift heavy loads to a vertical height which exceeds the vertical reach limit for most people and at a horizontal distance which is close to the functional reach limit. This can produce large stresses on the musculoskeletal system, and, in particular on the low-back, due to the large moment arm of the load.

ERGONOMIC EVALUATION

Warehouses used three different types of racks or slots commonly known as (i) a walk-in rack, (ii) a two-rack configuration, and (iii) a three-rack configuration. Walk-in racks were approximately 2.48 m wide and 2.48 m high.

The depth of the racks was 1.39 m at the bottom and 2.23 m at the top. Two- and three-rack configurations were approximately 2.48 m wide and 1.12 m deep. The heights of the racks were 1.22 m for the bottom rack and 2.56 m for the top rack in the two-rack configuration. In the three-rack configuration the heights were 0.86 m for the bottom rack, 1.67 m for the middle rack and 2.56 m for the top rack. Each rack had two pallets which were 1.22 m wide, 1.02 m deep and 0.13 m high. Pallets weighed from 29 to 38 kg. Pallets sitting outside and soaked with water weighed 45 kg, as determined by the subjective impressions of the workers.

Among the three different types of racks walk-in racks were the best. These were generally preferred by the order selectors. A worker can stand inside the rack and has maximum room to position the body to pick an object. However, it was found that often cases were stored too high and too far back (Figure 3.1). As a result, an order selector had to struggle to reach for a bulky and heavy case stored above shoulder height, or, in some cases, above overhead reach. Order selectors also did a lot of unnecessary walking and carrying to reach for cases stored too far back in the rack.

Warehouses 1 and 2 provided hooks or grabbers to pull cases stored in the top rack of the three-rack configuration. A worker would usually pull the case with a hook, drop it and catch it with his hands. Sometimes, more than one case came tumbling down. It was observed that all the top racks were not provided with hooks or grabbers. As a result the workers had to climb either on the cases in the bottom rack, on the pallets in the middle rack or on the motor jack to reach for the cases stored in the top racks of the two- and three-rack configurations. There were no hooks or grabbers in warehouse 3. Instead there was a triangular step or peg 7.6 x 1.5 cm for climbing.

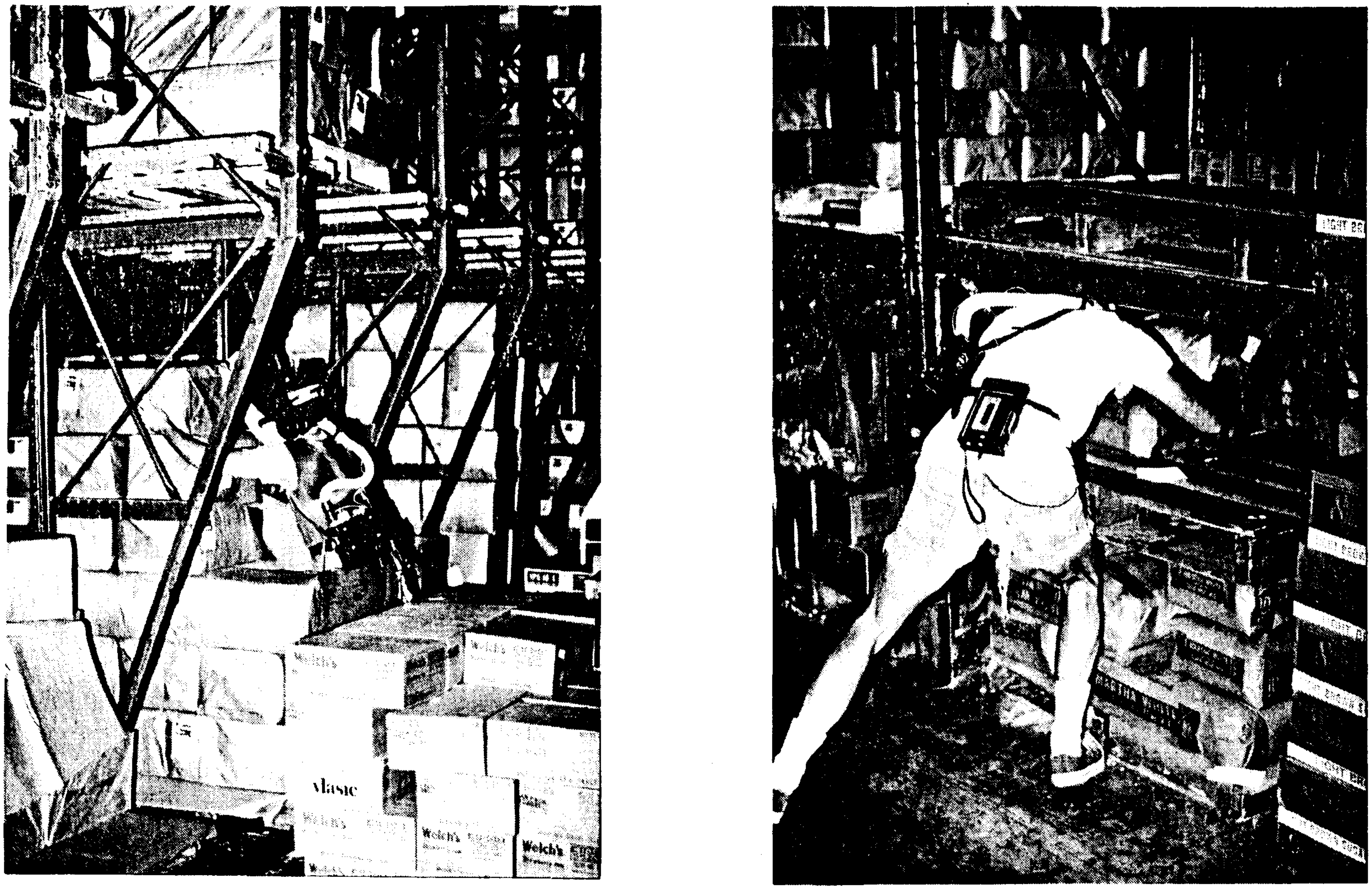

Figure 3.1: Examples of Picking a Load from a Walk In Slot (Left) and the Bottom Slot of a Two-Slot Configuration (Right)

