ASSESSING TRAILER MATERIAL HANDLING TASKS: BIOMECHANICAL MODELING, POSTURE CATEGORIZATION, PHYSIOLOGICAL MEASURE, AND SUBJECTIVE RATING

by

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(ABSTRACT)

Many variations of conveyor, facility, and trailer designs are available to aid the human operator in manual materials handling (MMH). This thesis describes an investigation to determine which of four different designs used in trailer MMH place the least physical stress on the human operator when unloading materials. Each trailer MMH design was evaluated by the criteria of biomechanical loading, working posture, physiological measure, and subjective rating of exertion. These four methods were used to generate four dependent measures: L5/S1 Compression Force, OWAS Action Category, mean heart rate, and Borg CR-10 RPE.

While no single assessment method provided a clear means for quantifying level differences in physical stress among MMH conditions, the methods employed furnished insight into which techniques and protocols might be useful in studying similar working situations. Based on relative sensitivity, ease of application, and administrative and equipment costs, the OWAS method was recommended as an assessment method useful for evaluating similar MMH work. The summary results of the four methods provided information to meet the experimental goals of this research and allowed conclusions to be drawn for the major areas of interest. Specifically, statistically significant differences were found between the Drop-frame - Floor Rollers condition and all other conditions in the SSPM - Placement analysis, between the Flat-floor - Power and the Drop-frame - Suspended Rollers conditions in the OWAS - Acquisition analysis, and between the Drop-frame - Suspended Rollers and the Drop-frame - Floor Rollers conditions in the OWAS - Placement analysis.

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Finally, my love and dearest thanks go to my family for their constant support and love. Most of all to my mother, Joyce, for always believing in me, supporting me in all things, and helping me find the strength I needed to believe in myself.

This work is dedicated to the memory of my father, Eugene S. Honaker Jr., who did not have the opportunity to see his sons mature into manhood, but whose spirit still guides and watches over us. He would be proud of our accomplishments.

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1.0 INTRODUCTION

Workplace injuries associated with manual material handling (MMH) are a focus of ergonomic research and program interventions. As ergonomic design awareness has risen, automation and job aids have reduced the types of situations in which these injuries occur. Examples of designs to reduce human operator injury include powered flow diverters for sorting materials and portable lift platforms to move materials. However, one area where these interventions have been difficult to employ is in unloading and loading materials, such as boxes, crates, and drums, from transport trailers. Because these materials come in large numbers, odd shapes, and dense loading schemes, automated methods are often costly and ineffective. Therefore the physical burden of unloading and loading these materials falls on the human operator. With this burden comes the physical stresses associated with MMH work and the inherent chance for physical injury.

Many variations of conveyor, facility, and trailer designs are available to aid the human operator in unloading materials from trailers. Engineering design of these systems dictates the environment and conditions under which the operator must work. Each combination of design variables influences the physical stress placed on the operator moving materials from the trailer. The question arises of how to compare individual trailer MMH designs to determine which place the least physical stress on the operator unloading materials. This project studied four different designs used in trailer MMH to determine which design(s) place the least physical stress on the human operator unloading materials. The designs differed based on placement and size of transport conveyors, location of transport conveyors in relation to the worker, and degree of conveyor mechanization.

2.0 REVIEW OF LITERATURE

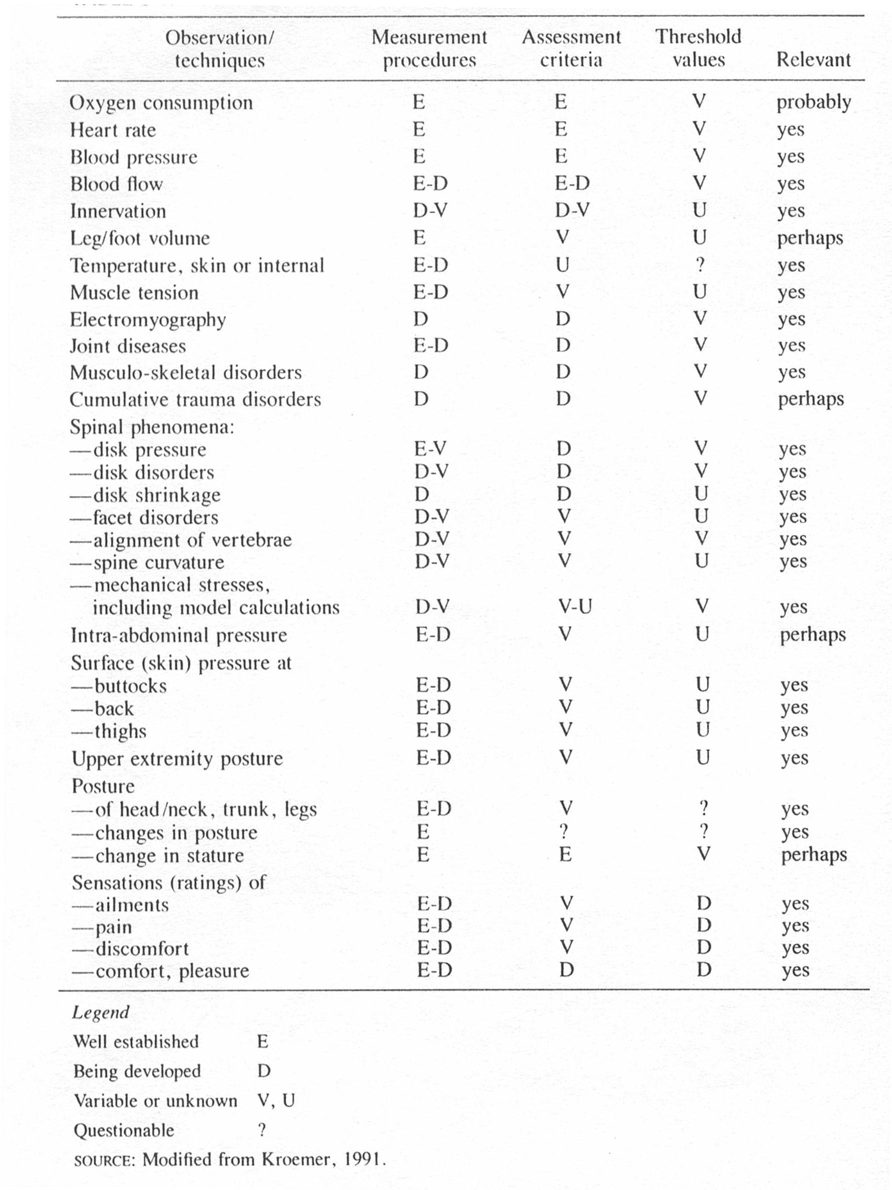
2.1 Overview

Statistics from the National Occupational Exposure Survey (National Institute for Occupational Safety and Health, 1989) indicate that injury is the most costly health problem in the United states (between $50 and $100 billion per year) and is the leading cause of physician contact and personal disability. Among the injuries reported in industry, musculoskeletal disorders have been recognized as one of the leading results of work related diseases and injuries (National Institute for Occupational Safety and Health, 1996). Musculoskeletal disorders (MSD) can be defined as any disease, injury, or trauma of the muscles, ligaments, nerves, tendons, joints, and bones arising principally from physical stress between the human body and its surrounding environment (Corlett, 1995). This includes physical stress from work tasks, leisure activities, and normal aging. Physical stress is the result of external loading, internal physiological reactions, or environmental influences. Situations creating physical stress can include whole-body lifting tasks, body movement, psychological unrest, and effects of gravity.

The physical stress demands of work components are largely responsible for MSD injuries in industry, particularly those operations related to manual materials handling (MMH). MMH involves the acts of lifting, lowering, carrying, pushing, pulling, and holding items. MMH injuries arise from overexertion when the physical stresses placed on workers exceed their physical capability (Genaidy, Karwowski, Guo, Hidaglo, and Garbutt, 1992). Principal factors in determining the physical stress on the operator include: 1) weight of the load lifted and 2) body posture assumed during loading (Colombini, Occhipinti, Molteni, Grieco, Pedotti, Boccardi, Frigo, and Menoni, 1985).

Workplace interventions generally follow one of three approaches to reducing MMH injuries: 1) improving job activities and aids to either eliminate MMH or reduce the load on the worker, 2) improving the physical capacity of workers through selection or physical training, or 3) improving the working methods and posture of workers through targeted MMH training (Kuorinka, Lortie, and Gautreau, 1994). The later is often seen as the most economical solution. However, methods and training programs for MMH vary widely (Authier and Lortie, 1992). Even the best of MMH training programs fail to overcome inadequacies designed into the work environment that require the use of poor working postures and create subsequent high physical stresses on the worker. Kroemer, Kroemer, and Kroemer-Elbert (1994, p. 496) state “How the job is designed determines the stress imposed by the work on the human material handler.”

Assessment methods used to evaluate working postures vary widely in focus, application, and sensitivity. Two basic aspects are inherent in posture analysis methodologies: the spatial arrangement of body sections and the assessment of physical ability for the worker (Colombini et al., 1985). Corlett, Wilson, and Manenica (1986) define the main characteristics of a method to describe working postures: it should be simple to use, easy to learn, and reliable. Kroemer et al. (1994) provide a listing of methods for posture assessment and the level of development associated with each (see Figure 1). These methods are categorized as being biomechanical, engineering related, physiological, or psychophysical in nature. In a review of



Observation/ techniques	Measurement procedures	Assessment criteria	Threshold values	Relevant
Oxygen consumption	E	E	V	probably
Heart rate	E	E	V	yes
Blood pressure	E	E	V	yes
Blood flow	E-D	E-D	V	yes
Innervation	D-V	D-V	U	yes
Leg/foot volume	E	V	U	perhaps
Temperature, skin or internal	E-D	U	?	yes
Muscle tension	E-D	V	U	yes
Electromyography	D	D	V	yes
Joint diseases	E-D	D	V	yes
Musculo-skeletal disorders	D	D	V	yes
Cumulative trauma disorders	D	D	V	perhaps
Spinal phenomena:				
—disk pressure	E-V	D	V	yes
—disk disorders	D-V	D	V	yes
—disk shrinkage	D	D	U	yes
—facet disorders	D-V	V	U	yes
—alignment of vertebrae	D-V	V	V	yes
—spine curvature	D-V	V	U	yes
—mechanical stresses, including model calculations	D-V	V-U	V	yes
Intra-abdominal pressure	E-D	V	U	perhaps
Surface (skin) pressure at				
—buttocks	E-D	V	U	yes
—back	E-D	V	U	yes
—thighs	E-D	V	U	yes
Upper extremity posture	E-D	V	U	yes
Posture				
—of head/neck, trunk, legs	E-D	V	?	yes
—changes in posture	E	?	?	yes
—change in stature	E	E	V	perhaps
Sensations (ratings) of				
—ailments	E-D	V	D	yes
—pain	E-D	V	D	yes
—discomfort	E-D	V	D	yes
—comfort, pleasure	E-D	D	D	yes

Legend

Well established	E
Being developed	D
Variable or unknown	V, U
Questionable	?

SOURCE: Modified from Kroemer, 1991.

Figure 1. Methods for posture assessment (Kroemer, Kroemer, and Kroemer-Elbert, 1994).

lifting models, Ayoub, Mital, Asfour, and Bethea (1980) propose a similar broad categorization of methods based on attributes of biomechanical stress modeling, working posture categorization, physiological energy requirement, and psychophysical capacity. Methods for assessing posture and resultant physical stress are examined for each of these four major areas.

2.2 Biomechanical Force Prediction Models

Biomechanical force prediction models allow analysis and comparison of physical stresses created during MMH work without the need for expensive and potentially harmful direct measurement of forces generated within body structures. Many two- and three-dimensional static and dynamic biomechanical models have been developed to determine musculoskeletal stresses on specific body regions during MMH (Ayoub, 1993). Such models have been developed by Martin and Chaffin (1972), Garg and Chaffin (1975), Ayoub and El-Bassoussi (1978), Leskinen, Stalhammer, Kuorinka, and Troup (1983), Bejjani, Gross, and Pugh (1984), Freivalds, Chaffin, Garg, and Lee (1984), and Kromodihardjo and Mital (1986). In general, the biomechanical models combine inputs of worker anthropometry, body posture, and load lifted to estimate compression forces on body segments, most often those of the lower back vertebrae.

Worker anthropometry for biomechanical models may be input using either measured body dimensions from the worker or using data banks of body dimensions for different populations as given and discussed by Kroemer, Kroemer, and Kroemer-Elbert (1990). Some discussion has developed as to the accuracy and sensitivity of biomechanical models with regard to anthropometric inputs. Changes in stature and body segment lengths create model changes with respect to body moment centers and lever arms. Chaffin and Erig (1991) found the effects of anthropometric changes on model prediction outputs to be small (a 3.7% overestimate of force predicted from actual measured) and judged the effects of postural input to have much greater bearing on the accuracy of the prediction model.

Many methods of posture measurement have been developed, both direct and indirect, two- and three-dimensional. The goal of each system is to provide an accurate, precise measurement of body and load positions to input into a modeling system. Hsiao and Keyserling (1990) identified six major groups of methods for registering and recording body posture: goniometry, photogrammetry, optoelectric analysis, video analysis, optomechanic analysis, and sonic analysis. Goniometry involves the direct measure of body part angles and combines these with anthropometric measures to determine overall body posture. These systems include exoskeletal devices such as that developed by Boocock, Jackson, Burton, and Tillotson (1994) for approximating lumbar saggittal position of the spine during work. Goniometry systems have the advantage of providing direct and accurate measures of body position but tend to inhibit natural work and posture by nature of their attachment.

