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BIOMECHANICAL ANALYSIS OF TASKS INVOLVING MANUAL MATERIALS HAND--ETC(U)
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BIOMECHANICAL ANALYSIS OF TASKS INVOLVING
MANUAL MATERIALS HANDLING

Richard H. Shannon

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February 1982

NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Two papers are presented which deal with biomechanics and its relationships with manual materials handling, sex differences and training. The first paper outlines a factor analytic model of lifting in the floor-knuckle and knuckle- shoulder regimens under experimental conditions. Sixteen subjects were divided equally into four groups of males trained/untrained and females trained/ untrained. Results indicated that (1) there were different motion patterns among the four groups, (2) male movements approximated the trained and female movements the untrained conditions, and (3) trained individuals demonstrated			

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BLODK 20 ABSTRACT (Continued)

more efficient and coordinated lifts. Training programs are recommended in the working environment if women are expected to lift moderately heavy loads because of their lower physical fitness and coordination when compared to men. This statement is further supported by the second paper, which conducted a critical incident technique of 484 strain/sprain/overexertion injuries of naval civilian government workers. Results indicated that males had significantly more injuries to the back, to craftsmen/operatives/laborers, using heavy/very heavy weight. On the other hand, women showed significantly more incidents to the shoulder/neck/arms, in sales/service/clerical occupations, using light/medium loads. Male incidents seem to be related more to a failure to recognize safety hazards, while female injuries appear to be caused more by poor load handling techniques.

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BIOMECHANICAL ANALYSIS OF TASKS INVOLVING
MANUAL MATERIALS HANDLING

Richard H. Shannon

February 1982

Bureau of Medicine and Surgery
Work Unit No. MF58.524-02E-0002

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SUMMARY PAGE

PROBLEM

The effectiveness of personnel within the working environment is lowered when the biomechanical laws of motion are not followed. Increased body fatigue, higher incidents of injury, lowered productivity, and decreased coordination and motion efficiency can result from this omission. The first paper examines this problem by studying the differences between males/females and trained/untrained personnel while lifting various weights in two height regimes under controlled conditions. The second paper extends this investigation by analyzing 484 strain/sprain/overexertion injuries in order to determine causality and possible remedial solutions.

FINDINGS

- (1) Male movements approximated the trained condition while female lifts were similar to the untrained sample.
- (2) Trained individuals demonstrated more efficient and coordinated lifts by having similar patterns of acceleration with, but significantly higher deceleration patterns from, the untrained sample.
- (3) Women, when compared with males, had significantly more injuries with lighter weights, to the shoulder/neck/arms, in sales/service/clerical occupations, due to poor load handling techniques.
- (4) Males, when compared with females, had significantly more injuries with heavier weight, to the back, to laborers/craftsmen/operatives, due to failure to recognize safety hazards.

RECOMMENDATIONS

- (1) Motor coordination tests should be practiced prior to use in a repeated measures experiment.
- (2) Factor analysis may be a viable method of analyzing dynamic motion.
- (3) Lift training and physical fitness programs should be implemented on a regular basis within the Naval Establishment.

The work was funded by the Naval Medical Research and Development Command and by the Biological Sciences Division of the Office of Naval Research.

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Each of these papers was presented at a professional meeting or symposium. Acknowledgement of previous publication appears at the beginning of each paper.

FACTOR ANALYTIC APPROACH TO BIOMECHANICAL MODELING¹

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INTRODUCTION

As an aid in the analysis of motor behavior during the lifting of materials, biomechanical models have been used to study the effects of reactive forces and torques on the joints and links of the human body. In order to apply the mechanical laws of Newton to this type of research, an individual's segment lengths, centers of gravity and weight should be known. One of the first significant works on segmental centers was performed in 1889 by Braune and Fischer (1963) through their dissections of three cadavers. In 1955, Dempster extended this work by analyzing eight cadavers which resulted in better estimates of body dimensions. This research was further expanded by Clauser (1969), Plagenhof (1971) and El-Bassoussi (1974). Other authors (Donskoi, 1973; Zatsiorsky, 1973; Kirjonen, 1968) have applied multivariate statistics to develop their biomechanical models. The underlying principle used in their studies was that individual segment motion is a part of a phase of motion, and that the combination of all phases represent the total system of activity. Roozbazar (1973) emphasized the need for more multivariate analysis in his review of various approaches to biomechanical modeling due to the complexity of body movement. Finkelman and his associates (1977) recommended that multivariate analysis of variance be used in combination with univariate F tests. He claimed that multiple univariate analysis of variance tests applied to simultaneous multimodality measures often resulted in alpha error and loss of information due to the interdependence of dependent variables.

¹The assistance and advice of Dr. M. M. Ayoub during this research effort is greatly appreciated.

For these reasons, the present investigation utilized factor analysis to extend El-Bassoussi's model (1974) involving non-repetitive, short duration lifts in the sagittal plane. The result was a bio-mechanical model based upon clusters of motion in the floor-knuckle and knuckle-shoulder ranges of lift. These two regimens of motion are close analogs to industrial handling conditions in the sagittal plane; such as lifting a load from the floor to a table and from a table to a shelf. A separate analysis was conducted on each range of motion by studying fifteen dependent variables of segment accelerations, electromyograms and forces at the feet. The resultant factor-variables were then utilized to compare lifting by male/female and trained/untrained individuals over time and weight within each regimen. The purpose of this paper is to outline the development, validation and utility of this factor analytic approach to further dynamic motion research.