Therefore, there was a lot more climbing involved in warehouse 3 as compared to the first two warehouses (Figure 3.2). Further, all racks did not have these steps. Using this step which was located at 76 cm height, workers usually climbed to the midde rack and bent over to reach for objects with one hand while holding the vertical rack post with the other hand. Often the workers had to climb to reach for cases located in the top racks of the two-rack configurations, especially if the cases were located far back in the rack.

It is concluded that the maximum height of 2.56 m for the top racks of two- and three-rack configurations is too high for practically all workers. This is especially true when the workers have to reach for objects which are located 1.12 m deep. The mean overhead reach for U. S. Air Force personnel is 2.01 m (Woodson, 1981). According to the Work Practices Guide, the upper range of vertical reach for most people is 175 cm (U. S. Department of Health and Human Services, 1981). Based on force capability and injury considerations, Chaffin and Ayoub (1975) recommended shoulder height, or approximately 127 cm for the general population, as the upper limit the hands should be raised when handling heavy loads.

There was excessive bending, crawling, kneeling, twisting and reaching involved when the workers had to pick an object from the bottom rack of a three-rack configuration, especially when the object was located deep inside the rack. Workers had to bend, crawl inside the rack and reach out to pull heavy and bulky cases and bags to the front of the rack (see Figure 3.3). A height of 86 cm for the bottom rack of the three-rack configuration is only slightly greater than the mean crawling height of 76 cm (Woodson, 1981). Given a depth of 112 cm, it is almost impossible to pick an object without assuming a very awkward body posture. Chaffin and Ayoub (1975) recommend that

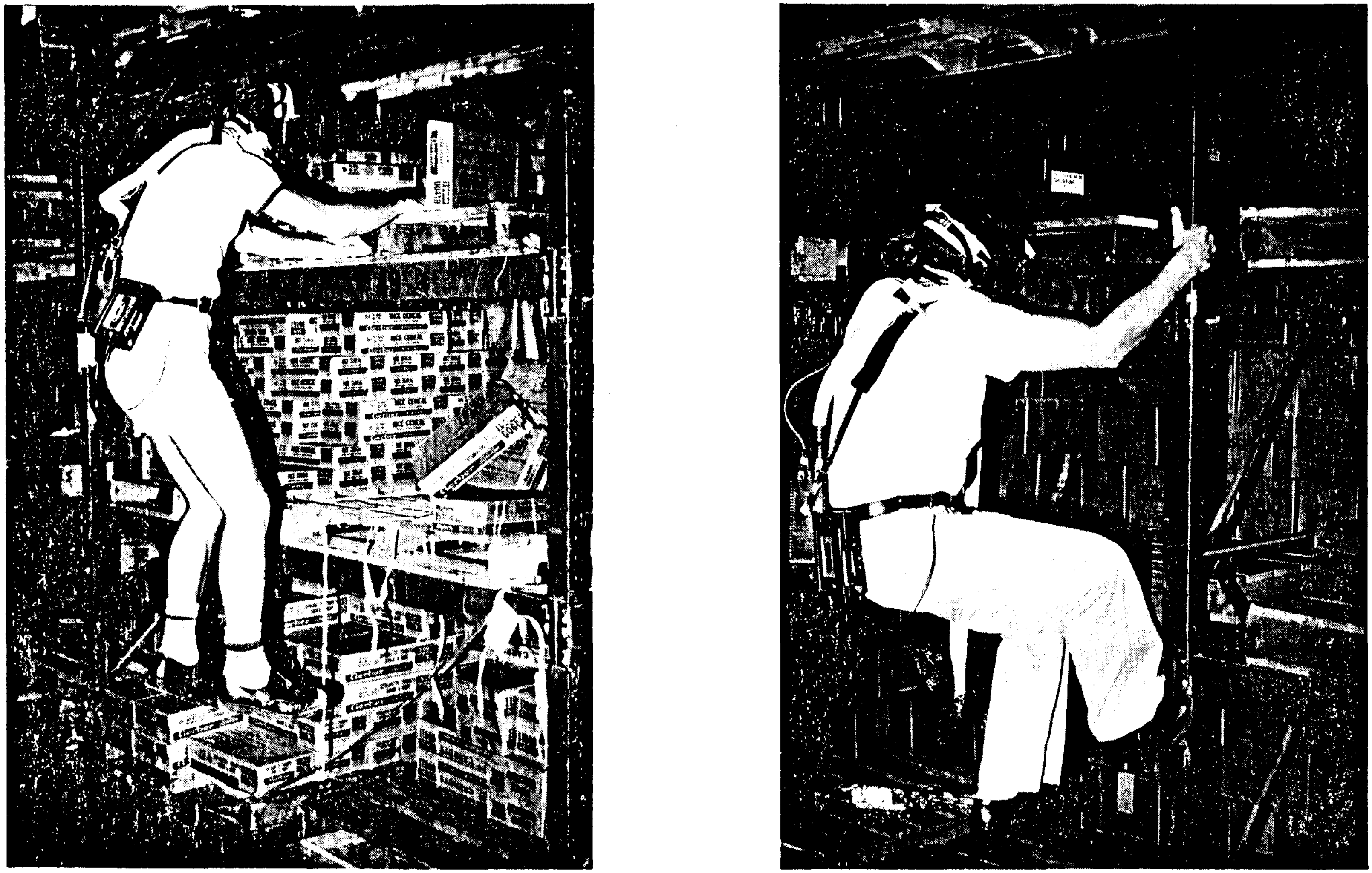

Figure 3.2: Examples of Picking a Load from the Top Slot of a Three-Slot Configuration. Figure on the Right Shows a Step Used for Climbing.