Photogrammetric devices employ light-reflecting markers or light-emitting diodes to mark joint centers and record the relative positions of markers using an orthogonal system of two or three specialized cameras. Photogrammetric systems have the advantage of being less invasive to the worker's movements and operations than goniometry. However, these systems are relatively difficult to setup and calibrate, require a large amount of data decoding, and involve expensive and sensitive equipment (Chaffin and Anderson, 1991).

Optoelectric systems also use light-emitting diodes to mark targeted joint centers, but employ optoelectric sensing units instead of cameras with film to record body position. The Selspot system is an example of this type of recording device (Selcom Selective Electronics, Inc., Valdese NC, 1984). These systems substantially reduce the time required for data analysis and allow computer based representations of body posture but are often very sensitive to environmental lighting conditions and are expensive (Hsiao and Keyserling, 1990).

Video analysis techniques follow the same basic principles as photogrammetric techniques but allow for high sampling rates and less sensitivity to environmental constraints. Body joint centers may be marked using light-reflecting markers or light-emitting diodes or may be marked simply with elastic bands or bright spots (Smith, 1982). One commercially available system for video analysis is the VICON System (Oxford Medilog, Inc., Clearwater FL, 1984). Video systems offer the advantages of being inexpensive and easy to use in the working environment. Data analysis effort depends largely on the automaticity inherent in the body marking and recording system.

Optomechanical systems use devices other than video cameras or electric image detectors to register joint positions. These systems still utilize the same principles for determining relative joint locations as other photogrammetric systems. One example of this type of system is the CODA-3 Movement Monitoring System which uses three rotating mirror scanners to detect targets mounted on the body (Movement Techniques Limited, Unit 5, Technology Center, Epina Way, Lumsburough, Leies, LE11 0OE, UK, 1987). This system has advantages and limitations similar to those of optoelectric systems.

The final and possibly least employed system for registering body posture relies on sonic techniques. Hsiao and Keyserling (1990) examined the use of ultrasonic transmitters to register body movements and found the system to be relatively inexpensive, easy to use, and fairly accurate. However, due to the nature of the sound medium used, assessments in noisy industrial environments are limited.

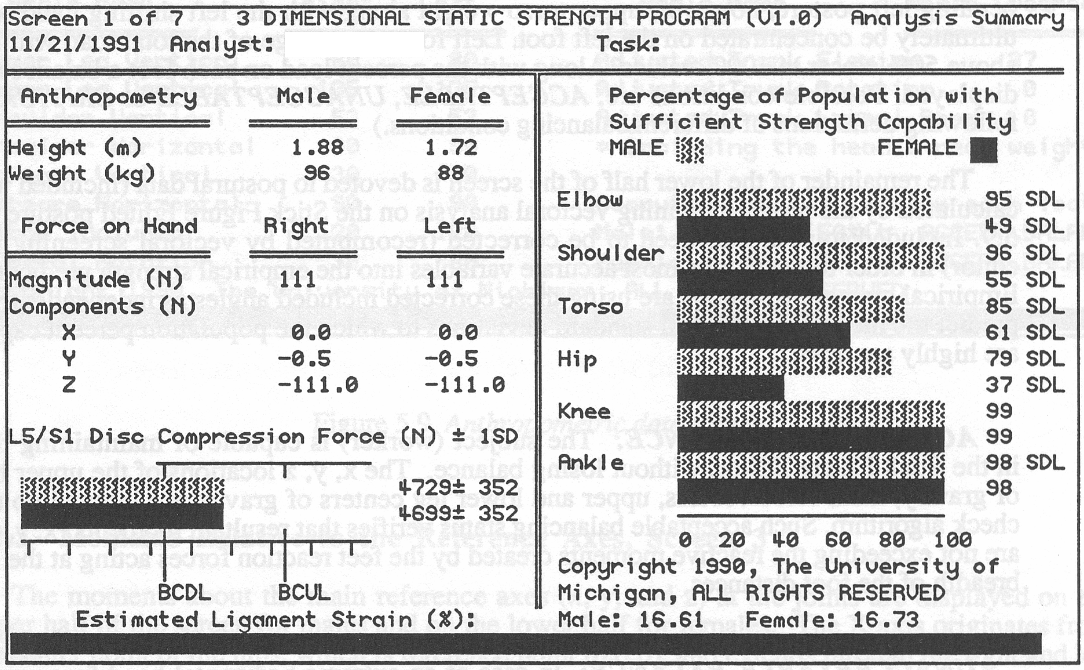
From the trade-off analysis between these types of systems, video analysis systems hold the lowest cost, most convenient method for recording posture in an actual work environment. Video analysis allows for a fairly high degree of accuracy within an absolute reference frame. The relatively small and unobtrusive joint markers allow for normal movement during work. Difficulties arise with this system when a reference point is not visible to the camera or when observation frames are not well synchronized. These systems also require considerably more time to reduce data for actual static working postures.

Several methods have been employed in the reduction of two or three video recordings to generate observed posture. Ma, Tatu, Seppo, Kari, and Matti (1992) employed a fairly simple, yet effective technique. Workers were video-taped using cameras positioned orthogonally to capture joint positions in space. The videos were played back on separate monitors and paused at the same place during work. A transparent sheet overlay was used to record the position of joint centers in each view. Then the positions of the joints on the sheet overlay were measured and used to generate the worker's posture. Chaffin and Erig (1991) point out the importance of obtaining good postural data to reduce validity confounds in a biomechanical model. They emphasize that the biomechanical model is only as good as the posture inputs that go into it.

Once the anthropometric, posture, and load data have been determined, a biomechanical modeling system is used to estimate resulting forces on body structures. The models used to estimate these forces may be two- or three-dimensional. Two dimensional models are often limited to symmetric sagittal lifting. In a survey of industrial box handling, Drury, Law, and Pawenski (1982) found that the greatest preponderance of lifting tasks involve asymmetric lifting, often while the trunk is twisted as the load is acquired. The incorporation of three-dimensional posture analysis would be required to examine the effects of this asymmetric lifting.

Another defining characteristic of biomechanical models arises from the use of static versus dynamic registering of work posture and resultant forces. The neglect of static models to consider inertial effects on the body during work can impact the calculation of compression forces on the spine (Ayoub, 1993). Smith (1982) indicates that neglecting to consider dynamic forces on the body during industrial lifting tasks can create statistically significant over- or under-estimations of forces generated in the body. However, as de Looze, Kingma, Thunnissen, van Wijk, , and Toussaint (1994) point out, static models can offer a simple and valid means for analyzing relatively static jobs and are applicable to the static positions assumed at load acquisition and placement. Incorporating dynamic qualities into the model creates unnecessarily complex and time-consuming data capture when an occupational setting is being analyzed.

Based on the outline and requirements presented, a biomechanical model to be used in assessing occupational work should be three-dimensional, accept posture inputs from a video imaging system, and be relatively easy to employ over a wide range of working situations. One of the most widely applied and validated biomechanical models meeting those criteria is the Three-Dimensional Static Strength Prediction Model (3-D SSPM) developed by The University of Michigan Center for Ergonomics (1993). This model represents the body as a series of 18 rigid link segments articulated about 17 joints, including the balls of the feet, ankles, knees, hips, L5/S1 intervertebral disc, shoulders, elbows, and hands. Anthropometric data may be input from actual subject dimensions or may be estimated for a specific population percentile. Posture inputs may be entered manually or drawn from a number of different imaging systems. Postural and loading information are used to compute resultant moments at each joint center for specified load configurations and body segment weights. The model provides estimates of forces on internal body structures using comparisons between voluntary moments produced by skeletal muscle actuation and the moments resulting from the load coupling and body segment weights (Garg, Sharma, Chaffin, and Schmidler, 1983). An example of the 3-D SSPM loading output is given in Figure 2 (The University of Michigan, 1993). In addition, the tension in the back muscles (erector spinae) and compressive force at the L5/S1 intervertebral disc are estimated (Garg and Herrin, 1979). Studies on model validation for lifting tasks showed a correlation



```
Screen 1 of 7   3 DIMENSIONAL STATIC STRENGTH PROGRAM (V1.0)   Analysis Summary
11/21/1991  Analyst:                          Task:

Anthropometry        Male      Female     Percentage of Population with
                                          Sufficient Strength Capability
Height (m)           1.88      1.72       MALE ▨              FEMALE ■
Weight (kg)           96        88
                                          Elbow                     95 SDL
Force on Hand        Right     Left                                 49 SDL
                                          Shoulder                  96 SDL
Magnitude (N)        111       111                                  55 SDL
Components (N)                            Torso                     85 SDL
    X                0.0       0.0                                  61 SDL
    Y               -0.5      -0.5        Hip                       79 SDL
    Z              -111.0    -111.0                                 37 SDL
                                          Knee                      99
L5/S1 Disc Compression Force (N) ± 1SD                              99
                                          Ankle                     98 SDL
                          4729± 352                                 98
                          4699± 352
                                                0  20  40  60  80  100
                                          Copyright 1990, The University of
      BCDL      BCUL                      Michigan, ALL RIGHTS RESERVED
  Estimated Ligament Strain (%):          Male: 16.61   Female: 16.73
```

Figure 2. Example 3-D SSPM output (The University of Michigan, 1993).

coefficient of 0.97 between measured and predicted strength and a coefficient of variation of 0.15 (Garg and Chaffin, 1975). The use of the 3-D SSPM provides a consistent, valid, and easy to employ means for assessing biomechanical stress on the body over a variety of working postures and occupational environments.

2.3 Categorical Posture Observation Systems

A second means for examining the effects of body posture and loading on workers arises from the categorical classification of working postures. These methods are most useful when postures can be identified by placing them general categories with a limited number of combinations (Stewart, 1993). Categorical posture observation systems are most often targeted toward observing and recording a continuum of postures using a defined method that is practical, reliable, and easy to learn and use (Keyserling, 1986). These methods are often employed while unobtrusively observing workers performing job tasks. The choice of particular method arises from a trade-off between the validity and usefulness of the data garnered with the speed and ease of applying the method. This review examines only those categorical posture observation systems that may be applicable to full body observations of MMH handling tasks performed in the occupational setting. This excludes systems such as VIRA (neck and shoulders only; Kilbom, Persson, and Jonsson, 1986) and Posture Classification System (trunk and shoulders only; Keyserling, 1986). Those systems examined include: Posturegram (Priel, 1974), OWAS - Ovako Working Posture Analyzing System (Karhu, Kansi, and Kuorinka, 1977), Posture Targeting (Corlett, Madeley, and Manenica, 1979), CPM - Categorized Posture Method (Silva, 1986), Posture Taxonomy (Malone, 1991), and RULA - Rapid Upper Limb Assessment (McAtamney and Corlett, 1993).

Posturegram, developed by Priel (1974), represents an early categorical system developed for occupational observation. This system requires the observer to examine a particular posture, describe the position of 16 major body segments with respect to three mutually orthogonal reference planes, and then estimate and record 48 resultant angles (Keyserling, 1986). An example of the observer's reference sheet is given in Figure 3. This method yields moderately useful data regarding body segment positions but requires an extensive amount of application time and judgmental input from the observer.

A more commonly applied system to identify and evaluate full body working postures was developed by Karhu et al. (1977). OWAS (Ovako Working Posture Analyzing System) was developed in response to the need for an analytical method that is simple, unambiguous, and valid. In the OWAS system the observer makes an instantaneous analysis of posture and defines it with a three digit code. The first digit describes the position of the back (four choices), the second digit describes the arms (three choices), and the third digit describes the legs (seven choices) (Keyserling, 1986). In later versions of this system a fourth data code has been defined to represent loading or use of force (three choices) (Corlett, 1995). Pictorial representations of the body segment positions are provided to the observer to aid classification An example of the classification chart is given in Figure 4. This method was extended by classifying the three-digit