METHOD

Eight male and eight female university students who were similar in age and anthropometric dimensions were used in this experiment. Age of the subjects ranged from 18 to 30 with a median of 25 years. Means and standard deviations, respectively, for the weight and height among the subjects were 62.4 kgs., 2.2 kgs. and 172 cms, 2.8 cms. Segment lengths were also controlled with the highest standard deviation among the links being 1.6 cms.

Initially all sixteen subjects were considered inexperienced and untrained. An inexperienced/untrained lifter is operationally defined in this experiment as one who did not participate in a regular physical fitness program or exercise routine, use weights, or have a job which involved manual handling of materials. From this sample, four males and four females were selected for the training program while the other eight subjects served as the control group. The experiment also involved separating these sixteen subjects into two equal groups of male/female and trained/untrained individuals (experimental and validation) for replication purposes. Each of the subjects were observed under all treatment conditions of weight (10, 25, 40 pounds), time (0-.25, .26-.50, .51-.75, .76-1.00, 1.01-1.25 second intervals), measure (pre and post training), and lift regimens (floor-knuckle, knuckle-shoulder). After completion of the training program, approximately a two week interval, the trained and untrained subjects were again measured. Although data for both replication groups were collected separately, the two training programs and time intervals between measurement periods were similar. In all, there were six independent variables and 960 cases per lift for each of the 15 dependent variables. A case represented the combination of the following levels within each independent variable on two trials and 16 subjects: sex-2, program-2, group-2 (between subject variables); weight-3, time-5, measure-2 (within subject variables).

The training program consisted of two males and two females in each replication group lifting 10, 25, and 40 pound weights in floor to knuckle and knuckle to shoulder lift regimens for fourteen practice periods. During each session, subjects in the training program lifted each weight by regimen approximately six to eight times. This totaled to approximately 42 lifts per subject per session. The goal of the program was to improve technique rather than to have muscular development. There was never any attempt to stress, fatigue or motivate the subject to complete more work than he or she wanted to do or was capable of doing. The program attempted to: (1) improve coordination between and rhythm within body segments, (2) decrease biomechanical stress, (3) increase movement efficiency and economy, and (4) stress a lifting method (National Safety Council, 1974) which relied upon balance, initial thrust and low moments upon the body. By emphasizing these rules repeatedly, it was assumed that each trained subject would optimize his performance through repetitive trial and error motion.

Data collection entailed the use of stroboscopic photography, force platform and electromyogram (EMG) methodologies. The equipment consisted of a still camera, lights and a rotating disc with equally spaced apertures for photography; a force plate and dynagraph for force recordings; integrating preamplifier and miniature surface electrodes ($\frac{1}{2}$ " diameter) for electromyograms, and weights and barbell. The resulting photographic negatives of the experimental lifts provided angular displacement-time data from the lighted movements of the joints. Angular displacements were found by measuring the angles between each joint's segments (El-Bassoussi, 1974). The floor-knuckle lift had six angular displacements (0, .25, .5, .75, 1.0, 1.25 seconds) for the ankle, knee, hip and shoulder joints, while the knuckle-shoulder lift data on the ankle, hip, shoulder and elbow joints was collected. In order to simplify the dynamic analysis of the data, the following assumptions were made:

1. The human body is composed of rigid links.
2. These links are joined at articulation points or joints.
3. The lower arm and hand, because they remain aligned during motion, were considered as one link in the analysis. The same was true of the arm during the floor-knuckle lift and leg during knuckle-shoulder lift, since the upper and lower portions of these appendages moved similarly.
4. The density and geometrical shape of a segment remained uniform throughout the lift.
5. Rotation occurred only about the sagittal plane.
6. Segmental motion was considered circular and the radius of rotation was constant.
7. Displacement between the joints and their connecting links was negligible.

8. The ankle remained fixed in one position throughout a lift.

The displacement - time relationship of Slote-Stone (1963) was used next in the calculations. This equation is:

$$\text{Angular Displacement (time } t_1) = \frac{D_{\max}}{2\pi} \left(\frac{2\pi t_1}{T} - \sin \frac{2\pi t_1}{T} \right)$$

where; D_{\max} = maximum angular displacement, radians
 T = total displacement time, seconds
 t_1 = incremental time, seconds

Instantaneous angular displacement is seen in this equation as being of equal increments of total displacement in radians. These increments of displacement are determined from the relationship between the incremental time period to total time of movement. The total time used in the analysis of each segment was the difference between start and end of motion or 1.25 seconds. The advantages of having fixed time intervals and a total time limitation in the study were that the problems associated with the analysis of continuous data was avoided, while all of the pertinent information was included and numerical handling was facilitated. The first and second derivatives with respect to time of the angular displacement equation are angular velocity and angular acceleration. These values determined linear acceleration for each segment. Also important in these calculations is the determination of each segment's weight from percentages of actual body weight and center of gravity from percentages of actual segment length. These transformation values can be found in Plagenhoff (1971). The results of this effort in each lift regimen were: (1) accelerations in the z and x axes for each segment analyzed, and (2) inertial forces at the hands in the z and x axes. The z and x axes (Thomas, 1972) represent, respectively, vertical (up/down) and horizontal (forward/backward) movement with positive acceleration being in the direction of motion.