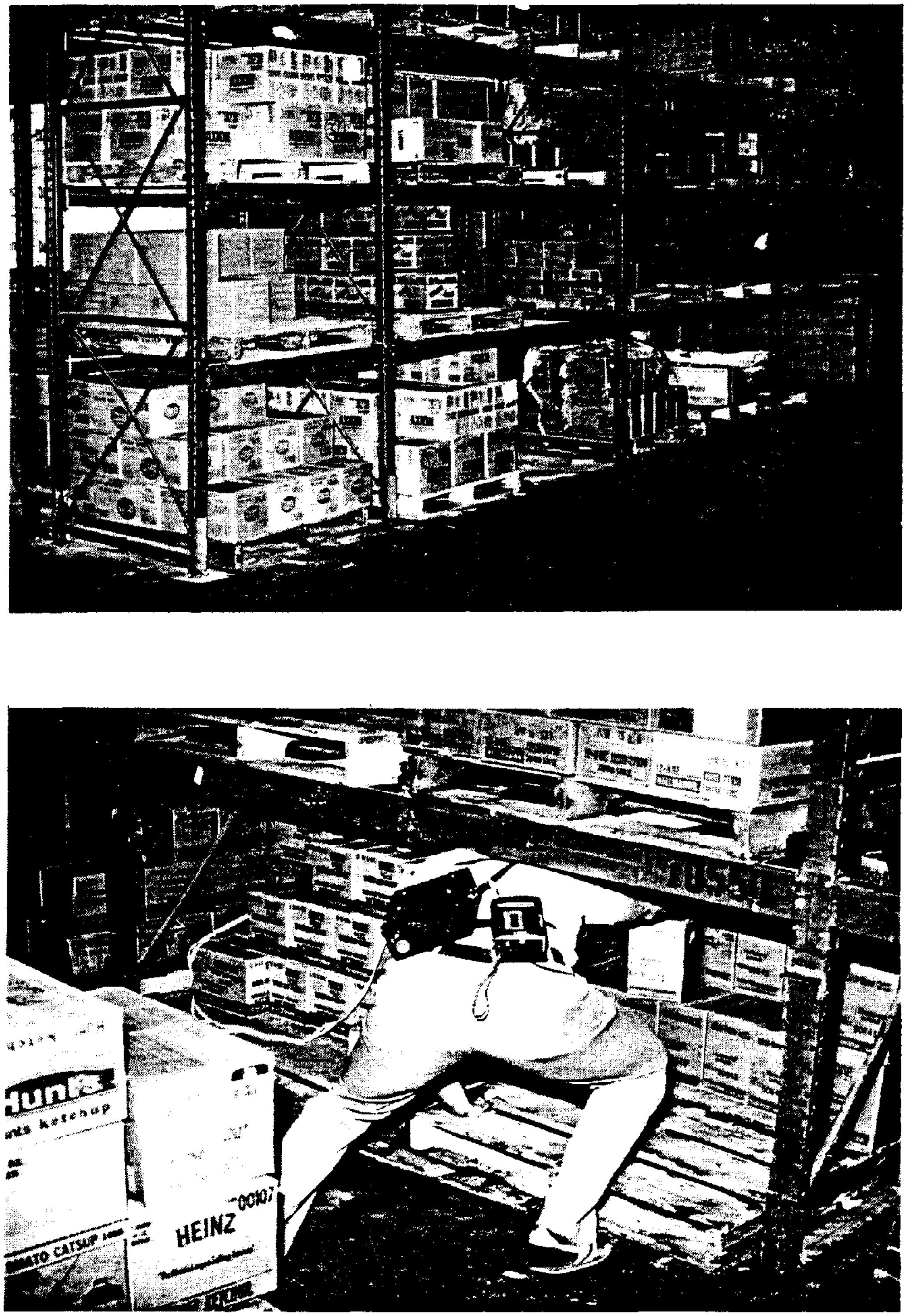

Figure 3.3: An Example of a Three-Slot Configuration (Top) and Body Posture Used to Pick Up a Load from the Bottom Slot (Bottom)

the workers' hands should be no lower than 51 cm from the floor when handling heavy objects (weighing more than 16 kg) to avoid excessive low-back stresses. Biomechanically, lifting a load weighing as little as 10 kg with the body extended can produce moments on the shoulder joint, in addition to the low-back, which exceed the voluntary strength capability of 90% of the female industrial population and about 40% of the male industrial population (U. S. Department of Health and Human Services, 1981). Excessive bending and stretching causes physical fatigue and postural stress which are two of the several contributory factors for the etiology of back pain (U. S. Department of Health and Human Services, 1981). Based on the above considerations, it is concluded that a height of 86 cm for the bottom racks of three-rack configurations is ergonomically unacceptable.

Generally, knuckle to shoulder height is the recommended height range for lifting heavy loads. However, it was observed that often the workers had to either climb or bend excessively to reach for an object even in this height range because of the 112 cm depth of the racks (see Figure 3.4). Excessive bending or reaching increases the moment arm of the load from the body. This increased moment arm can produce large compressive forces on the low-back even at a reasonable lifting height. Chaffin and Park (1973) have shown that the incidence rates for low-back pain were related to back compressive forces on the L5/S1 disc. Thus, it is concluded that lifting moderate to heavy loads from deep racks is certainly an added stress to the workers. It is recognized that it may not be possible to change the depth of the racks because of the standard size of the pallets that are used throughout the grocery industry, but the heights of the racks certainly need to be modified.