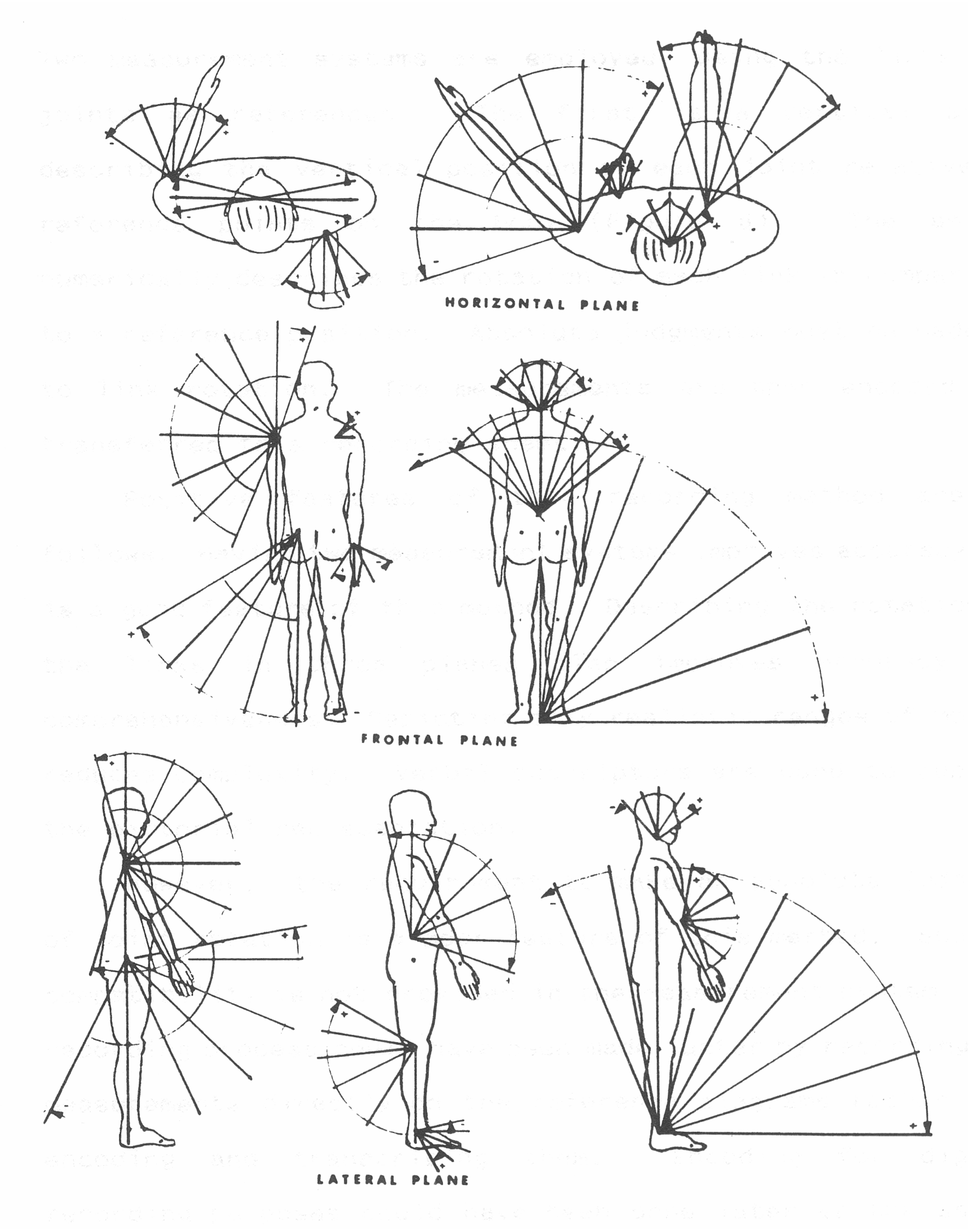
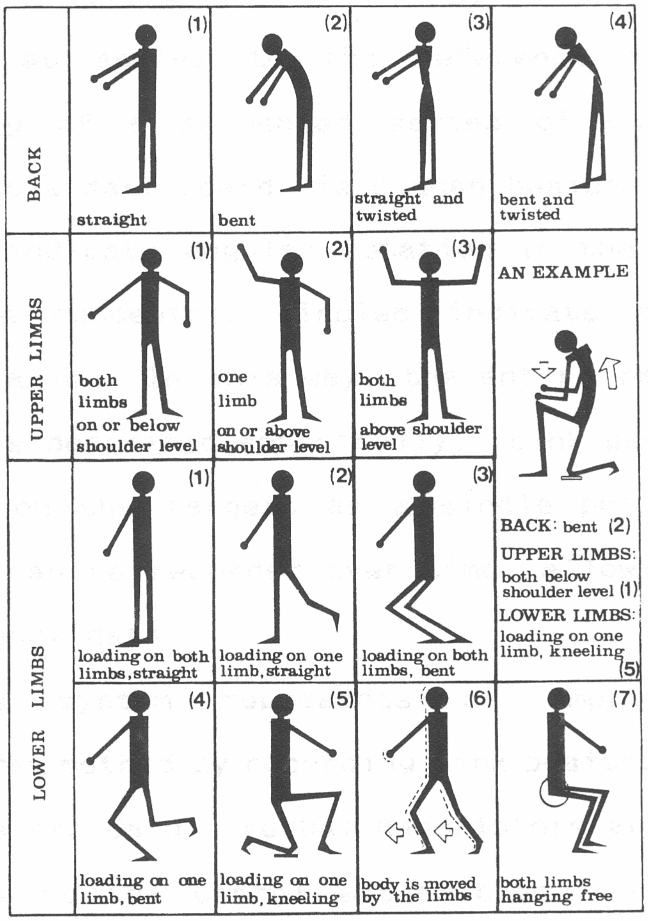


Figure 3. Posturegram reference sheet (Priel, 1974).



List of items classified by OWAS (the Ovako Working Posture Analysing System). A code number is given for each item. Each posture can be described with a three-digit code.

Figure 4. Example OWAS classification chart (Karhu, Kansi, and Kuorinka, 1977).

codes into operative classes that define high to low discomfort levels. In this way, OWAS represents an easy to use, reliable means for classifying and evaluating posture. The central disadvantage of OWAS arises from the possibility that the broad classification categories may contribute to a lack of precision in the method and thus lower its validity for predicting poor working postures.

Posture Targeting, by Corlett et al. (1979), represents a move toward a quantitatively definable means for recording actual body postures. A template (see Figure 5) is used by the observer to mark the position of the head, trunk, upper arms, lower arms, upper legs, and lower legs relative to a standard reference posture. The system requires approximately 30 seconds for an experienced observer to record each posture. The method was found to be highly reliable, but no accuracy data were given. This method is more comprehensive than the Posturegram direct recording method but has the disadvantages of being relatively slow, defining the posture only in the frontal plane, and requiring observer judgments of positions in the transverse plane (Stewart, 1993). The resolution of data from the diagrams to actual body segment positions requires additional analysis time and increases the error in the system.

CPM (Categorized Posture Method) was created by Silva (1986) in response to the time-consuming and complex nature of quantitative systems such as Posturegram and Posture Targeting. The goal of this method was to allow for simple, easy identification of posture by relatively untrained observers while garnering accurate quantitative posture data. The CPM system employs a series of diagrams that allow the observer to record deviations from a pre-defined standard work position (see Figure 6). Four basic deviations from the “standard” work position are defined: lean, bend, stoop, and squat. This method has the advantages of being easy to learn, quick to apply, and highly reliable. However, the method is limited because representations are only in the saggittal plane, therefore deviations in the frontal and transverse plane are lost. Also the analysis and transfer of posture data can be time-consuming and contribute to the overall error of the system (Stewart, 1993).

The Posture Taxonomy System (Malone, 1991) was studied as an alternative to existing descriptive recording systems such as Posture Targeting and CPM and places an emphasis on the cognitive and perceptual issues related to posture recording. Posture Taxonomy uses a model based on 10 enfleshed body segments. Each segment’s relative position is recorded in three orthogonal planes: frontal, saggittal, and transverse. A target is used to record the position of each individual body segment. An example Posture Taxonomy chart is given in Figure 7. The evaluation of this method found it to be very time consuming to use (over 4 minutes per posture) and showed it to produce only moderate reliability. While the recording of posture can be fairly precise with this method, additional time and error are introduced by the need to reduce data from the recording charts (Stewart, 1993).

McAtamney and Corlett (1993) developed the RULA (Rapid Upper Limb Assessment) system as a categorical survey method for assessing workplaces where upper limb disorders are reported. Similar to OWAS, this system uses diagrams of postures and three scoring tables to assess possible posture exposure risks factors (see Figure 8). Application of RULA involves

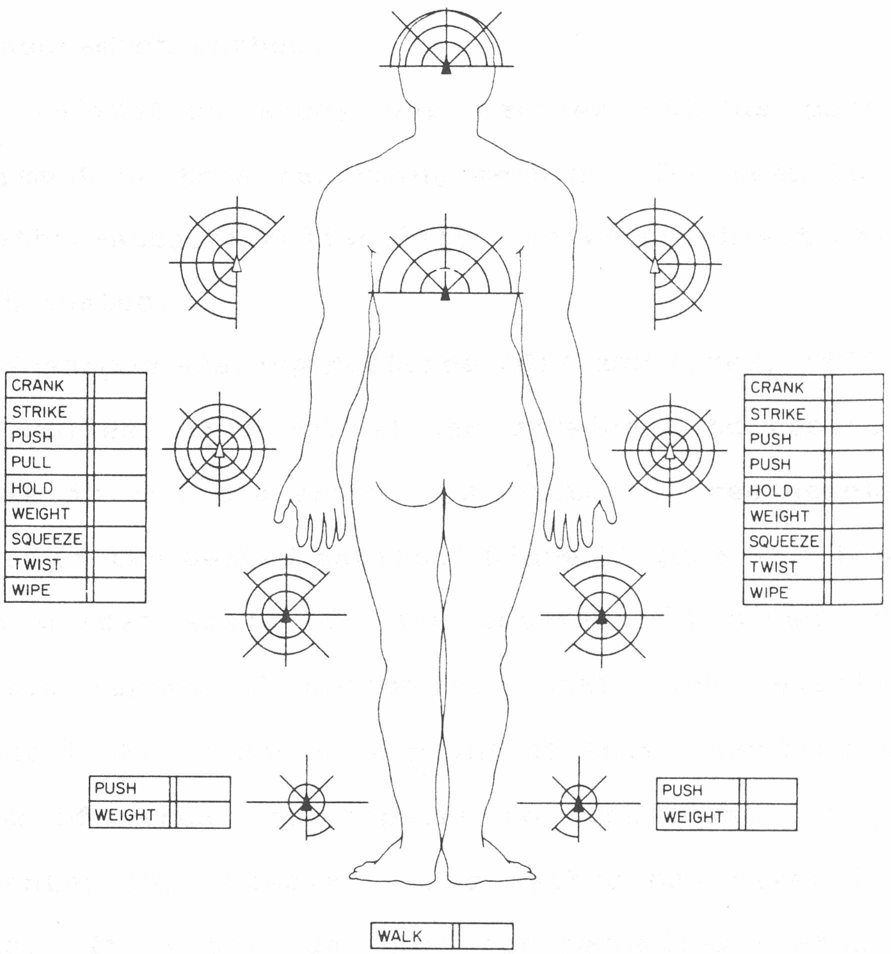


Figure 5. Posture Targeting reference sheet (Corlett, Madeley, and Manenica, 1979).

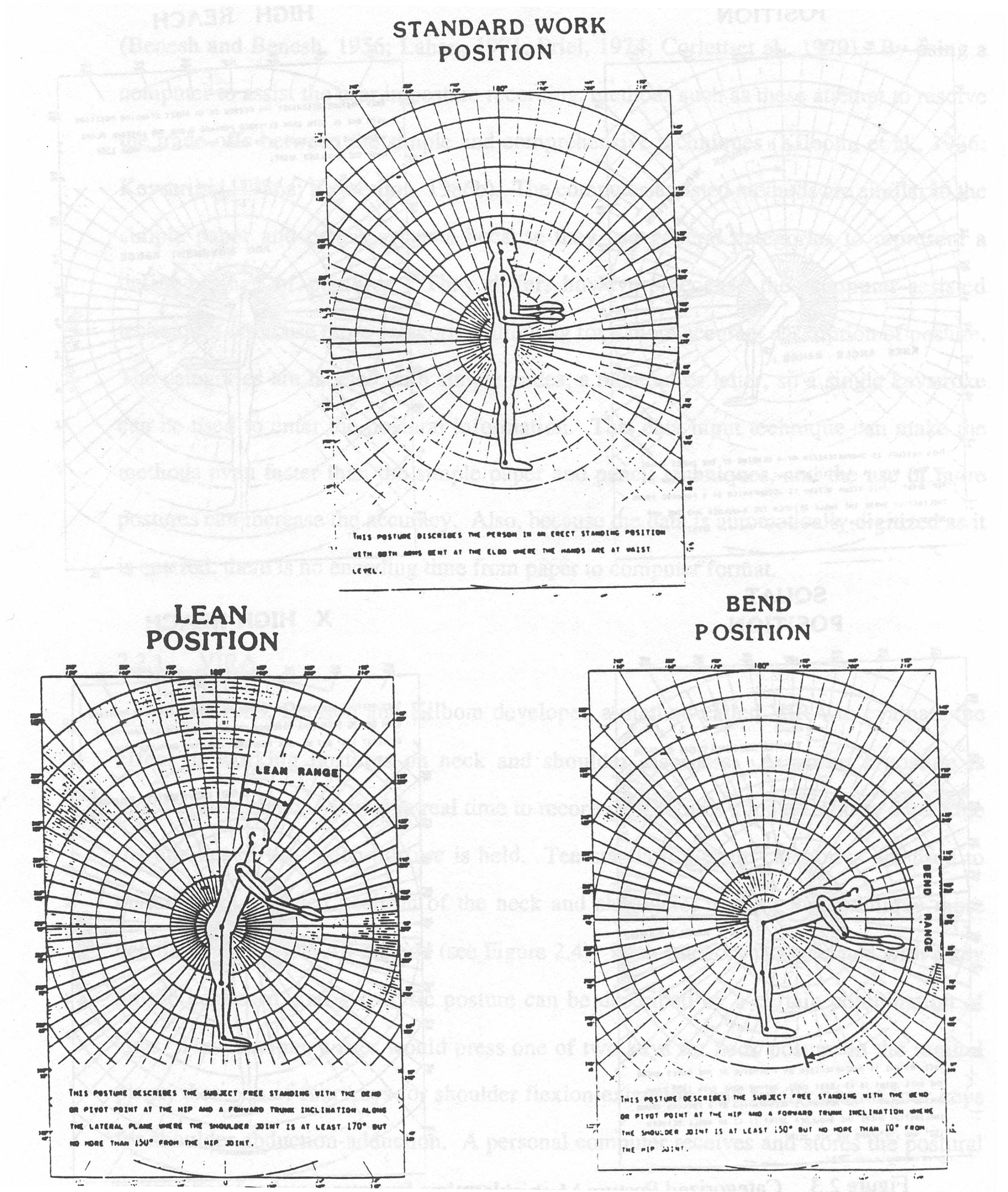


Figure 6. CPM reference sheet (Silva, 1986).