Integrated electromyograms in arbitrary units for each incremental time period were collected on two muscles: medial deltoid and rectus femoris, quadriceps. The main functions of these muscles are that of shoulder abduction (deltoid), and knee extension and hip flexion (quadriceps). During the experiment, muscular activity was measured by placing both sets of probes in the center of the muscle on the right side of the body. Tracings of these electrode attachments were made during the first measurement period so that placement during the second period would be standardized. Two curves were determined, unstressed (relaxed) and stressed (lifting) conditions. The unstressed baselines were subtracted from the stressed muscular outputs in order to correct for measurement error, heart rate and muscular tension. Lastly, a dynagraph and force platform were used to record force changes at the feet: frontal (forward/backward), lateral (left/right), and vertical (up/down). Data output was in

terms of peak variations of positive and negative forces for each time interval above and below a zero baseline.

The last topic of discussion in this section is the experimental procedure. Prior to the placing of electrodes, the subject was allowed a familiarization or warm-up period of 15 minutes, which involved calisthenics and the lifting of 10, 25, and 40 lb. weight loads. Each individual was then connected with electrodes and positioned on the force platform. During the experiment, each person performed three lifts with each weight in each regimen. There was a total of 18 lifts per subject. The first lift was a practice one, while data were collected on the second and third lifts. The sequence of weight lifted by one subject was randomly selected, and maintained across both regimens.

RESULTS

Factor analysis was performed separately for each lift regimen on the 15 dependent variables involving acceleration patterns in the x and z axes, forces at the feet in three axes, and two electromyograms. Inertial forces at the hands in the x and z axes were not included in these analyses, but were studied during the validation phase of this experiment. The conceptual model for factor analysis utilized in this study treated the testing conditions (dependent variables) as variables, the time segments and independent variables as cases, and people as constants. In this approach, the resultant factors were clusters of variables as they covary over time. The principal axis method was conducted to maximize the amount of variance shared commonly among the factors. Factoring was halted when the eigenvalue slipped below 1.0. Accordingly, two factors explained 58% of the variance for the floor to knuckle lift, and three factors explained 53% of the variance for the knuckle to shoulder lift. Varimax rotation was performed so that each variable loaded mainly on only one factor. In this way, factorial interpretation is as simple as possible. Table 1 contains the results of the statistical rotation with the variable loadings outlined by factor. A factor loading is similar to a correlation coefficient. The square of the loading indicates the amount of variance explained by a variable on a factor. The sum of the squares in any column gives the total amount of variance by a factor, while the average of these squared loadings depicts the proportion of total variance. The sum of squared loadings in a row (h^2) shows the proportion of variance by a variable on all of the factors. The higher the h^2 , the more common variance a variable shares with the other variables (Nunnally, 1967).

TABLE I
 FACTOR MATRIX AND LOADINGS FOR FLOOR-KNUCKLE AND
 KNUCKLE-SHOULDER LIFTS OF THE COMBINED SAMPLE

VARIABLES	FLOOR-KNUCKLE LIFT			KNUCKLE-SHOULDER LIFT			
	FACTORS		h ² *	FACTORS			h ² *
I	II	III		IV	V		
Rectus Femoris	.20	.11	.05	.09	.00	.00	.01
Medial Deltoid	.08	-.02	.01	.20	.02	.01	.04
Frontal Force	-.34	-.22	.16	.21	-.06	.24	.11
Lateral Force	.29	.03	.09	-.16	-.22	.28	.15
Vertical Force	.78	-.04	.61	.22	-.09	.53	.34
Leg - X Axis	-	-	-	.70	-.06	.06	.50
Lower Leg - X	.76	.42	.75	-	-	-	-
Upper Leg - X	-.73	-.19	.57	-	-	-	-
Trunk - X	.46	-.60	.57	.94	.03	.11	.89
Arm - X	.94	-.20	.92	-	-	-	-
Upper Arm - X	-	-	-	.88	.08	.06	.78
Lower Arm - X	-	-	-	.91	-.03	.08	.84
Hand - X	.96	-.04	.92	.63	-.13	.18	.45
Leg - Z Axis	-	-	-	.00	.75	-.03	.56
Lower Leg - Z	-.23	.67	.50	-	-	-	-
Upper Leg - Z	-.10	.84	.72	-	-	-	-
Trunk - Z	.29	.95	.99	.02	.93	-.09	.87
Arm - Z	.45	.85	.93	-	-	-	-
Upper Arm - Z	-	-	-	-.13	.80	.25	.72
Lower Arm - Z	-	-	-	.02	.38	.89	.93
Hand - Z	.53	.77	.87	.07	.11	.90	.83
Total Variance	.31	.27	.58	.24	.15	.14	.53

*h² = common variance explained by variable

Table I indicates that most of the variance is explained by the acceleration data. In the floor-knuckle lift, factor I was represented by movement in the x axis, while factor II was defined by changes in the z axis. Factor III in the knuckle-shoulder regimen stood for x axis movement. Trunk/upper arm/leg and lower arm/hand movements in the z axis, respectively, defined factors IV and V. Although the electromyogram and force platform variables did not contribute heavily to the factor structure, many of the factor loadings were significant at .20 and above. Quadriceps and deltoid muscles loaded, respectively, on the x axis of the floor-knuckle and knuckle-shoulder lifts. This was as expected since these lifts coincided closely with each muscle's specific function. Vertical force explained

most of the variance of the platform variables within the factor structure. These significant loadings demonstrated some concurrent validation between the different sources of data collection and analysis.