The warehouses had several other ergonomic problems. Some of these are briefly mentioned as follows:

Figure 3.4: Examples of Picking a Load from the Top Slot of a Two-Slot Configuration

1. Often heavy items weighing 16 to 23 kg (35 to 50 lbs) were stored in top racks while lighter items were stored in the bottom racks of the two-rack configuration (see Figure 3.5). Martin and Chaffin (1972) and Snook (1978) have shown that a person's strength capability decreases significantly above shoulder height. Similarly, bulky and heavy items weighing more than 23 kg were stored in the bottom racks of the three-rack configuration where it is very difficult to reach, pull and lift heavy bags and boxes. It is worth mentioning that it is especially difficult to lift and carry bags as they sag in the middle.
2. On several occasions the height of the load on the pallet jack was as high as 2.4 m (96 inches). It is very stressful to lift a bulky and heavy box or bag above one's head (Figure 3.6) and place it or throw it to a 2.4 m height. It was observed that the workers climbed on their jacks to build such high loads. Orders need to be controlled so that:
   (a) the maximum height of the load on the pallet jack is below shoulder height,
   (b) heavy and bulky items are not placed at the top, and
   (c) heavy and bulky items are not lifted above shoulder height.
3. Cases in a rack are interlocked (see Figure 3.1). Therefore it is very difficult for an order selector to pick the case or bag closest to him or in front of him. A worker has to pick the case which is at the top even though it may

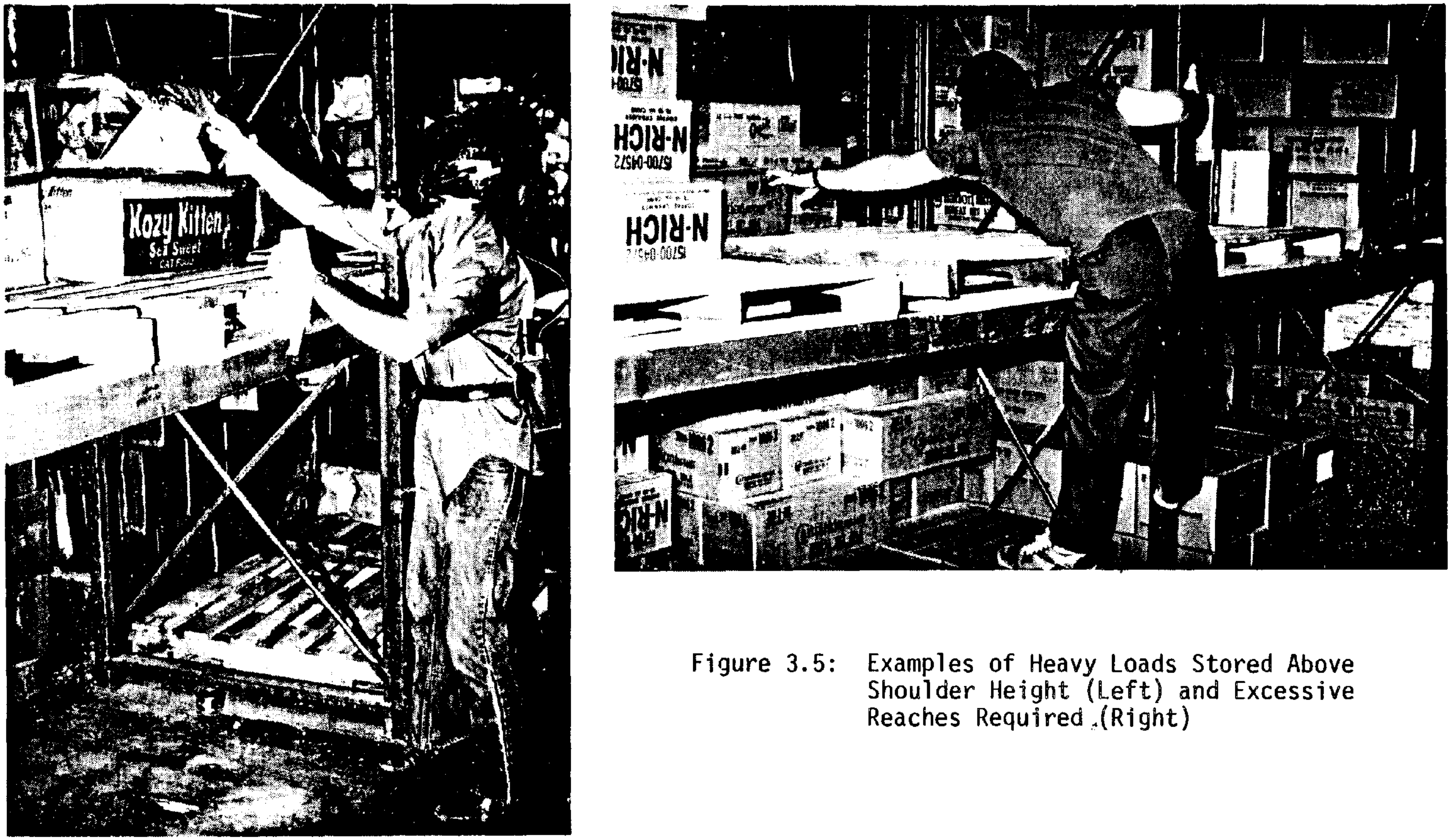

Figure 3.5: Examples of Heavy Loads Stored Above Shoulder Height (Left) and Excessive Reaches Required (Right)

Figure 3.6: Examples of Over-Head Reach Required.
Left: Picking a Load from the Top Slot of a Two-Slot Configuration.
Right: Setting a Load on the Pallet Jack.

be at the back of the rack. This causes excessive reaching and bending which is fatiguing. This can also cause back and other musculoskeletal injuries.