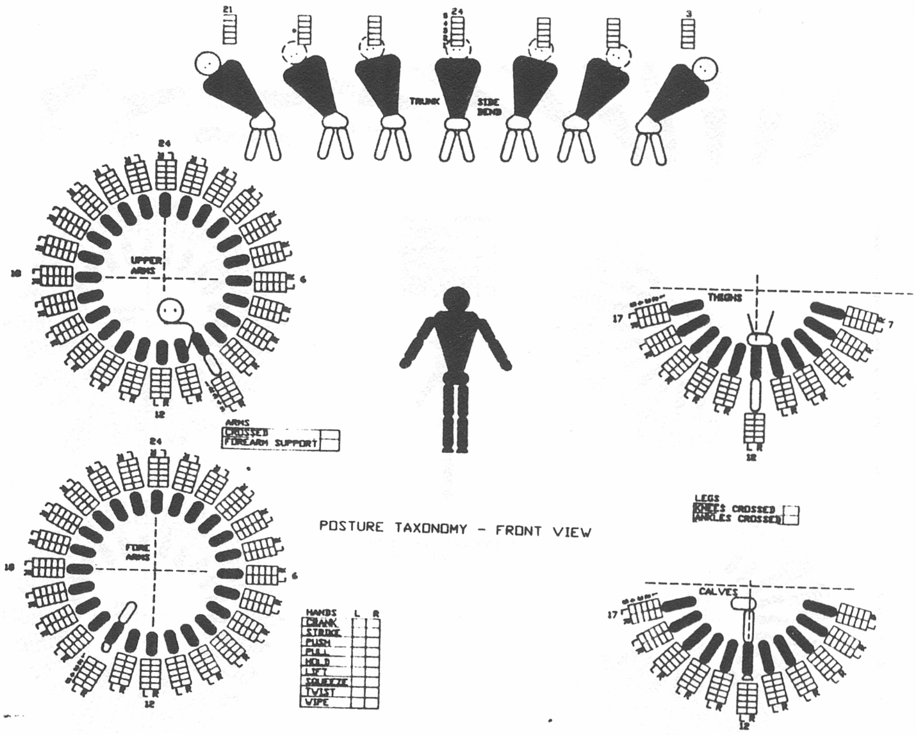
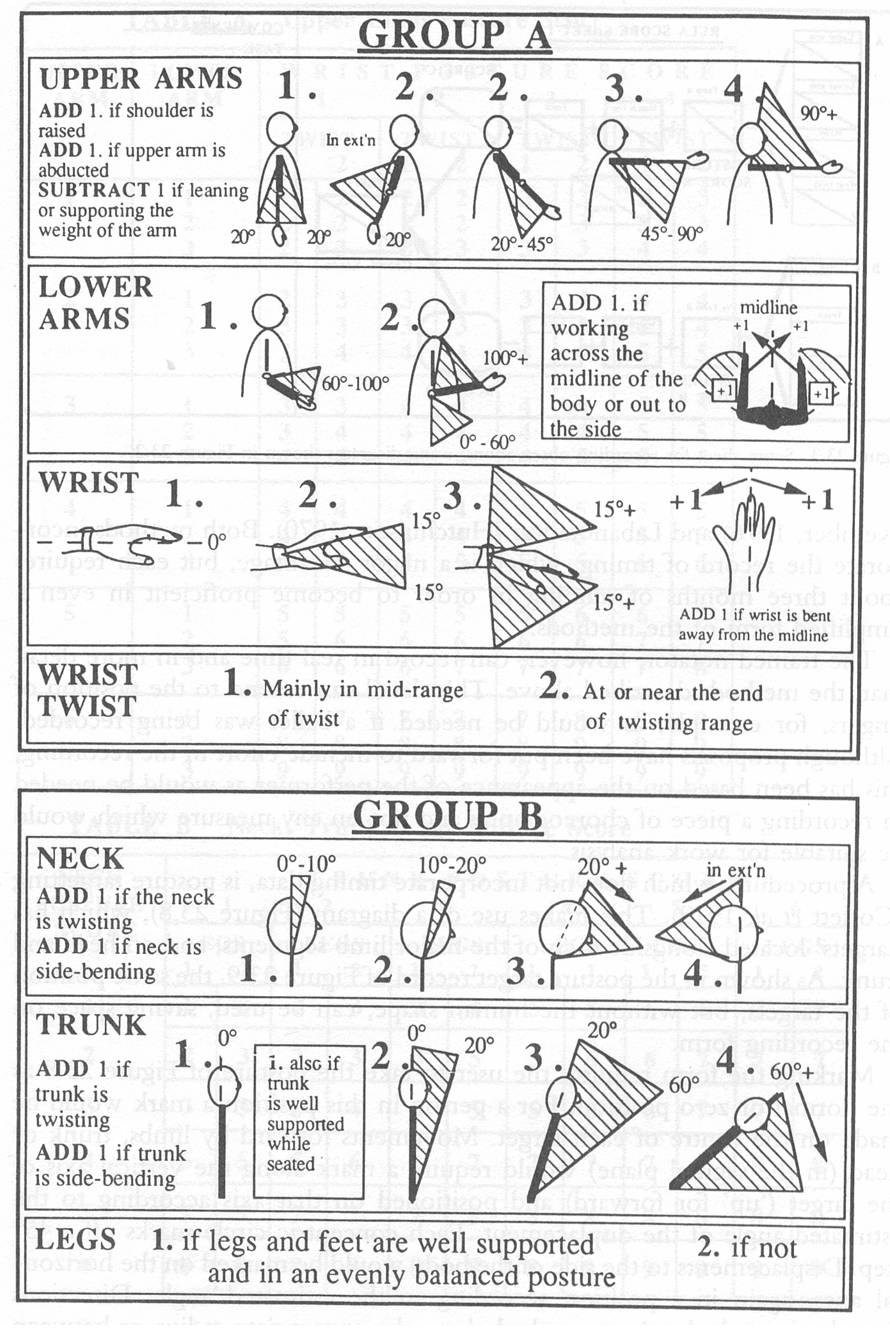


Figure 7. Posture Taxonomy recording chart (Malone, 1991).



GROUP A

UPPER ARMS

ADD 1. if shoulder is raised
ADD 1. if upper arm is abducted
SUBTRACT 1 if leaning or supporting the weight of the arm

LOWER ARMS

ADD 1. if working across the midline of the body or out to the side

WRIST

ADD 1 if wrist is bent away from the midline

WRIST TWIST

1. Mainly in mid-range of twist
2. At or near the end of twisting range

GROUP B

NECK

ADD 1 if the neck is twisting
ADD 1 if neck is side-bending

TRUNK

ADD 1 if trunk is twisting
ADD 1 if trunk is side-bending

1. also if trunk is well supported while seated

LEGS 1. if legs and feet are well supported and in an evenly balanced posture 2. if not

Figure 8. RULA Reference sheet (McAtamney and Corlett, 1993).

observing the worker's posture and scoring the posture in relation to the given diagrams. Then associated tables are used to provide a score for muscle use and loading. Tallying the scores provides inference for level of risk. This method is easily learned and provides consistent and reasonable accuracy comparable to that of OWAS. However, the focus of this system is on the upper body and limbs, neglecting information on the position of the legs and the symmetry associated with loading during work (Corlett, 1995).

For the categorical posture observation systems discussed, there is an important trade-off between the time and effort required to perform the analysis and the level of detail produced by the analysis. Genaidy, Simmons, Guo, and Hidalgo (1993) raised some questions regarding the ability of observers to correctly estimate body part angles. While Malone (1991) attempted to address the cognitive and perceptual issues related to observations through the creation of the Posture Taxonomy system, he found only limited success in increasing observer precision and created a marked increase in observation time. Of the categorical methods discussed, the OWAS system appears to offer the best combination of speed and accuracy, encompassing the ability to observe a large number of postures with fair reliability and yielding results with little need for additional data reduction. The lack of sensitivity inherent in using OWAS can be examined in comparison with other analytical methods to determine what applications in physical stress assessment are appropriate.

2.4 Physiological Assessment Methods

Physiological methods for assessing physical workload often include measuring the energy expenditure of the worker during activity, a process known as indirect calorimetry. The basis for energy expenditure measurement follows from estimating the body's metabolic energy production while performing work (Kroemer et al., 1990). A full accounting of the physical and metabolic processes required for producing energy and work in the body is given by Astrand and Rodahl (1977). In general, two physiological measures for approximating the physical stress on the worker are used in field research: oxygen uptake and heart rate (Astrand and Rodahl, 1977).

Measurement of oxygen uptake allows a reliable assessment of physical workload for activities lasting five minutes or longer. By comparing the oxygen and carbon dioxide content of inhaled air to the contents of exhaled air, a reliable estimate of energy metabolism can be made and the results compared within and between subjects performing similar work tasks (Kroemer et al., 1990). This assessment method provides a very reliable means for assessing physical stress and can be applied to a range of physical activities. Measurement of oxygen consumption can be made by readily available commercial apparatus, however this apparatus is often expensive and complex (Kilbom, 1995). A further disadvantage of oxygen uptake measure involves artifacts introduced by the measurement equipment. For a reliable uptake measure, an air-tight mask must be fitted on the worker. Astrand and Rodahl (1977, p. 454) note that "It is a common experience that the test subject tends to be affected by the investigation, causing the test situation to be atypical. The test equipment is apt to affect heart rate, pulmonary ventilation, and oxygen uptake, and may hamper the actual work operation."

A second physiological assessment method arises from the measure of heart rate. Studies by Astrand and Rodahl (1977) show a high level of correspondence between oxygen uptake and heart rate, especially when compared over dynamic whole-body work. The relationship between the two is roughly linear (Corlett et al., 1986). This linear relationship appears to break down only for very light or very heavy work. Kroemer et al., (1990, p.137) note that "Given this relationship, one often can simply substitute heart rate measurements for measurement of metabolic processes, particularly for O_2 (oxygen) assessment." The chief advantage of measuring heart rate changes over oxygen consumption arises from the faster response of heart rate to work demands. This faster response time allows for easier measurement of quick changes in body metabolism due to changes in the work environment. Equipment used to measure and record heart rate is relatively simple and inexpensive (Kroemer et al., 1990). These units also tend to be smaller and less likely to hamper the normal work processes of the worker (Mellerowicz and Smodlaka, 1981).

Another advantage of heart rate over oxygen uptake arises from the nature of the heart rate to return to its initial value within a few minutes, even after a long work period (Stegemann, 1981). Mellerowicz and Smodlaka (1981) note that this recovery follows a negative exponential function and may be influenced by the training level of the individual in the work activity. Trained workers have a lower maximum heart rate at steady state, but show more sensitivity at the beginning and end of the work activity. Trained workers "ramp-up" to a steady state heart rate more quickly and then recover in a shorter time.

Several studies provide examples of using heart rate to assess MMH work. Drury and Deeb (1986) used a combination of heart rate and perceived body-part discomfort to gauge physical stress during a dynamic lifting task. Mean heart rate and standard deviation were measured over the duration of several lifting trails, with two minute break periods between trials to allow the heart rate to return to resting levels. Mean heart rates and deviations were compared within and between subjects to rate lifting task differences and subject effects. Drury, Deeb, Hartman, Woolley, Drury, and Gallagher (1989) examined differences between symmetrical and asymmetrical MMH lifting tasks using heart rate data. Mean heart rate measures and standard deviations were recorded over several trials of symmetrical and asymmetrical lifting. When compared, the heart rate measures showed marked sensitivity to symmetry and coupling changes between work trials. Sharit and Salvendy (1982, p.137) remark that "The heart rate measure has undoubtedly been proven to be the most versatile measure of stress."

2.5 Subjective Assessment Methods

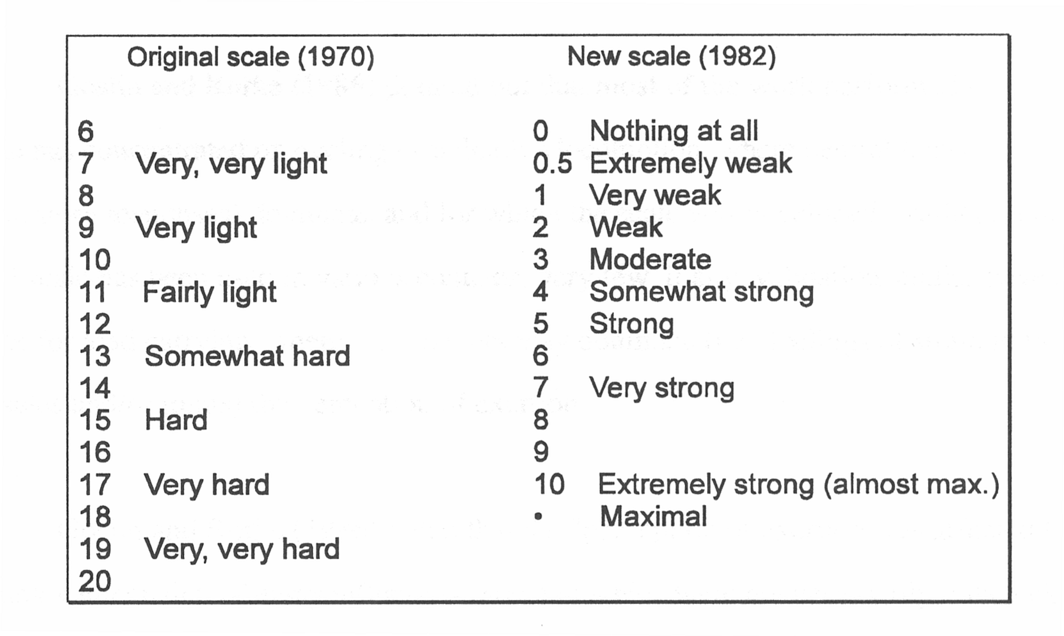
A fourth measure of physical stress placed on the worker performing MMH tasks arises from the worker's subjective perception of physical stress. Borg (1970) indicates that the perceived intensity of physical stress in workers arises from both physical and psychological continua. The importance of this finding suggests that biomechanical, postural, and physiological measures may overlook the psychological attributes of fatigue. This suggestion is supported by the work of Legg and Mahanty (1985) and Kirk and Schneider (1992) comparing participants physical and psychological reactions to load carrying situations. The use of subjective assessment methods for physical stress levels provide a more holistic view of the workers reaction to MMH tasks.