Validation of this factor variable model was performed by comparing the factor structure of both the experimental and validation samples. The factor scores for each person from either the experimental or validation group were correlated with the scores from the combined data set. The comparability of the factors was judged by the size of the relationships (Nunnally, 1967). Factor scores are computed using a multiple linear regression model which utilizes the loadings as beta weights that are multiplied by the case's standard score on each variable. The following results indicated a high similarity between both factor structures: I = .751, II = .911, III = .360, IV = .685, V = .915. Validity of the Slote and Stone equations was also important since the development of the present model depended upon the determination of angular velocities and accelerations for each body segment. Validation procedures were performed using the Kolmogorov-Smirnov goodness-of-fit test. Results indicated that there were similar distributions in both lift regimens for (1) observed and predicted (Slote and Stone) angular displacements on all of the segments over time, and (2) the resultant forces in the x and z axes from both the feet (platform) and hands (film). Multiple regression was also used which demonstrated that there were significant relationships between inertial forces at the hands (film) and forces at the feet (platform). The average multiple correlation for the four regression analyses was .467.

DISCUSSION

A valid biomechanical model utilizing factor analysis was developed for non-repetitive, short duration tasks in the sagittal plane during floor-knuckle and knuckle-shoulder lifts. The factor analytic procedure was performed in order to determine similarities or clusters among the variables, to erect a structure or classification model to ease the burden of analysis and interpretation, to increase experimental power and validity, and to act as a screening device for testing the aggregate effects of each variable. The utility and extension of this methodology to future experimental studies could be demonstrated by the combination of factor analysis with analysis of variance in this research effort. Fifteen dependent variables in each regimen were collapsed to five dependent factor-variables. Factor scores from these analyses were then studied at four different statistical levels. Analysis of variance, simple main effects, and Tukey multiple comparisons helped to determine significant main and simple main effects. In this way, large amounts of information were efficiently and effectively studied through the clustering and screening of the data. T-tests were then used to evaluate the impact of significant indepen-

dent variables on each of the 15 dependent measures within each factor by studying the initial (non-factored) values. This last effort completed the computations by isolating the critical components of motion in order that inferences could be stated. Throughout these statistical tests, the alpha probability level was made smaller as the level of testing changed in order to minimize the occurrence of a Type I error.

SUMMARY AND CONCLUSIONS

(1) Males had higher accelerations and decelerations than females during the floor-knuckle lift.

(2) Males relied more on back and arm strength, while women used more leg and back motion to supplement strength differences during the knuckle-shoulder lift.

(3) Male movements approximated the trained condition while female lifts were similar to the untrained sample in both lifts.

(4) Trained individuals demonstrated more efficient and coordinated lifts by having similar patterns of acceleration with, but significantly higher deceleration patterns from, the untrained condition during both lifts.

(5) If women are expected to lift moderately heavy loads, training programs should be considered in the industrial environment because of their lower physical fitness and coordination when compared to men. This last conclusion was supported by another study (Shannon, 1980) in which a critical incident technique of strain/sprain/overexertion injuries in the industrial environment was conducted.

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MANUAL MATERIALS HANDLING INJURIES OF NAVAL CIVILIAN WORKERS

CDR RICHARD H. SHANNON, Ph.D.

INTRODUCTION

Utility of Human Factors Analyses

The design, production and verification stages of consumer product development as well as the long-term effects upon society and the environment can best be studied using a human factors systems approach. This technique examines the interdependencies between man, material and the environment involving present circumstances as well as projecting future outcomes. This effort is not only concerned with improved productivity, efficiency, sales and maintainability, but with the safe match between people and the handling of consumer products within the home and the industrial environment. The importance of these goals to the consumer product industry are highlighted when compared with the resultant problems associated with nonsystematic practices, vested interests, fixity of professional intent and bureaucratic staticism.

The most powerful arguments for the use of human factors research in developing new consumer products is that such research can limit the financial risk, either by reducing product failure, safety litigation or lost workdays due to injury. Throughout the developmental process, the human factors specialist can definitely be a cost-effective addition to the manufacturer (Cannon, 1975; Levy, 1973). Directly related to this argument is that of the social responsibility of the manufacturer to the worker and the community. Silverstein (1973) believes that the human factors specialist can help the consumer product industry to become more accountable for its activities by specifying its inadequacies and prescribing plans for corrective actions.

Lifting injury

One important part of the consumer industry is that of worker safety during the handling of goods either during production, transportation, storage, maintenance or sales. The manual handling of materials is one of the necessary tasks performed by people in the industrial environment. The risk of injury, especially to the lower back, during load handling is affected by numerous variables. These variables were outlined in a recent review (Herrin, Chaffin, Mach, 1974) of the manual materials handling literature. A classification schema was used in this survey which categorized 488 research reports into the four following groups:

(1) worker variables consisting of physical, sensory, motor, personality, experience and health measures.

(2) material/container variables such as weight, load distribution, container size/shape and handle size/shape/location measures.

(3) task variables involving spatial (distance and direction of path), time (frequency, duration, pace) and environmental (temperature, humidity, noise, vibration) measures.