4. Sometimes workers pull an item from the middle or bottom of a stack to avoid climbing even though it may require a large pulling force. In the process some cases may come tumbling down and hit the worker.
5. Cases for certain items such as pineaple chunks, green beans, stroganoff, etc., are glued together. Workers had to pull and push to separate these cases before lifting them. These items should not be stored in the top racks.
6. Sometimes merchandise comes wrapped in a plastic cover. It was found that the order selectors had difficulty tearing and removing the plastic before picking up a case. It is recommended that the forklift operators should remove the plastic when placing such merchandise in a rack.
7. Often it is necessary to rearrange boxes and bags to build a balanced load on the pallet jack because these come in several different sizes and shapes. It is especially difficult to stack bags as they do not stay in place and the load shifts. There is some decision making process involved in building a load and explicit time should be allowed to build or rearrange the load on the pallet jack.
8. Sometimes the aisles were so congested that either a worker had to wait for the workers ahead of him to finish picking or do a lot of unnecessary walking and carrying (Figure 3.7).

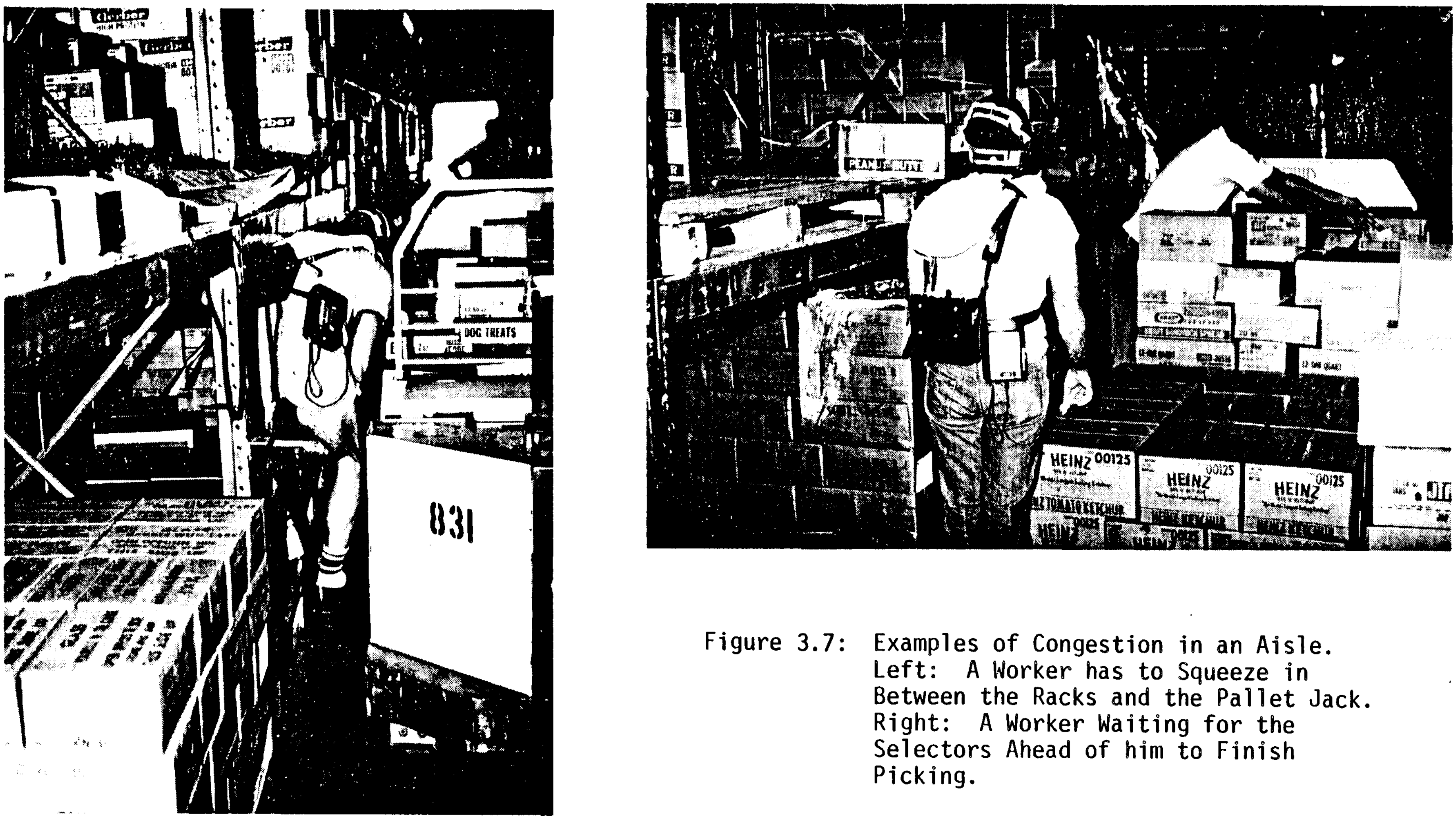

Figure 3.7: Examples of Congestion in an Aisle. Left: A Worker has to Squeeze in Between the Racks and the Pallet Jack. Right: A Worker Waiting for the Selectors Ahead of him to Finish Picking.