Development of subjective rating scales or questionnaires creates questions with regard to the validity and reliability of the data generated. In the general development of rating scales and questionnaires, Wierwille (1994) notes that rating scales have the distinct advantage of offering quantitative data. Whether the data follow an ordinal or interval scaling determines the level of implied sensitivity and statistical power available for analysis. Questionnaires have the advantages of offering simple and quick methods for assessing subjective criteria and have been shown to be fairly sensitive (Wierwille, 1994). However, Williges (1995) notes that these qualitative means for assessment are more subject to operator biases (such as leniency errors or central tendency errors) and require extensive pre-testing and refinement before they may be confidently employed. A large number of rating scale techniques for assessing psychological workload have been validated and used. Some of these are reviewed by Williges and Wierwille (1979) and include the Subjective Workload Assessment Technique and the National Aeronautics and Space Administration - Task Load Index. Other subjective rating scales have been developed specifically to assess the level of physical workload perceived by the worker. McAtamney and McPhee (1987) recommend the following three factors in developing these scales:

1. The scale being used must take into account the contributing factors of perceived stress and how combinations of these factors vary between and within participants.
2. The scales used must be sensitive enough to register sub-clinical as well as marked physical discomfort, symptoms, and signs.
3. Confounding factors occurring outside the experimental setting, such as extra-curricular activities and physical histories may need to be considered.

Following these developmental strategies, a few measures have been created and widely employed to garner valid, reliable data for assessing subjective physical stress levels. Those of interest include: Rating of Perceived Exertion (RPE) scales (Borg, 1970 and Borg, 1982), Body Part Discomfort (BPD) scaling (Corlett and Bishop, 1976), and the Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka, Jonsson, Kilbom, Vinterberg, Biering-Sorensen, Andersson, and Jorgensen, 1987).

Borg (1970, 1982) and his associates have long used psychophysical methods to study the perception of exertion in different groups of workers. From these studies, a curvilinear relationship has been developed between the intensity of physical stimuli and our perception of their intensity (Kilbom, 1995). This perception follows from the interrelation of neuro-muscular sensations of the circulation and respiration organs, muscles, skin, and joints used during physical exertion. Thus, for a given individual there is a reliable relation between physical workload and perceived exertion. This Rating of Perceived Exertion (RPE) or Borg scale follows from a mathematical relationship between sensations in the psychological domain and stimuli in the physical domain (Meunier, 1994). The original scale developed by Borg (1970) is given in Figure 9. RPE ratings may be given for specific body segments or for whole body exertions. The



Original scale (1970)		New scale (1982)	
6		0	Nothing at all
7	Very, very light	0.5	Extremely weak
8		1	Very weak
9	Very light	2	Weak
10		3	Moderate
11	Fairly light	4	Somewhat strong
12		5	Strong
13	Somewhat hard	6	
14		7	Very strong
15	Hard	8	
16		9	
17	Very hard	10	Extremely strong (almost max.)
18		•	Maximal
19	Very, very hard		
20			

Figure 9. Borg RPE scales (Borg, 1970, 1982).

selection and placement of verbal anchors is made such that there is a linear relation between workload and RPE. The scale begins at 6, corresponding to 60 heart beats per minute, and ends at 20, corresponding to 200 beats per minute. This scale is considered to be a ratio scaling of exertion (Kilbom, 1995).

Following much discussion, study, and updating, Borg (1982) developed a modified version of the RPE scale called the CR-10 (Category Ratio-10) scale, so named for the properties of the RPE scale. The CR-10 RPE scale is also given in Figure 9. This updated scale was validated across a number of tasks and sensory modalities, with very good results in the RPE domain (Borg, 1982). Since its development, the CR-10 RPE scale has been successfully employed in a number of applications including evaluation of MMH training programs (Genaidy, 1991), gauging of physical stress in tank truck drivers (Johansson and Borg, 1993), and evaluating MMH carrying endurance (Genaidy, Mital, and Bafna, 1989).

The CR-10 RPE scale has the advantages of offering a category scale with ratio properties that produces relative comparisons as well as level estimates (Johansson and Borg, 1993). Kilbom (1995) points out that the RPE scale is a simple, effective means for garnering subjective responses to physical work, especially when taken in conjunction with physiological measures. This subjective assessment technique is especially suited to dynamic work, providing only small RPE differences for static postural loading but significant RPE sensitivity in workers moving objects. However, Kilbom cautions that the reliability of the scaling may be subject to confounds from worker motivation and previous experience. Goslin and Rorke (1986) also found that the scale may be subject the effects of interrelated psychological factors, such as perceived physical comfort during work activity. They caution against using the RPE scale for tasks not requiring significant full-body physical work and where environmental stresses may skew the RPE.

A second means for subjectively evaluating physical stress arises from Body Part Discomfort (BPD) scaling (Corlett and Bishop, 1976). This subjective measure uses muscular pain as its underlying indicator. The initial study promoting this method found that the growth of discomfort during physical work was roughly a linear relation to postural loading. To specify the site(s) of discomfort, a body map divided into several segments is used (see Figure 10). In using the technique, workers are asked to identify body areas where they are experiencing discomfort and to rate the discomfort on a verbally anchored linear scale from 0 (no discomfort) to 5 or 7 (extreme discomfort). This method can be employed several times over the working day to gauge cumulative effects of physical loading over several job types or long endurance activities (Corlett, 1995).

The BPD scale has the advantage of breaking loading effects down into specific musculoskeletal regions of the body. This allows a targeted approach to alleviating physical stress for the worker. However, the technique is limited in application for gauging physical stress resulting from working postures. The BPD ratings are sensitive to physical stresses resulting from long static postures and to those resulting from mechanical pressure on body regions. This rating method shows little sensitivity for dynamic work (Corlett, 1995). The BPD scale also lacks statistical robustness due to the nature of the rating scale. The scale is designed

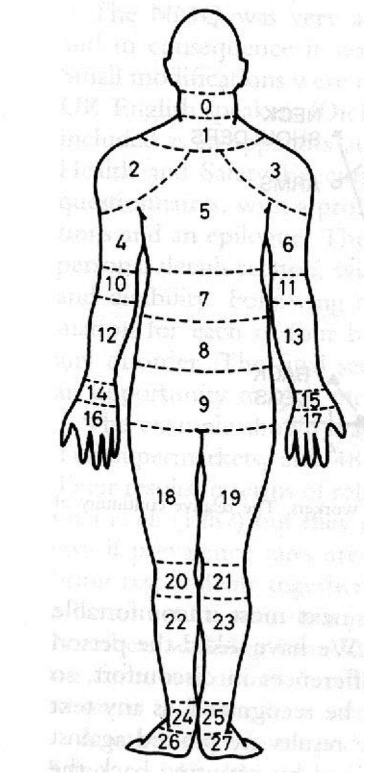


Figure 10. BPD map (Corlett and Bishop, 1976).

to approximate a Likert scale and provide interval data. However, no studies were found to support the supposition that a true interval scale exists. This subjective method has been employed in several postural studies, including the original by Corlett and Bishop (1976) for assessing discomfort from prolonged force exertion and by Meunier (1994) for measuring comfort when load carrying using backpacks.

The third subjective assessment technique of interest is the Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al., 1987). The aim of this system is to develop a standardized means for recording and assessing musculoskeletal symptoms and disorders in a simple, quick, and efficient manner. The NMQ consists of structured, forced, binary or multiple choice variants that can be collected by self-administration or by interview. A general diagnostic questionnaire is given with the human body divided into nine anatomical regions (see Figure 11). Questions are directed to determine in which areas the worker experiences discomfort or has experienced discomfort in the past. Once general epidemiological data have been gathered for a worker, specific questionnaires can be administered for specific body regions to determine information related to injuries, discomfort, and life-style changes. Dickinson, Campion, Foster, Newman, O'Rourke, and Thomas (1992) noted several improvements that could be made to increase the effectiveness of the NMQ for English speakers, including changes in wording, layout, and administration.

The NMQ offers the advantage of standardizing the record of musculoskeletal disorders for workers across functions and work sites. This standardization allows a large pool of data to be amassed and available for epidemiological analysis. The relative simplicity and cost-effectiveness of the method allows wide application of the questionnaire. However, the nature of the NMQ method allows for little diagnostically or sensitivity to work place design problems. The NMQ is designed mainly as a "first-cut" means for identifying and assessing work types and sites with musculoskeletal problem areas (Corlett, 1995). Kroemer et al. (1994, p. 355) comment that "further changes may be advantageous to check on particular conditions."

Given the relative sensitivity and diagnosticity provided, the RPE CR-10 Scale would appear to be most applicable subjective assessment method for gauging physical stress during MMH. The method provides interval data for comparative statistical analyses and maintains a simple, unambiguous application format. The CR-10 RPE scale would provide the greatest level of sensitivity to the dynamic physical nature of the MMH work under scrutiny.

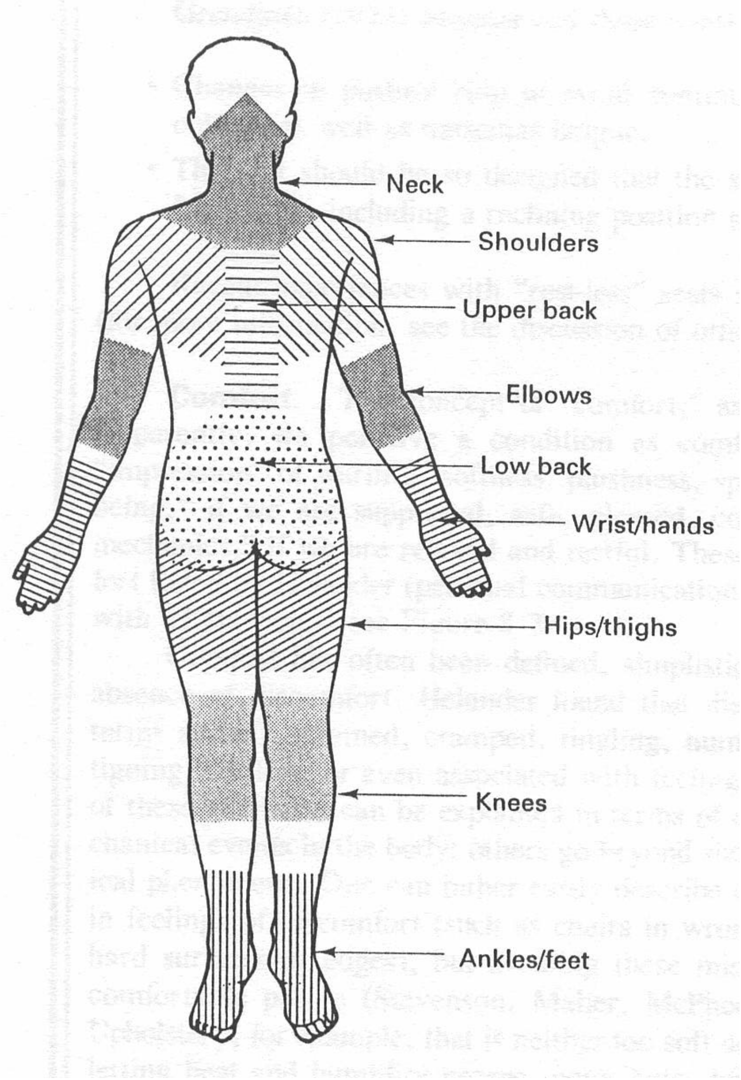


Figure 11. NMQ body regions (Kuorinka, Jonsson, Kilbom, Vinterberg, Biering-Sorensen, Andersson, and Jorgensen, 1987).

3.0 METHODS AND MATERIALS

3.1 Overview

This section describes the methodology used to assess differences among trailer unloading conditions for a manual material handling (MMH) task. This project studied four different designs used in trailer MMH to determine which design(s) place the least physical stress on the human operator unloading materials. The designs differed based on placement and size of transport conveyors, location of transport conveyors in relation to the worker, and degree of conveyor mechanization. The intervention focused on MMH design as it influenced the physical loading of the operator. Performance issues, such as production and work methods, were not a focus of this research and were treated as control variables. The experimental procedure was a "field study" using skilled industrial workers performing actual trailer unloading tasks.