(4) work practice variables including lifting/posture technique, organizational (teamwork, supervision) and administrative (safety training, job rotation, compensation, work shifts) measures.

Taxonomic classification such as this outline is a very important tool. Without a unifying system, Chambers (1969) believes it would be exceedingly difficult to achieve generalization of research results, communication between research and applied workers, application of research results to applied problems, and utilization of data acquired from one applied situation to another. This outline can be used to determine the size and scope of the lifting problem as well as to isolate specific areas for future investigations. Company insurance and medical reports involving injury from material handling operations can be analyzed. A content analysis would be performed on these qualitative records which would result in the extraction of quantitative information giving insight into the frequency, causes and seriousness of the problem (Flanagan, 1954). There are certain limitations to this technique (Shannon, Waag, 1973), however, which are:

- (1) All mishaps are not reported.
- (2) The reports, although based on expert opinion, are still subjective and open to error.
- (3) The reports are too concise and not sufficiently detailed.
- (4) The content analysis of the reports depends upon the subjective evaluation of an investigator.

Although these field surveys have limitations, they can be considered very useful in giving the researcher an historical perspective. Troup (1965) indicated that approximately 12% of industrial injuries are related to back problems caused by handling materials. Magora and Traustein (1969) listed the percentages of total injury by specific occupations having back pain as varying from 6.4% for policemen to 21.6% for heavy industry with an average of 13.2% for the total listed occupations. Snook (1978) stated that approximately one-quarter of compensable work injuries are associated with manual handling of materials, and of these eight percent are to the lower back. A study of a California work sample (Leavitt, Johnson and Beyer, 1971) indicated that 60% of the injuries were due to strain and overexertion. Of these, approximately 80% were back and spine strains. The highest rate of occurrence by age was 40-49 (30%), with 20-29 (20%) and 50-59 (20%). Adams (1973) cited information from Accident Facts (1971) that 22.6% of all compensable work injuries and 13.9% of all fatal or permanent injuries during 1971 were related to manual materials handling. The author concluded that handling injuries are among the most frequent and costly types of compensable work injuries. Since Adams believed that standards could not be determined that would protect all workers from possible injury, he stated that the best approach would be to focus upon the frequent and serious problem of back overexertion.

Other individuals have studied back injury prevention in a more controlled experimental setting. Both Snook (1978) and Ayoub (1978) have determined safe weight lifting values for male and female workers over various lift ranges, frequency rates and box sizes. The average weight lifted by females was 57 percent of the male value in the lift ranges analyzed (Ayoub, 1978).

This research also had application in the selection of workers who were capable of handling the typical loads for a specific task or job.

Some experimenters have chosen to study lifting techniques as a means of alleviating injury. Grieve (1974), Roozbazar (1974) and El-Bassoussi (1974), in general, agreed with the lift method recommended by the National Safety Council (1974) of straight back, stable feet position, arms close to the body and knees bent. Shannon (1978b) compared sex and training variables during non-repetitive, short duration lifts in two height ranges. He concluded that lift training programs are at least advisable and may be necessary in the industrial environment if women are to be expected to lift loads of approximately 40 pounds, especially in the height range from the hip to the shoulder.

Some analysts have believed physical fitness to be one of the more important variables in lifting tasks (Snook and Ciriello, 1972). Presently, H. Kraus and A. Melleby are successfully guiding a YMCA training program designed to relax, limber and tone abdominal and back muscles in order to reduce back pain (Galton, 1978). The importance of training and exercise can be underscored by its results: increased muscular size and heart efficiency; improved motor unit transmission, motion precision and economy, and cardiovascular recovery; healthier blood pressure, respiration and blood distribution (Brouha, 1960).

Lastly, Kroemer (1978) has emphasized the need to design jobs so that manual materials handling is either avoided, or performed in such a way that physical stress is lowered. He advocates a systematic approach using ergonomics and human factors principles and findings which would be used to either automate handling or design better equipment. His goal was to lower the amount of manual handling of goods by the worker.

Purpose

The importance of human factors methods to the consumer product industry was reviewed in the Introduction of this paper. In addition, one segment of that industry, the manual handling of materials, has been shown to have potentially a higher incidence of back injury. Various attempts at alleviating that problem have been discussed. The purpose of the present paper is to study worker and task variables through a critical incident technique of examining strain/sprain/overexertion injuries resulting from load handling. Recommendations will then be presented based upon these and other results from the literature which can be useful to worker safety programs and industrial systems designs within the consumer product industry.

METHOD

The critical incident technique (Flanagan, 1954; Shannon, Waag, 1973) appeared to be applicable to the aims of the present investigation, which were to catalogue, describe and analyze human injuries relating to the manual handling of materials. The incidents with which this technique deals are descriptions of directly observable human activities which are sufficiently complete in themselves to permit inferences to be made about the person performing the act. For the incident to be critical, it must describe segments of human behavior that are pertinent to a desired objective. In other words, if the purpose of the study is to reduce personnel injury while

handling commodities in the naval civilian government sector, the observer must describe situations in which injuries do occur in that specific environment.

There were 484 strain/sprain/overexertion injuries resulting from load handling by naval civilian government workers between 1 July 1976 and 30 June 1977, which were obtained from the computer records kept on file at the Naval Safety Center in Norfolk, Virginia. This agency maintains standardized and readily accessible information pertaining to personnel injuries and mishaps from all naval environments (air, sea, land involving military and civilian personnel). In particular, the information in this paper were reported to the Safety Center via a civilian personnel injury/death report. These reports follow a standardized format of commentary and are completed by knowledgeable and competent observers.