At times it was not possible for a pallet jack to pass one that was in front of it because of narrow aisles which resulted in delays. Crowded aisles also increase the amount of twisting to stack items on pallet jacks. Proper scheduling of orders is needed to minimize these delays, extra work and twisting. There were several other sources of unavoidable delays. Some of these are:

(a) extra time and travel associated with missing items (for example, there were 2.25 missing items/order in one warehouse),

(b) waiting for a forklift operator to complete a breakdown,

(c) forklift operator in the way,

(d) merchandise lying in the aisle to be stored.

9. Reserve stock is stored too high increasing the risk of falling objects. Paper towels and toilet paper boxes draw moisture. Humidity softens the box and makes it collapsible. The box can collapse and fall over the workers, especially when the humidity is high. Also, forklift operators cannot clearly see above when placing a pallet full of merchandise in the reserve stock area. A slight push of the pallet on the forklift truck to reserve stock causes cases to come tumbling down and these may hit the workers picking in the nearby area.

10. Floors should be kept clean all the time. A jack may slide if the floor is slick and may run over the feet of the

worker. Also, an order selector may lose control of the jack.

11. Pallets were supported on two railings on the right and left edges of the pallet. There was no support in the middle, front or back of the pallet. A pallet weighing 29 to 45 kg can drop and hurt the worker when one is pulling the empty pallet out of the rack.

An order selector is constantly on his feet. He is either standing and driving a pallet jack, walking to pick up merchandise, carrying merchandise or lifting, pushing, pulling, etc. Constant standing, walking or carrying in itself is fatiguing.

CHAPTER 4

SUMMARY OF RESULTS AND RECOMMENDATIONS

CONCLUSIONS

The objective of the present study was to study the physiological and biomechanical stresses to the grocery order selectors. Sixty-three male and six female order selectors from three different warehouses participated in the study. The duration of the experiment ranged from 12 to 64 minutes depending upon the size of the order and the pace of the worker. The average time was approximately 34 minutes. A number of measurements were made while the subjects performed their routine work of selecting groceries. These included resting heart rate, resting metabolic rate, rating of perceived exertion, performance index, working metabolic rate, working heart rate, peak heart rate, recovery heart rate, and number of pieces, weight and volume picked. In addition, selected tasks were biomechanically analyzed to quantify stresses to the musculoskeletal system and, in particular, to the low-back. Stressful work postures and motions were identified by performing an ergonomic study of representative task elements of order selecting. The major findings were:

* The performance standards or time standards based on Time and Motion Study, Methods Time Measurement and Master Standard Data Systems were physiologically unacceptable. Significant additional fatigue allowances are needed so that the stresses to the workers are within physiologically acceptable limits.
* Based on average energy demands, the job of an order selector is classified as very heavy to extremely heavy. In general,

order selectors also perceived their job between "hard" and "very hard".

* Average heart rates indicated that in two out of three warehouses subjects were working at a level close to or greater than 50% of their maximum aerobic power for bicycle ergometer.
* Peak heart rate showed that for short spells a significant number of workers might be working close to or at maximal working capacity for this type of work.
* Heart rate recovery curves showed that most workers and practically all workers in one warehouse experienced excessive fatigue.
* Approximately 40% of the workers failed to meet the 100% performance level while their average energy expenditure rate and heart rate were well in excess of the acceptable limits.
* There were large inconsistencies in performance indexes within a warehouse and large differences among the three warehouses as determined by the physiological cost of work. In two out of the three warehouses studied there was no significant correlation between performance index and energy expenditure or heart rate.
* Biomechanical evaluation of selected tasks showed that certain tasks produced large stresses on the muskuloskeletal system and to the low-back. It is estimated that at least one out of three male industrial workers and three out of four female industrial workers do not have sufficient strength to lift certain objects even occasionally without overexerting themselves.

* Estimated compressive force on the L5/S1 disc exceeded the recommended limit of 350 kg by the Work Practices Guide for Manual Lifting. Large compressive force along with physical fatigue increase the risk of back injuries.
* The risk for musculoskeletal and back injuries is high as the loads are heavy and bulky; they are lifted frequently; and the center of gravity of the load is remote from the body.
* Ergonomic evaluation showed that the racks were very deep and either too high or too low. The order selectors are required to lift heavy and bulky loads to a vertical height which exceeds the reach limit for most people and at a horizontal distance which is close to the functional reach limit.
* There were several ergonomic related problems found in the layout of the warehouses and the work methods.
* The job of an order selector requires excessive lifting, lowering, pushing, pulling, bending, twisting, stooping, reaching, climbing and crawling.

RECOMMENDATIONS

The objective of biomechanically analyzing jobs and determining the physiological cost of work in the industrial setup is to fit the job to the worker so that one can work without excessive physical stress, fatigue or harm to one's health. This study clearly showed the importance of obtaining quantitative data on biomechanical and physiological responses of workers as they are actually performing their job. Results of this study show that it is practically impossible to estimate accurately the difficulty of a physically demanding job from traditional work measurement techniques. Time study and predetermined motion-time data systems are based on psychomotor skills or body movement. They need to be modified to include physiological stresses especially for moderate to strenuous work. The job of order selector places a heavy physiological load upon the workers. Measures of heart rate and oxygen uptake provide a valid and reliable means of analyzing and assessing these jobs.

Lack of consistency within a traditional work measurement system and large differences between different work measurement systems as applied to physically demanding work should not be ignored. Physiological responses are especially useful to resolve this issue as it is well established that both energy expenditure and heart rate are linearly related to physical work intensity for a given type of work and ambient environment. For example, a given work intensity should produce about the same level of energy expenditure irrespective of the order and the warehouse.