Each trailer MMH design was evaluated by the criteria of biomechanical loading, working postures, physiological measure, and subjective rating of exertion. Physical stress created by biomechanical loading was assessed and compared using The University of Michigan Three-Dimensional Static Strength Prediction Model (3-D SSPM) (The University of Michigan Center for Ergonomics, 1993). Working posture was evaluated by videotaping each participant while unloading boxes in each MMH trailer design. The Ovako Working Posture Analyzing System (OWAS) (Karhu et al., 1977) for recording and rating postures was used to compare the designs. The physiological stress created by each design was measured using the average heart rate of each participant during unloading tasks. Subjective rating of perceived exertion (RPE) was compared within-subjects by administering the Category-Ratio 10 Rating of Perceived Exertion (CR-10 RPE) (Borg, 1982) questionnaire immediately following trailer MMH work. The CR-10 RPE questionnaire addressed the workers' overall RPE.

Once each design was evaluated by the four assessment methods, the results were compared within each subject for relative sensitivity to differing trailer MMH designs. Based on relative sensitivity, ease of application, and administrative and equipment costs, recommendations were made for an assessment method useful in the field for evaluating similar MMH work. Finally, recommendations were made regarding the design that minimizes physical stress during trailer MMH work. Throughout this study a single observer, the researcher, interacted with participants and collected and analyzed all data.

3.1.1 Experimental objectives.

This study used the four specified assessment methods to:

1. Determine which trailer MMH design minimizes biomechanical stress during trailer unloading
2. Determine which trailer MMH design minimizes poor working postures during trailer unloading
3. Determine which trailer MMH design minimizes physiological stress during trailer unloading
4. Determine which trailer MMH design minimizes rating of perceived exertion during trailer unloading

5. Determine which method of assessment shows the greatest sensitivity to differences in experimental conditions
6. Make recommendations for an assessment method useful in the field for evaluating similar MMH work
7. Make recommendations for a MMH design that minimizes physical stress during trailer unloading

3.1.2 Experimental hypotheses.

To meet the experimental objectives, four hypotheses were generated for statistical testing:

Hypothesis 1: Biomechanical stress is significantly different among the different MMH designs studied

Hypothesis 2: Working posture is significantly different among the different MMH designs studied

Hypothesis 3: Physiological stress is significantly different among the different MMH designs studied

Hypothesis 4: Rating of perceived exertion is significantly different among the different MMH designs studied

3.2 Participants

Four participants were used in the single-factor within-subjects design. Participants' ages ranged from 25 to 38 years. All were recruited from the same local industry to ensure similar training and working conditions. The participants had worked at least six months in trailer MMH unloading and had received the same documented training for MMH and safe working methods during the past year. Motivational control for work pace was maintained by asking that participants use the level of normal skill and effort required during their MMH training.

Each participant was briefed regarding the purpose, methods, and intent of the experimental procedure using a standardized set of instructions (see Appendix A - Section II). The participant was given the opportunity to have answered any questions about the study. The participant was required to read and sign an informed consent (see Appendix A - Sections VIII and IX) and received a copy of the consent form. All participants were in good health and did not have a history of back pain or musculoskeletal injury within the last year as assessed by the screening questionnaire in Appendix A (Section X). The participants' height and weight were measured and recorded by the observer during completion of the physical fitness questionnaire. These data were used for determining anthropometric information in the biomechanical analysis. All participants were male. No female participants were available for the study because none were currently employed in trailer unloading jobs.

A pre-work briefing session was held with each participant to provide instruction, obtain consent, attach heart monitor leads, and answer any questions. Then the participant was observed continuously during normal working conditions over the course of his assigned work shift. Following the observations a debriefing session was held. The participant was given the opportunity to have answered any additional questions about the study. The briefing and debriefing sessions lasted approximately 30 minutes each. Participants were asked to refrain from vigorous physical activity outside of work on the days of the experimental sessions with compliance gauged by self report on the screening questionnaire and by signature of the informed consent.

Participants were identified in the study only by number. All video and other recordings of their work were confidential through the course of the study and were destroyed upon completion of the data analysis. The participants were compensated for an extra normal days pay by their industry employer for all time spent in relation to the study. The participants were free to withdraw from the study at any time. No participant withdrew from the study prior to its completion.

3.3 Experimental Design

The experimental design consisted of a single-factor within-subjects configuration with four levels of the independent variable. This design allowed for maximum data collection with minimum cost and impact to the industrial facility.

3.3.1 Independent variables.

Levels of the manipulated independent variable arose from the MMH system design types. Each design differed based on placement and size of transport conveyors, location of transport conveyors in relation to the worker, and degree of conveyor mechanization. Four different combinations of these design variables comprised the following four conditions:

1. Flat-floor trailer with telescoping roller conveyor
2. Flat-floor trailer with powered belt conveyor
3. Drop-frame trailer with floor mounted rollers
4. Drop-frame trailer with suspended rollers

These four conditions represented the four primary systems for MMH in the industrial environment. Each participant was observed in each condition of the independent variable, yielding a total of 16 observation periods.

In employing a within-subjects experimental design, the advantages of using fewer subjects and refining the statistical error in analysis of variance were garnered. However, ordering of treatment conditions could have introduced a confounding variable to the analysis. This potential confound was controlled by having the conditions presented in a balanced Latin Square design. This presentation scheme balanced the ordering of treatments to allow each condition to proceed and follow every other condition an equal number of times, thus reducing confounding influence of treatment order. Table 1 depicts the resulting experimental design using the balanced Latin Square. The four participants were randomly assigned a participant number and subsequent ordering of treatments.

3.3.2 Dependent variables.

Dependent variables were assessed using the four methods outlined and selected in the Review of Literature section: The University of Michigan Three-Dimensional Static Strength

Table 1. Experimental Design with balanced Latin Square treatment ordering.

		PARTICIPANT NUMBER			
		Participant 1	Participant 2	Participant 3	Participant 4
ORDER	First	Flat-floor Trailer Roller Conveyor	Flat-floor Trailer Power Conveyor	Drop-frame Trailer Floor Rollers	Drop-frame Trailer Suspended Rollers
	Second	Flat-floor Trailer Power Conveyor	Drop-frame Trailer Floor Rollers	Drop-frame Trailer Suspended Rollers	Flat-floor Trailer Roller Conveyor
	Third	Drop-frame Trailer Suspended Rollers	Flat-floor Trailer Roller Conveyor	Flat-floor Trailer Power Conveyor	Drop-frame Trailer Floor Rollers
	Fourth	Drop-frame Trailer Floor Rollers	Drop-frame Trailer Suspended Rollers	Flat-floor Trailer Roller Conveyor	Flat-floor Trailer Power Conveyor

Prediction Model (3-D SSPM) for biomechanical force prediction, the Ovako Working Posture Analyzing System (OWAS) as a categorical posture observation system, heart rate for physiological assessment, and the Category-Ratio 10 Rating of Perceived Exertion (CR-10 RPE) for subjective assessment. Using these techniques, the measured dependent variables were:

1. Estimated low back (L5/S1) compression force at materials acquisition and placement
2. OWAS action category at materials acquisition and placement
3. Heart rate
4. Whole-body Rating of Perceived Exertion (RPE)

Each dependent variable was measured for each subject over the four conditions using the specified experimental protocol. Throughout this study, the point at which the participant appeared to apply force to lift the box was designated the acquisition point for the lift and was estimated from the video tapes of the participant's lifting actions. The point at which the participant appeared to release the securing force necessary to lift and move the box was designated the placement point for the lift and was also estimated from the video tapes of the participant's lifting actions.

3.3.3 Control variables.

Employing this design in an industrial facility using normal working operations created the opportunity for several confounding variables to interact with the experimental design. The size and weight of materials in the MMH process could not be controlled and may have influenced posture for the 3-D SSPM and OWAS inputs, heart rate, and RPE. However, over a large sampling of items in regular every-day MMH, the distribution of item sizes and weights should be fairly regular. Therefore the work task included moving at least 300 items. Given this sample size and the random but regular distribution of sizes and weights, materials handled in each condition were considered equivalent.

Participants may vary in experience, working methods, and physical dispositions for lifting. These participant differences were controlled through inquiry and screening of potential participants. All participants were required to have at least six months of work experience in trailer MMH unloading, although a maximum experience level was not specified. All participants received the same documented training from their employer for MMH and safe working methods in the past year. All participants completed a screening questionnaire to ensure they were in good health and had been free from back pain or musculoskeletal injury within the last year.

A final potential confound to the experimental design arises from the motivational level of the participant. Dependent variables of heart rate and RPE may be susceptible to influences in work pace between participants. Also work pace may influence the postures used when moving materials. Motivational differences between participants were controlled by asking them to follow normal working methods and work at a normal pace.

3.3.4 Pretesting.

Pretesting was conducted first in a laboratory setting following the experimental and data analysis protocols. The focus of pretesting was to determine that data collection equipment worked properly, protocols were complete, and analysis techniques were applicable to the data collected. A trailer and MMH device were simulated in the laboratory using moveable partitions to define trailer walls and a table as a material handling device. One pretest participant was observed moving boxes in the simulated trailer. This procedure was used to set camera distances and lens heights needed to capture the full range of participants' motions during video data collection.

Subsequent to the laboratory pretest, a mock data collection trial was performed at the industrial facility to identify potential "field" data collection or protocol problems. The observation period was short, approximately five minutes, because large numbers of materials could not be unloaded during this mock trial. No data collection or protocol problems were identified in this mock trial.

3.4 Apparatus and Materials

3.4.1 The industrial environment.

The trailers and MMH equipment of a local industrial facility were used in the study. The facility is primarily involved in the sorting, consolidation, and shipping of boxed materials. Box sizes are limited to 325 cm combined length and girth. Individual box weight is limited to 31.75 kg. The trailers observed during unloading were of two types: a standard flat-floor design and a drop-frame design. The flat-floor trailer was unloaded using a telescoping roller conveyor (see Figure 12 for a drawing of the condition and Figure 13 for a picture of the actual equipment used) and a powered conveyor (see Figure 14 for a drawing of the condition and Figure 15 for a picture of the actual equipment used).

The drop-frame trailer had a fixed internal roller conveyor with loading flaps that folded down flush with the rollers. Boxes were loaded under the flaps to the height of the rollers, the flaps folded down, and then more boxes placed on top of the flaps. These were considered as two unloading conditions; one with rollers along the floor (flaps down - see Figure 16 for a drawing of the condition and Figure 17 for a picture of the actual equipment used) and the other with rollers suspended (flaps up - see Figure 18 for a drawing of the condition and Figure 19 for a picture of the actual equipment used). These four conditions represented the four primary systems for trailer MMH in the industrial environment. All equipment used was in good repair and did not require manipulation by the worker.

Sizes and weights varied among boxes observed during the unloading process. Historical information from size and weight surveys showed that over a large sampling of items, the distribution of item sizes and weights was fairly consistent among trailers. A large sample of at least 300 boxes (approximately 30% of a trailer load) was used for the experimental protocol to ensure generalizability of the data garnered.

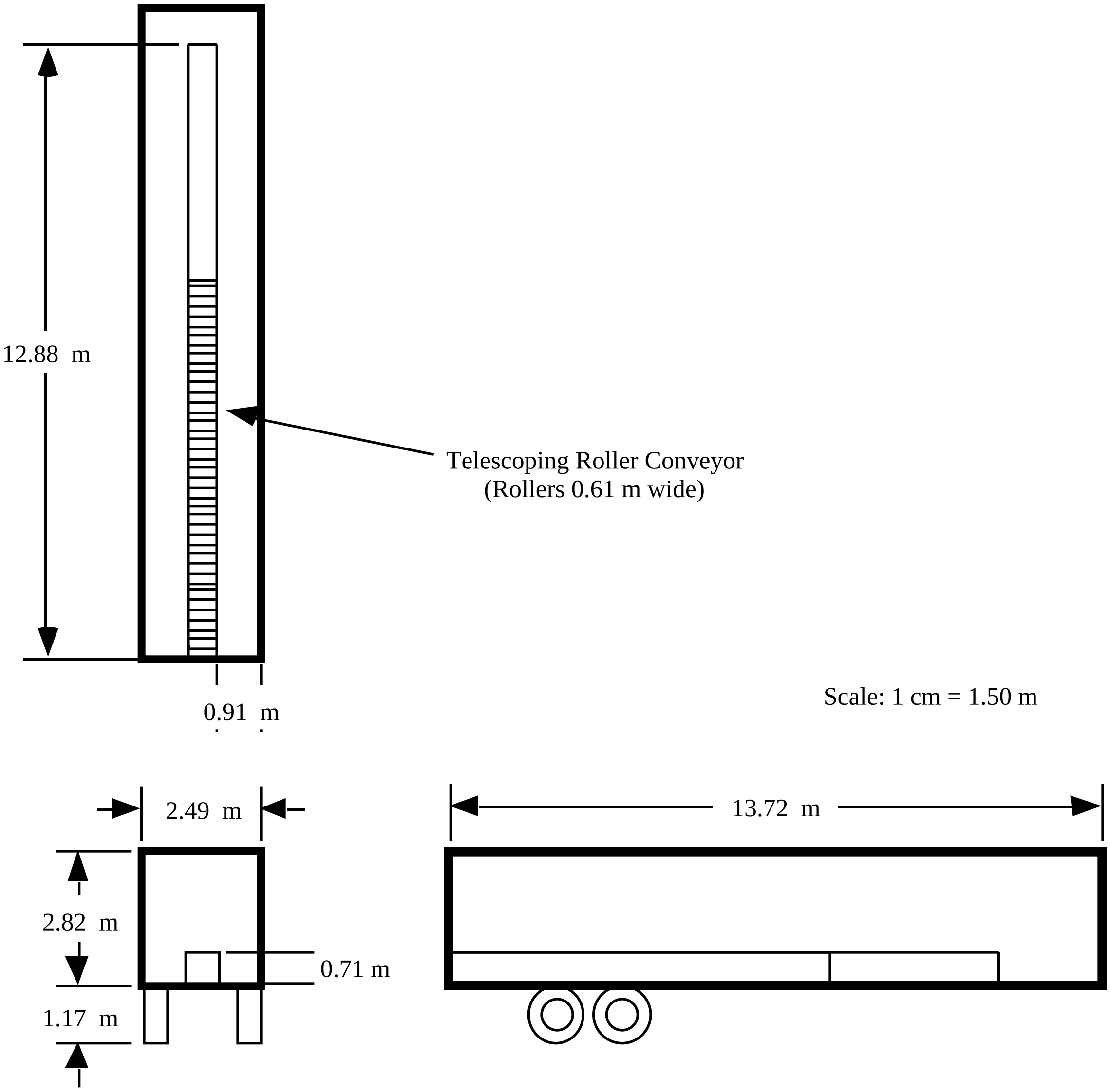


Figure 12. Flat-floor trailer with roller conveyor - drawing.