A content analysis was performed on these injury reports by isolating information based on age, body injury, days absent (injury severity), month of year, occupation, type of handling, weight handled, and human error causality. Human error was defined in this investigation to be any deviation from a previously established, required or expected standard of human performance which resulted in or occurred during the incident. Two or more errors or locations of bodily injury were possible during a single situation and were treated as separate data points. Also, an error could be: (1) primary, if its occurrence was directly responsible for the injury; (2) contributory, if its occurrence, although not directly responsible, enhanced the conditions ultimately leading to the injury.

Before proceeding, two assumptions relating to the analyses of the data should be outlined. The information presented in this paper has limitations such as subjective opinion, totality of incidents due to omitted reports, and lack of detail in the described injuries. Statistical significance of a category is quite dependent upon these problems. If these limitations are kept in mind, this writer believes that this type of investigation definitely has utility in the isolation of and solution of critical problems involving systems design, development and utility. Secondly, approximately half of the incidents analyzed are not consumer oriented because they are related to aircraft and automobile systems and parts. However, the similarity of handling loads is considered to be generalizable across industries; and therefore, the results of this study are applicable to the consumer product industry.

RESULTS

Table 1 depicts quantitative information based on worker and task variables for the 484 critical incidents analyzed. Age within the sample ranged from 17 to over 60 years with a median of 37 years (38 for males, 34 for females). Injury severity (minor, major) and sex (male, female) function as dependent variables. The TOTAL columns represent both minor and major injuries. A major injury is defined as one in which the worker is absent five or more days from work. Minor injury includes one to four days of absence. The range of lost workdays were from one to 140 with a median of six days for males and one day for females. In some cases the numbers are

TABLE 5
WORKER/TASK VARIABLE BREAKDOWN OF 484 INJURIES BY
SEVERITY AND SEX WHILE HANDLING MANUAL MATERIALS

VARIABLES	MALES		FEMALES		COMBINED	
	MAJOR**	TOTAL***	MAJOR	TOTAL	MAJOR	TOTAL
AGE: TOTAL	212*	377*	24	79	236	456
17 - 29	43	117	5	27	48	144*
30 & OVER	169	260	19	52	188*	312
BODY LOCATION: TOTAL	242*	412*	28	88	270	500
BACK	189	317*	22	58	211*	375*
THORAX/ABDOMEN	12	17	2	8	14	25
SHOULDER/NECK/ARMS	23	44	3	17*	26	61
PELVIS/LEGS	18	34	1	5	19	39
MONTHS OF YEAR: TOTAL	223*	401*	26	83	249	484
JAN - MAR	32	90	9*	26	41	116
APR - JUN	87*	120*	5	13	92*	133
JUL - SEP	44	102	9	27	53	129
OCT - DEC	60	89	3	17	63	106
OCCUPATION: TOTAL	223*	401*	26	83	249	484
SERVICE/SALES/CLERICAL	17	80	14*	51*	31	131
CRAFTSMEN/OPERATIVES/ LABORERS	206*	321*	12	32	218*	353*
TYPE OF HANDLING: TOTAL	223*	401*	26	83	249	484
LIFT	166	303	15	58	181*	361*
PUSH/PULL	29	47	5	15	34	62
CARRY	28	51	6	10	34	61
WEIGHT: TOTAL	223*	401*	26	83	249	484
LIGHT/MEDIUM(1-35 LBS)	49	97	16*	56*	68	153
HEAVY/VERY HEAVY (OVER 35 LBS)	174*	304*	10	27	181*	331*
HUMAN ERROR CAUSALITY: TOTAL	92*	155*	13	27	105	182
POOR LOAD HANDLING TECHNIQUE	31	60	7	17*	38	77
FAILURE TO RECOGNIZE SAFETY HAZARD	61	95*	6	10	67*	105*

* $p < .05$

** REPRESENTS 5 OR MORE DAYS ABSENCE

*** TOTAL = MAJOR + MINOR INJURIES

higher (body location) or lower (causality, age) than 484 indicating that more than one area of the body was overexerted during an incident or that some of the reports did not contain age or causality data. Whichever the case, the data are compared using the number of data points per descriptive section.

The t-test of percentage differences was used in Table 1 (Garrett, 1968) to determine whether there were a proportionately higher number of injuries and major injuries per qualitative category by comparing (a) males and females and (b) total cases to a standard probability representing chance. Male and female injuries are considered as representing two statistically separate samples drawn from their respective populations. The null hypothesis was that there were no differences between population parameters (injuries and major injuries); and therefore, the samples were drawn from the same population of incidents. The critical t value for two-tailed tests having a .05 level of significance is 1.96. In general, males had significantly more injuries to the back (total), between April - June (major and total), to craftsmen/ operatives/laborers (major, total), using heavy/very heavy weights (major, total), and failing to recognize safety hazards (total) than the female sample. On the other hand, females showed significantly more incidents to the shoulder/neck/arms (total), during January - March (major), sales/ service/clerical occupations (major, total) using light/medium weights (major, total), and demonstrating poor load handling techniques (total) than the male sample.