Several ergonomic changes need to be made in grocery warehouses to avoid excessive fatigue, injury and illness and maintain standards which are within the physical work capacity of most industrial workers. Some of the specific recommendations are:

* Physiological measures such as oxygen uptake and heart rate should be used to quantify the physiological demands being placed on the order selectors and to check whether the performance standards based on traditional work measurements techniques are within physiologically acceptable limits.
* Oxygen uptake should be used to establish the duration and frequency of fatigue allowances needed by the workers who perform physically taxing work.

* Ergonomic principles should be used in the design of racks, physical layout, size of the order and arrangement of grocery items. This should minimize the physiological cost of work, reduce injury and illness to order selectors and improve productivity.
* Jobs should be biomechanically analyzed to estimate stresses to the musculoskeletal system and, in particular, on the low-back. Biomechanical job evaluation can be very useful in identifying highly stressful tasks and evaluating alternate methods or workplace layouts.

Since both the physical strength and endurance requirements for the order selector's job are very high, certain administrative controls may be necessary even with the recommended changes to reduce the future risk of injury and illness among the order selectors. The suggested adminstrative controls are:

* Order selectors should be rotated to physically less demanding jobs within a warehouse.
* Overtime should be kept to a minimum as the energy requirements for the job are very high. Further, overtime should be made voluntary so that a tired worker with a limited aerobic capacity is not forced to maintain a certain level of performance after an eight-hour work day.
* Maximum aerobic capacity should be determined before placing the workers on the order selection job. Maximum aerobic capacity can be estimated from submaximal tests to determine whether a worker is physically fit to endure the high level of muscular work required in the warehouses without causing

excessive strain on the respiratory and cardiovascular systems.

* Some form of a strength testing program should be initiated to select the workers for the order selector's job because of high strength requirements of the job.

One final recommendation is that the warehouses should develop a better system to monitor injury and illness profiles of the workers. This system can be useful in preparing injury and illness statistics and establishing causes of many different types of musculoskeletal and contact injuries.

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Table A.1

Total Cases, Weight and Volume Handled and Allowed Time for the Twenty-One Male Subjects Studied in Warehouse 1

Subject No.	Cases/ Order	Weight/ Order (kg)	Volume/ Order (m^3)	Allowed Time (min)
1	103	874.1	1.689	36.7
2	59	886.4	1.538	20.9
3	77	1056.4	1.695	26.2
4	65	851.8	1.533	27.5
5	83	891.4	1.506	37.1
6	38	341.4	0.692	19.1
7	35	236.4	1.939	20.6
8	54	506.4	1.509	23.6
9	77	970.4	1.549	28.5
10	78	840.9	1.472	36.7
11	57	319.1	1.506	24.6
12	79	1237.3	1.693	25.5
13	79	1094.5	1.668	27.2
14	103	1018.6	1.690	32.7
15	65	649.1	1.509	25.9
16	55	675.9	1.685	22.4
17	54	1126.4	1.515	22.4
18	53	834.1	1.555	22.9
19	88	1098.6	1.688	31.6
20	79	1247.3	1.685	26.9
21	83	1211.4	1.651	26.1

Table A.2

Total Cases, Weight and Volume Handled and Allowed Time for the Twenty Male Subjects Studied in Warehouse 2

Subject No.	Cases/ Order	Weight/ Order (kg)	Volume/ Order (m^3)	Allowed Time (min)
1	58	760.0	1.897	32
2	81	797.3	5.805	41
3	84	751.4	1.133	22
4	108	1393.6	3.568	31
5	206	2315.0	1.925	47
6	99	974.5	1.926	26
7	110	1064.5	1.812	33
8	214	1736.4	3.058	56
9	59	1122.7	2.463	27
10	130	1452.3	3.993	33
11	182	2078.2	3.058	44
12	81	1156.8	2.747	31
13	102	2131.8	4.587	44
14	74	843.2	2.294	24
15	71	1233.2	1.926	28
16	61	1016.8	1.501	19
17	117	1205.9	1.784	27
18	108	1145.5	1.727	26
19	195	1980.4	2.945	49
20	216	2333.2	3.426	49

Table A.3

Total Cases, Weight and Volume Handled and Allowed Time for the Twenty-Two Male Subjects Studied in Warehouse 3

Subject No.	Cases/ Order	Weight/ Order (kg)	Volume/ Order (m^3)	Allowed Time (min)
1	146	1368.6	3.990	48
2	137	1820.0	4.004	44
3	94	1430.9	2.730	32
4	161	1820.9	3.882	47
5	142	1864.5	3.959	51
6	175	2815.9	4.061	43
7	131	1731.4	3.964	37
8	162	1703.2	4.029	46
9	198	2395.0	4.131	55
10	124	2853.6	3.967	29
11	125	2431.8	3.950	35
12	141	1371.8	4.593	38
13	110	1420.0	3.964	40
14	112	1207.7	3.330	35
15	186	2449.5	3.942	44
16	134	2740.5	3.976	36
17	171	1754.1	3.953	52
18	130	1690.5	4.052	43
19	168	1617.3	3.953	45
20	195	2151.8	3.978	53
21	176	2200.9	3.896	47
22	197	1368.6	3.953	52

Table A.4

Total Cases, Weight and Volume and Allowed Time for the Six Female Subjects Studied in the Three Warehouses

Warehouse No.	Subject No.	Cases/ Order	Weight/ Order (kg)	Volume/ Order (m^3)	Allowed Time (min)
1	1	102	1178.2	1.668	30.7
2	2	51	943.2	1.444	17.0
2	3	117	1425.4	3.709	31.0
2	4	54	739.4	1.840	21.0
2	5	79	735.4	1.104	21.0
3	6	151	2191.4	3.995	44.0

Table A.5

Rating of Perceived Exertion, Performance Index and Resting (Standing Relaxed) and Working (Average) Metabolic and Heart Rates for the Twenty-One Male Subjects Studied in Warehouse 1