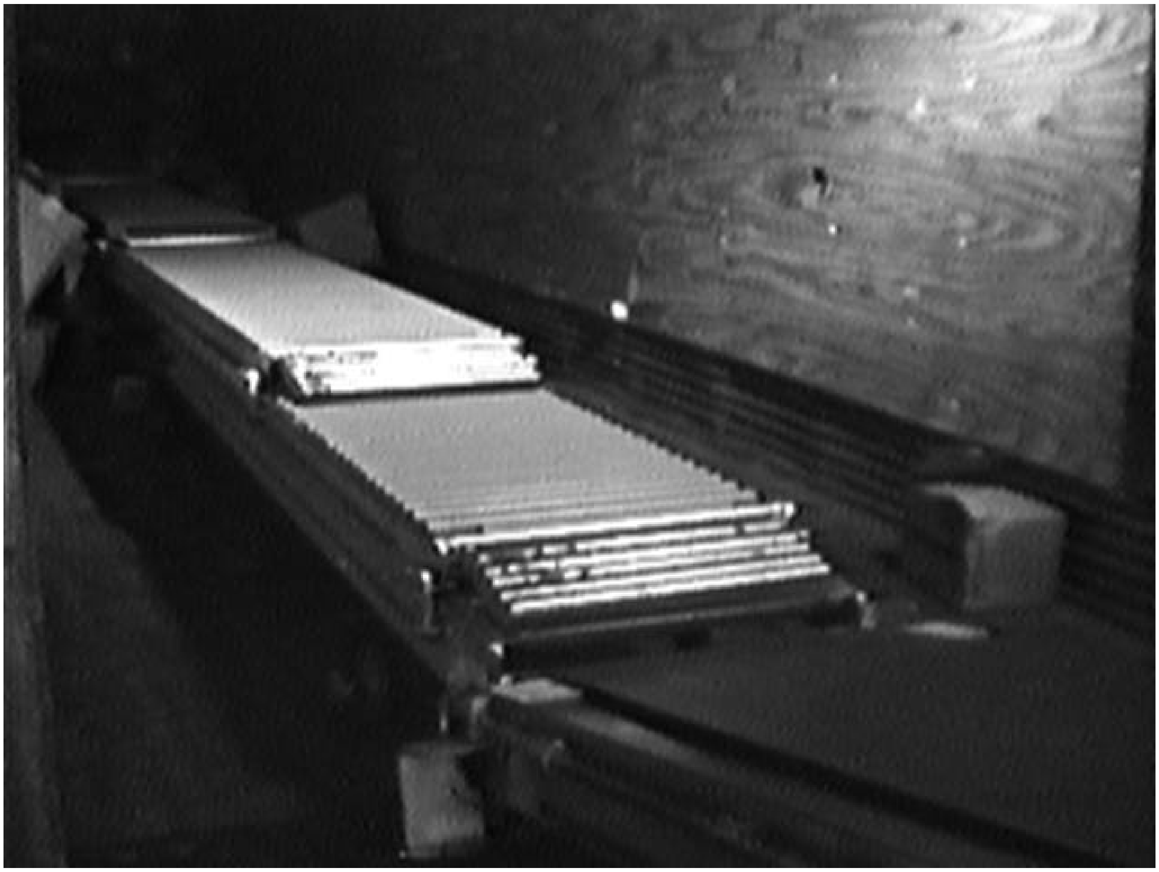


Figure 13. Flat-floor trailer with roller conveyor - picture.

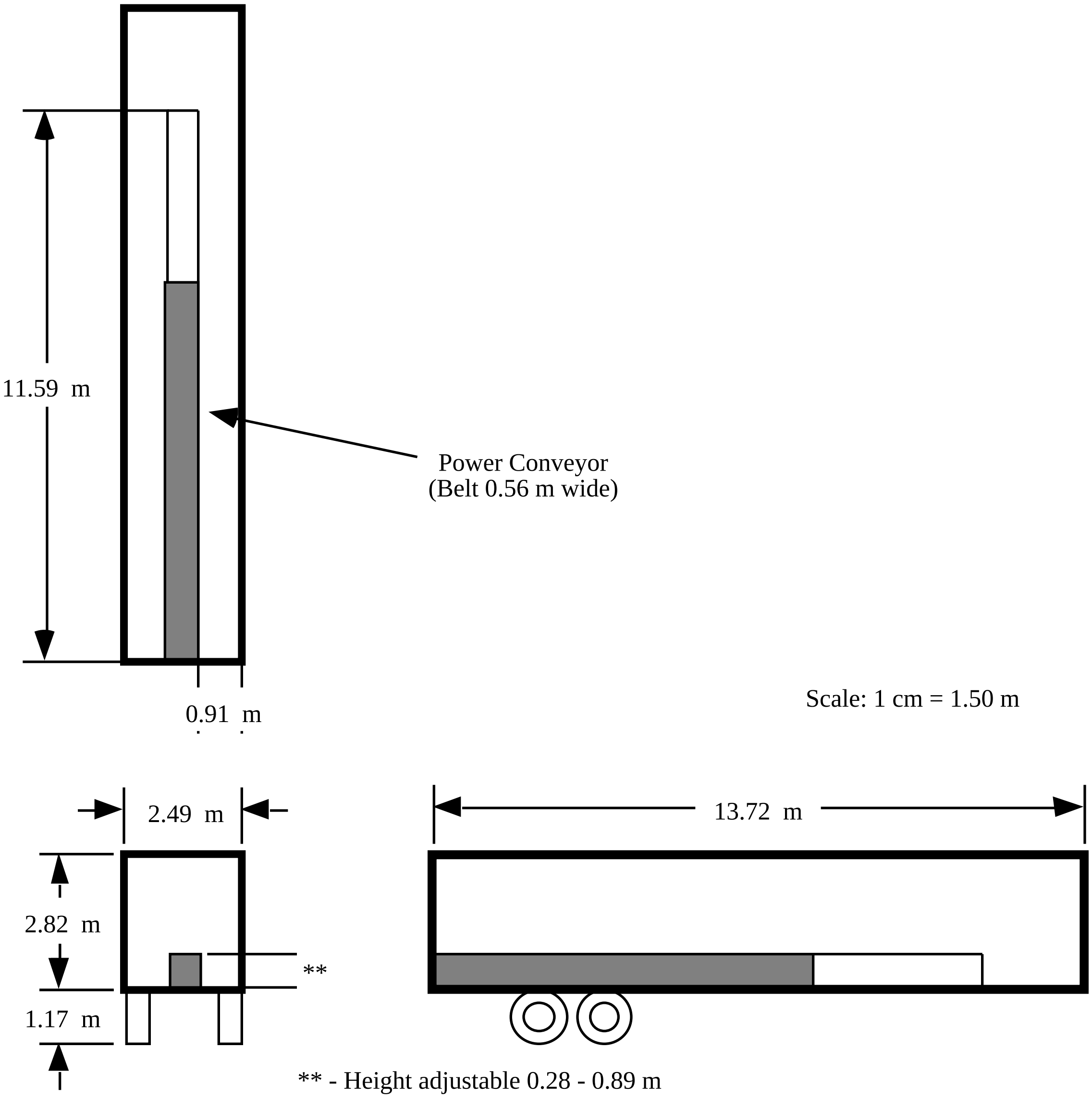


Figure 14. Flat-floor trailer with power conveyor - drawing.

Figure 15. Flat-floor trailer with power conveyor - picture.

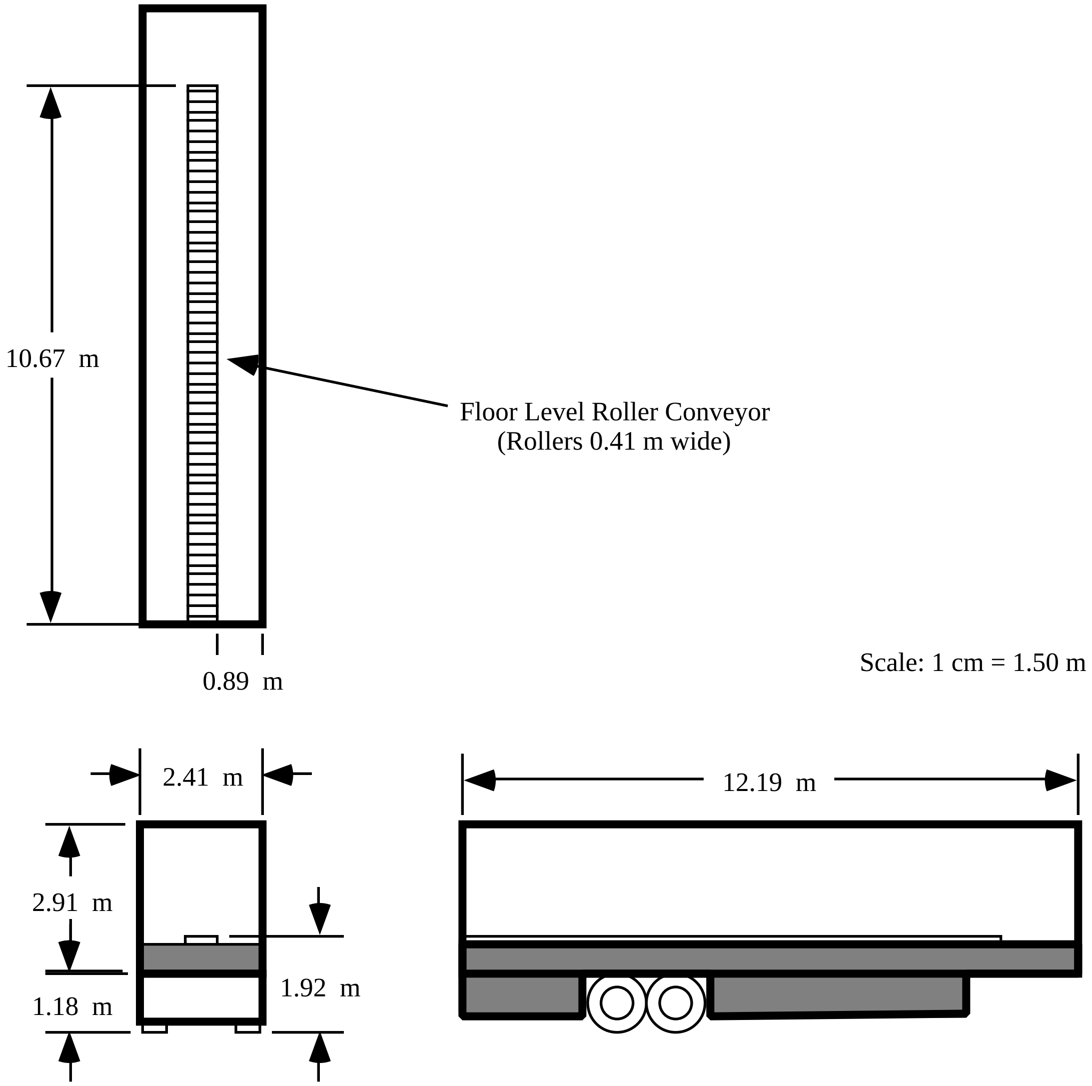
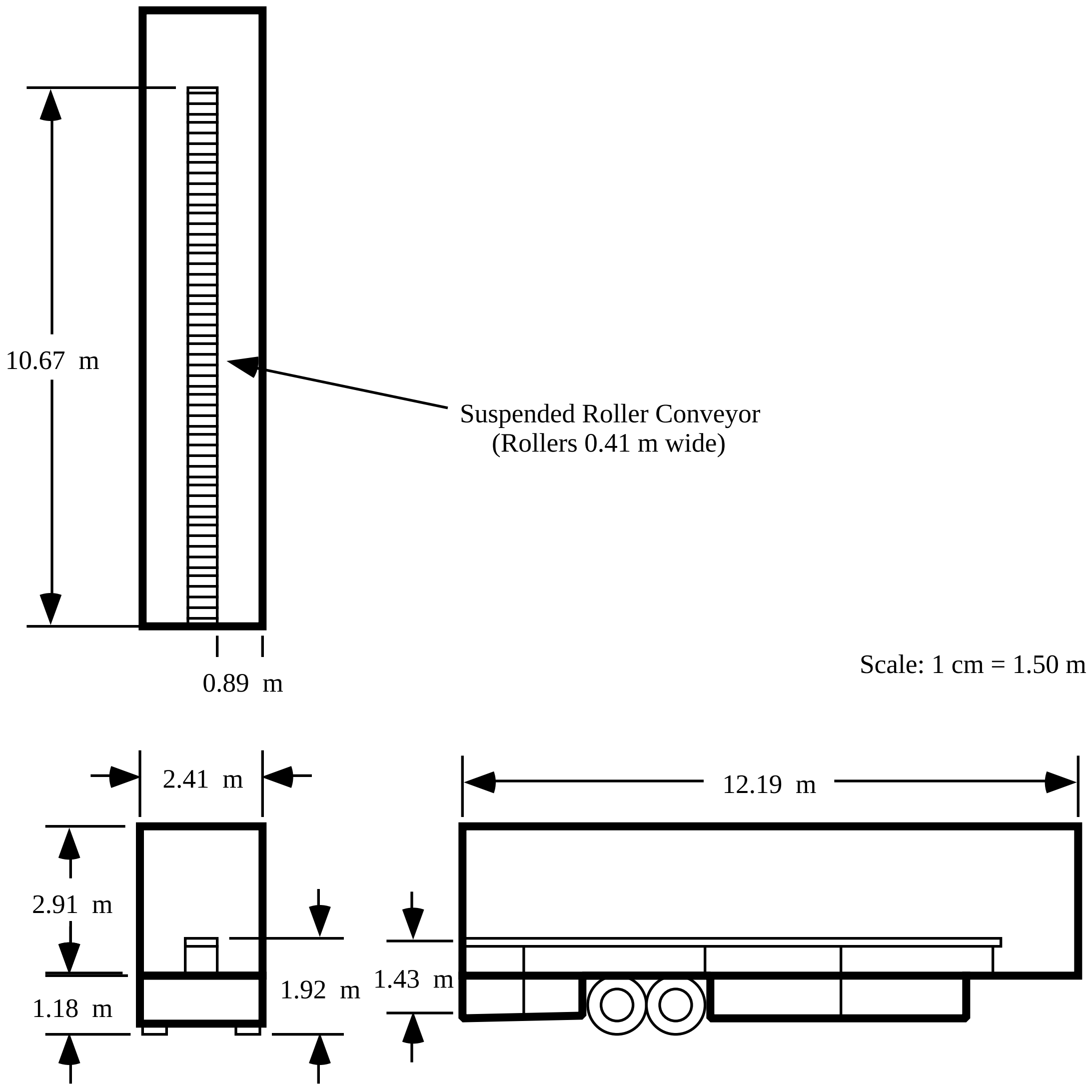