The second series of statistical t-tests used reference values to signify chance. The null hypothesis was that the occurrences of combined injuries and major injuries within this sample did not differ from the expected number of the population. One-tailed tests setting .05 as the level of significance were performed using a critical t value of 1.65. The population reference values for chance occurrence were computed in all cases except three (age, occupation, sex) by dividing 100 percent by the number of specific categories within a section. For example, there are four categories listed under body location (Table 1) which resulted in a reference value of 25 percent. Probabilities of the three variables that did not fit this method of estimation were determined from published 1970 census values of the labor force (Wattenberg, 1976). These estimates are: sex (males, .65; females, .35), age (17 - 29, .25; 30 and over, .75), occupation (sales/service/clerical, .60; craftsmen/operatives/laborers, .40). In general, the number of injuries were significantly higher in the 17 - 29 age category (total), for the 30 and over age group (major), to the back (major, total), during April - June (major), within the craftsman/operative/laborer occupations (major, total), during lift handling (major, total), with heavy/very heavy weights (major, total), and failing to recognize safety hazards (major, total) than expected by chance. Also, males had significantly more major and total injuries in all categories.

Table 2 depicts the phi correlations or coefficients (Winkler, Hays, 1975) and the amount of association between the dichotomous variables of weight (0 = light/medium, 1 = heavy/very heavy), occupation (0 = sales/ service/clerical, 1 = craftsmen/operatives/laborers), age (0 = 17 - 29, 1 = 30 and over), sex (0 = male, 1 = female) and injury severity (0 = minor, 1 = major). A correlation of .109 was considered significant at the .01 level using the smallest sample size of 456. Two multiple regression analyses were

TABLE 2
 MATRIX OF PHI COEFFICIENTS SHOWING ASSOCIATION
 AMONG DICHOTOMOUS HANDLING INJURY VARIABLES*

	WEIGHT	OCCUPATION	AGE	SEX	INJURY SEVERITY
WEIGHT	-	.027	.026	.351	.121
OCCUPATION		-	.030	.352	.261
AGE			-	.026	.250
SEX				-	.183
INJURY SEVERITY					-

* $p < .01 = .109$

performed using the significant correlations with the dependent variables of either sex or injury severity. The multiple correlations of these analyses are .377 for the injury severity and .494 for the sex variables which indicate the following associations:

(1) 30 and over years of age, male sex, heavy/very heavy weights, craftsman/operative/laborer occupations for major injuries; and 17 - 29 years of age, female sex, light/medium weights, sales/service/clerical occupations for minor injuries.

(2) heavy/very heavy weights, craftsman/operative/laborer occupations, major injuries for male sex; and light/medium weights, sales/service/clerical occupations, minor injuries for females.

Although the explained variance is moderate to low as indicated by these two correlations, the results are very similar to two other studies using multiple regression and critical incidents (Shannon, 1978a; Shannon, Waag, 1974). In other words, an upper bound for explained variance may be approached (approximately 14 - 25 percent) when applying regression analysis to safety records.

Table 3 outlines the human error causes involved in the handling injuries within this sample. Human error causality could only be assigned in 152 cases (128 male, 24 female) indicating an error by event rate of 31 percent, which agrees with other studies in the literature (Meister, 1961; Robinson, et al, 1970; Shannon, Moroney, 1972; Shannon, Alkov, 1979). In these reports, human error involvement varied from 16 to 38 percent of the total number of critical incidents. In the present study, two or more errors were assigned

TABLE 3
HUMAN ERROR CAUSES OF 484 INJURIES
WHILE HANDLING MANUAL MATERIALS

HUMAN ERROR CAUSES	NO. OF INJURIES	NO. OF DAYS ABSENCE	NO. OF DAYS OFF WORK
A. POOR LOAD HANDLING TECHNIQUE: (TOTAL) (60) (17) (38)			
1. TWISTED BODY WHILE HANDLING LOAD	18	6	7
2. BODY/FEET NOT PROPERLY BALANCED	9	1	5
3. LOAD NOT PROPERLY GRIPPED	8	1	5
4. KNEES NOT BENT	3	4	4
5. BACK NOT STRAIGHT	2	0	1
6. POORLY TRAINED IN PROPER METHODS (SUPERVISORY)	6	4	2
7. USED ONE NOT TWO HAND LIFTS CAUSING UNBALANCED SITUATION	2	0	2
8. DID NOT COORDINATE TWO PERSON LIFT CAUSING UNBALANCED WEIGHT DISTRIBUTION	3	0	2
9. LIFTED LOAD TOO FAR FROM BODY	7	2	6
10. DID NOT PROPERLY POSITION LOAD AT TRUCK'S EDGE PRIOR TO LIFT CAUSING INADVERTENT FALLING FROM TRUCK OF LOAD	2	0	2
B. FAILURE TO RECOGNIZE SAFETY HAZARD: (TOTAL) (95) (10) (67)			
1. CARRIER NOT SECURED CAUSING CARRIER MOVEMENT AND BODY STRAIN DURING LIFT	3	0	2
2. MATERIAL ON CARRIER NOT SECURED, STRAIN CAUSED BY ATTEMPTED PREVENTION OF LOAD FALLING	5	0	4
3. POOR DESIGN OF EQUIPMENT (SUPERVISORY)	3	0	2
4. POOR MAINTENANCE OF EQUIPMENT (SUPERVISORY)	4	0	1
5. HANDLING EQUIPMENT NOT AVAILABLE (SUPERVISORY)	1	0	1
6. DID NOT CHECK LOAD'S RESISTANCE PRIOR TO HANDLING	18	4	12
7. DID NOT USE HANDLING EQUIPMENT	19	1	13
8. DID NOT SEEK ASSISTANCE FROM OTHER PERSONNEL	25	2	17
9. SHOULD NOT HAVE EXCEEDED BODILY LIMITATIONS DUE TO PRIOR INJURY	17	3	14
TOTAL:	155	27	105