Subject No.	RPE	Performance Index %	Avg. Metabolic Rate (Kcal/min) Resting	Avg. Metabolic Rate (Kcal/min) Working	Heart Rate (Beats/min) Resting (Standing)	Heart Rate (Beats/min) Working Avg.	Heart Rate (Beats/min) Working Peak
1	13	129.6	--	7.47	--	118	128
2	13	98.6	--	5.86	66	98	113
3	13	123.0	--	4.86	--	116	133
4	13	96.5	--	4.77	--	71	91
5	9	124.9	--	7.40	72	112	129
6	15	159.1	--	6.28	--	113	132
7	13	137.3	--	5.77	98	142	159
8	16	136.4	--	4.70	66	83	93
9	13	109.6	--	6.12	74	105	119
10	16	136.9	--	5.24	81	108	123
11	15	120.0	--	4.39	77	93	101
12	13	93.4	--	7.17	104	149	168
13	15	101.3	--	5.58	81	115	127
14	11	148.6	--	8.67	83	124	140
15	13	116.4	--	8.00	96	136	155
16	16	99.5	--	6.97	94	125	132
17	13	133.0	--	6.44	64	104	115
18	12	114.5	--	5.05	63	88	97
19	11	118.8	--	5.41	71	102	118
20	14	93.0	--	6.95	80	109	120
21	13	105.1	--	6.27	72	103	108

Table A.6

Rating of Perceived Exertion, Performance Index and Resting (Standing Relaxed) and Working (Average) Metabolic and Heart Rates for the Twenty Male Subjects Studied in Warehouse 2

Subject No.	RPE	Performance Index %	Avg. Metabolic Rate (Kcal/min) Resting	Avg. Metabolic Rate (Kcal/min) Working	Heart Rate (Beats/min) Resting (Standing)	Heart Rate (Beats/min) Working Avg.	Heart Rate (Beats/min) Working Peak
1	19	121.5	1.66	4.82	84	106	118
2	15	124.2	2.30	6.89	111	139	154
3	19	89.4	1.84	5.44	76	100	108
4	17	101.3	2.13	5.65	80	115	129
5	15	93.2	1.99	5.20	86	116	139
6	17	114.2	1.60	6.41	80	122	130
7	17	133.3	1.85	7.20	81	121	136
8	13	120.4	2.20	6.04	93	136	163
9	19	136.1	1.57	8.11	83	158	171
10	19	117.1	1.80	6.20	109	148	162
11	14	115.7	2.25	6.32	76	122	139
12	17	136.2	1.66	5.21	124	147	161
13	17	114.2	1.66	5.22	74	105	126
14	13	92.3	2.18	5.97	111	132	141
15	15	137.2	1.85	6.62	83	128	139
16	19	108.5	1.66	4.83	66	84	104
17	15	114.8	1.99	7.00	80	116	129
18	17	91.2	1.80	4.98	73	113	130
19	17	80.2	2.04	5.06	81	98	109
20	17	85.2	1.80	6.01	95	132	140

Table A.7

Rating of Perceived Exertion, Performance Index, and Resting (Standing Relaxed) and Working (Average) Metabolic and Heart Rates for the Twenty-Two Male Subjects Studied in Warehouse 3

Subject No.	RPE	Performance Index %	Avg. Metabolic Rate (Kcal/min) Resting	Avg. Metabolic Rate (Kcal/min) Working	Heart Rate (Beats/min) Resting (Standing)	Heart Rate (Beats/min) Working Avg.	Heart Rate (Beats/min) Working Peak
1	16	105.4	2.27	5.74	78	115	127
2	19	91.3	2.18	7.97	91	134	141
3	18	106.3	2.46	9.08	90	120	128
4	13	78.8	2.42	8.95	106	161	181
5	15	92.7	2.08	7.63	93	127	143
6	15	97.7	2.27	10.61	105	164	180
7	15	83.3	2.04	11.05	82	134	160
8	15	85.8	2.20	6.49	71	120	149
9	15	91.9	1.38	8.39	65	107	120
10	15	112.4	1.52	9.07	85	144	158
11	17	97.7	2.32	5.76	69	124	137
12	13	99.7	2.15	8.34	102	140	158
13	13	103.0	2.04	7.71	91	134	154
14	19	115.1	2.74	9.94	110	148	161
15	14	92.0	2.98	11.51	100	138	155
16	19	106.1	2.13	9.63	80	140	160
17	17	80.4	2.04	8.96	85	141	161
18	15	86.5	1.66	5.82	66	96	108
19	17	99.5	2.46	8.80	89	130	143
20	19	88.3	2.08	6.91	72	140	161
21	17	120.5	2.04	8.76	100	139	153
22	14	112.3	1.66	6.59	70	129	141

Table A.8

Rating of Perceived Exertion, Performance Index, and Resting (Standing Relaxed) and Working (Average) Metabolic and Heart Rates for the Six Female Subjects Studied in Three Different Warehouses

Warehouse No.	Subject No.	RPE	Performance Index %	Avg. Metabolic Rate (Kcal/min) Resting	Avg. Metabolic Rate (Kcal/min) Working	Heart Rate (Beats/min) Resting (Standing)	Heart Rate (Beats/min) Working Avg.	Heart Rate (Beats/min) Working Peak
1	1	15	105.8	--	5.15	83	129	142
2	2	16	144.6	1.77	7.57	110	162	181
2	3	17	93.9	1.81	5.15	106	154	176
2	4	17	107.6	1.75	6.07	104	144	161
2	5	13	113.5	1.83	5.35	100	129	136
3	6	13	90.1	2.04	6.11	131	169	179