* REPRESENTS 5 OR MORE DAYS ABSENCE

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permit fully legible reproduction*

to an incident, thereby explaining the difference between the number of causes (182) and incidents (152). The major causes of injury were:

- (1) did not check load's resistance.
- (2) did not use handling equipment.
- (3) did not seek assistance from other personnel.
- (4) exceeded bodily limitations due to prior injury.
- (5) twisted body while handling load.

(6) body/feet not balanced, knees not bent, back not straight and load too far from body (items which are in opposition to the recommended method of the National Safety Council, 1974).

These particular errors accounted for 77 percent of all causes for both major and total injuries. Significantly more males demonstrated a tendency not to recognize safety hazards, while females had more errors relating to poor load handling techniques.

DISCUSSION

The results of this study indicate that lifting injuries resulting in back strain/sprain/overexertion occurred in 57 percent of the cases, and resulted in an average of five days of worker absence from the job. This average falls within the classification of a major injury. These statistics are in general agreement with other findings in the literature. In order to lower the effects of handling injuries within the industrial environment, the most effective approach appears to be one that focuses upon back overexertions and lifting regimens. Remedies pertaining to worker selection, safe weight lifting standards, lift training programs, physical fitness, workplace design and managerial emphasis upon human factors methods have been discussed in the Introduction. All of these solutions have merit, however, their emphasis and importance appears to change as one analyzes the relationship of sex differences to type of injuries.

Prevention of male injuries can best be affected by observing safe weight lifting standards, more managerial supervision and dedication to safety, emphasis upon workplace design and automation of material handling. These conclusions are based upon the results that male injuries are more serious and involve heavier weight in the more manual, physical jobs. In addition, men appear to ignore safety restrictions and hazards either due to the lack of managerial concern, poor equipment/workplace design, worker complacency or the demands of the job. Lifting techniques and worker selection are important but not critical. Male movements approximate the recommended lifting technique of the National Safety Council (1974) and may be due to men being more accustomed to physical exercise and the handling of weight (Shannon, 1978b).

The problem of female injuries, on the other hand, is a different matter. The fact that women are injured more by lighter weight (1 - 35 lbs.) than men would seem to indicate that the increased biomechanical effects of body weight, poorer lifting techniques, lowered physical fitness and weaker physical

strength are major causes of injury. Males use more accelerated motion early in the lift and rely more on back and arm muscles, while women use more leg and back motion to supplement strength differences (Shannon, 1978b). To surmount these physical limitations, a training program can effectively teach women to utilize biomechanical principles during a lift, thereby increasing movement efficiency and the amount of weight that can safely be handled (Shannon, 1978b). For example, Ayoub (1978) recommended the lifting of 35 pounds in six lift regimens for approximately 25 percent of the female population. This limitation could potentially be changed upward with physical exercise and lift trainings programs. This recommendation also appears to have merit based on the result that the young (17 - 29), more inexperienced age group has significantly more total injuries. In addition, managerial awareness of the handling problem, workplace design, better selection procedures, and the setting of weight limitations are important recommendations and should have an effect upon female injuries.

The importance of these findings and other analyses and research into male/female differences can be underscored by the number of women entering the work force into jobs that are more manual and "male" oriented. In this study, 39 percent of the female injuries were related to more physical occupations; and between 1950 and 1975, the number of women entering the work force had increased from 29 to 40 percent of the total working community (U. S. Bureau of the Census, 1975). There are also pressures by government and feminist organizations to integrate women into more non-traditional jobs. Therefore, questions concerning selection, training and human engineering must be answered with these changes in the work force roles.

A recent article in Human Factors (Hudgens and Billingsley, 1978) attempted to determine whether research was keeping abreast of this industrial trend with its concurrent problems. The content of Human Factors and Ergonomics was analyzed between 1965 and 1976. These authors concluded from their findings that the increasing number of women in the work force was not reflected in a higher interest in the sex variable. Reasons for ignoring this variable, they explained, could partially be attributed to availability of subjects, increased time and money to coordinate larger efforts, undesired public attention, political pressure and more experimental complexity. Another study (Grasley, Ayoub, Bethea, 1978) indicated the need to update information concerning the capabilities and limitations of females within the industrial environment. They recommended that more research be conducted on normal women in all age categories, as well as those who consistently exert high levels of physical activity.

In conclusion, one aspect of the consumer product industry, that of manual handling injuries among male and female workers was studied. The emphasis has been upon alleviating injury through a redesign of the total system: more training, increased managerial awareness, better selection, more involvement of human engineers into product flow and equipment design, and increased research of sex differences. In other words, a human factors systems approach throughout all stages of product development is necessary if worker, and for that matter, consumer injuries, liabilities and lost workdays are to be decreased within this industry.

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