Figure 16. Drop-frame trailer with floor roller conveyor - drawing.

Figure 17. Drop-frame trailer with floor roller conveyor - picture.



Scale: 1 cm = 1.50 m

Figure 18. Drop-frame trailer with suspended roller conveyor - drawing.

Figure 19. Drop-frame trailer with suspended roller conveyor - picture.

3.4.2 Anthropometric data.

Participants' height and weight were measured using a Continental Scale Corporation Health-o-meter ® Series 400 beam scale with built-in height pillar. The scale was calibrated by the observer before taking measurements. Height and weight measures were recorded on each participant's physical fitness questionnaire.

3.4.3 Biomechanical modeling.

During trailer unloading the participants' actions were recorded using two General Electric Corporation VHS Movie System video cameras (model number 9-9806) using standard VHS HQ tape format recording in the short play (SP) mode for maximum image clarity. The cameras were placed behind the participant in two locations following the experimental protocol. Elapsed working time and times for rest and warm-up periods were kept by the observer using a digital stopwatch.

The video tapes were played back on a General Electric Corporation VHS Video Cassette Recorder (model number 9-7885) and a General Electric Corporation VHS Video Cassette Recorder (model number VG7500) for synchronization and analysis. Frames depicting lifting and placement of boxes were displayed using two General Electric Corporation 25-inch video monitors (model number 8-2668) for maximum image detail. These two video images were displayed simultaneously to determine the spatial locations of participant's body segments during acquisition and placement of boxes. The spatial locations of body segments were input into the University of Michigan 3-D Static Strength Prediction Program™ version 2.0 to determine estimated low back compression forces. The SSPM input screen was displayed on a 17-inch CTX Graphics Monitor to allow for maximum image detail and precise manipulation of model inputs. A picture of the equipment and configuration used for video playback and SSPM analysis input is given in Figure 20.

3.4.4 Categorical posture evaluation.

The video recordings of the worker captured for biomechanical analysis were also analyzed using OWAS (Ovako Working Posture Analyzing System) (following Karhu et al., 1977). Both video recordings were synchronized and viewed simultaneously using the equipment and configuration shown in Figure 20. Following the examples of work sampling plans employed in past studies, every tenth acquisition and placement posture was analyzed for position of the back, upper limbs, and lower limbs. For each posture an action category was determined. All data codes and action categories were recorded on an OWAS data analysis sheet. The OWAS posture recording reference, action table, instructions, and data analysis sheet may be found in Appendix B.

3.4.5 Physiological assessment.

A physiological assessment of physical stress incurred during the work task was made using a measure of heart rate recorded at five second intervals over the working period. A Polar Vantage NV™ transmitting heart monitor was used. The heart rate monitor consisted of a chest strap sensor with built-in electrodes, an integrated signal transmitter, and a wrist watch for data display, capture, and storage. All data captured during the observation period was stored in the

Figure 20. SSPM and OWAS analysis apparatus and configuration.

Vantage NV wrist watch unit. To avoid signal transmission problems between the transmitter and receiver, the participant wore the wrist watch receiving unit on an adjustable neck strap during observations. Figure 21 shows the apparatus, chest strap monitor and wrist watch receiving unit on the neck strap, fitted on an example participant.

Once the observations were complete, the data samples were transferred from the watch unit to a personal computer using a Polar Advantage™ serial interface and an IBM compatible 80486 computer running in the Windows 3.1 operating environment. Subsequent data storage, analysis, and graphing was facilitated using the Polar Precision Performance - Heart Rate Analysis software version 5.03.

3.4.6 Subjective assessment.

The participant's subjective assessment of physical stress for the work task was gauged using the Borg CR-10 RPE scale (following Borg, 1982). Prior to the work task the participant was given an instruction sheet for using the rating scale. Following the work task, the participant was asked to rate the physical exertion required to unload the boxes using the given MMH equipment. The observer recorded the RPE provided by the participant. A sample scale, instruction set, and data sheet are given in Appendix C.

3.5 Experimental Protocol

The overall experimental task involved observing the participant unload at least 300 boxes of varying size and weight from a trailer using a specified MMH system. The experimental protocol was employed over four distinct phases: participant selection, pre-observation briefing, task observation, and post-observation debriefing. No participant chose to discontinue the protocol or to withdraw from any portion of the study.

3.5.1 Participant selection.

A pool of participants was selected at random from the population of MMH unloading personnel at the industrial facility. From the pool, only participants meeting the selection criteria of six month minimum experience, one year prior documented training, and lack of prior recorded injury requirements were considered for observation. Assistance from the facility management was used to screen participants' files for inclusion in this study.

3.5.2 Pre-observation briefing.

Each participant selected for observation attended a briefing 30 minutes before the start of his assigned work shift. The participant was greeted by the observer and given an overview of the purpose, goals, and requirements for participation. If the participant agreed to learn more, he was given an informed consent statement (see Appendix A) to read, ask questions about, and then sign. The observer returned a copy of the consent form to the participant and retained the signed form. The participant was given the rating scale instructions to read and ask questions about. Once all of the participant's questions were answered and a full understanding of his duties reached, the participant was prepared for the observation procedure.

The first step in preparing the participant was to complete a physical fitness questionnaire. The observer weighed and measured the participant and recorded the values on the

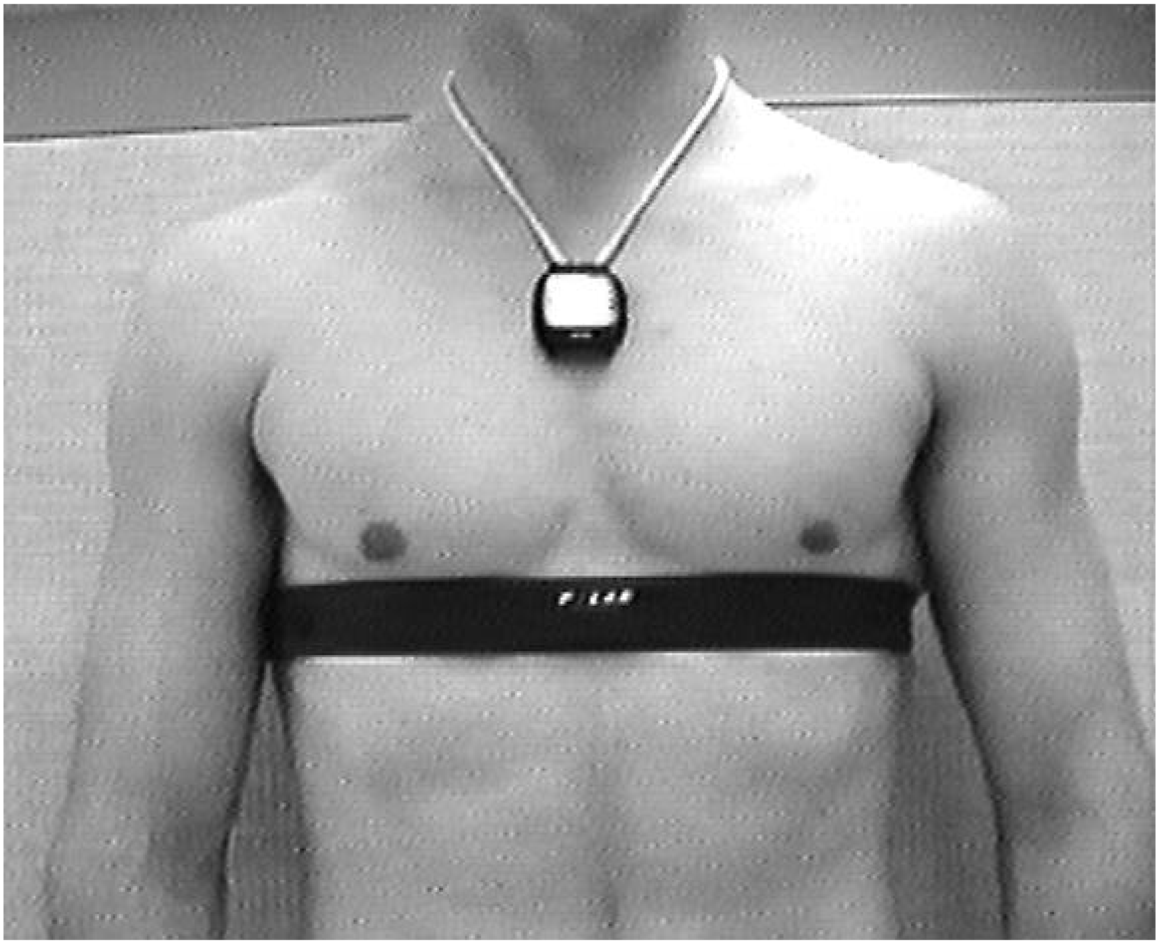


Figure 21. Heart rate monitoring apparatus.

questionnaire. These values were used to select anthropometric inputs to the 3-D SSPM. The second step in preparing the participant was to attach the heart rate monitor to the participant and ensure proper recording of heart rate data. The heart rate monitor was placed in recording mode for a pre-work capture of baseline heart rate. Once the participant was readied for observation, the observer answered any further questions and accompanied the participant to the site for the first experimental condition.

3.5.3 Task observation.

On arriving at the site for the first condition, the observer verified the operation of the heart rate recorder and the readiness of the participant. The participant reviewed the instructions for using the exertion rating scale. The observer initiated data recording by the heart rate monitor and the participant was then be asked to begin work unloading boxes from a trailer following prior MMH training, safe work methods, and the special instructions given in the briefing. The participant worked for five minutes unobserved, to allow a warm-up period and "ramp-up" period from resting heart rate for physiological measure (following Stegemann and Skinner, 1981).

While the participant was in the warm-up period of work, the observer placed two video recording cameras to capture lifting motions. Each camera was positioned behind the participant, perpendicular to the coronal (frontal) plane, at an approximate height of 1.0 m floor to lens center and an approximate distance of 3.0 m from the participant to capture the full range of motion during work. The two cameras were placed in different locations behind the participant to capture the entirety of the unloading task. The camera distances and placements were manipulated by the observer as needed to capture full-body posture throughout each unloading condition. The participant's working actions were video-taped while unloading 300 boxes from the trailer, comprising approximately 15 minutes of observed working time.

Once the participant's five minute warm-up period was complete, the observer started each video camera. As the participant continued in the unloading task, the observer repositioned the video cameras as necessary to capture full body posture throughout the observation. The observer also monitored the participant for any difficulties or excessive fatigue. No participant experienced difficulty or excessive fatigue during the experimental protocol.

After the participant completed the unloading task, he was given a rest period of 15 minutes to allow heart rate to return to resting (following Stegemann and Skinner, 1981). During the rest period, the participant completed the CR-10 RPE scale given in Appendix C for the recent unloading condition. The observer stopped the heart rate recorder, stored the data, and then initiated recording for the rest period. The observer also stopped the video recorders and prepared them for the next condition.

The participant and observer then moved to the second condition and followed the above protocol. The participant and observer continued in a like manner through the third and fourth conditions. A depiction of the protocol schedule is given in Figure 22. Before beginning work at each condition, the observer verified the operation of the heart rate recorder, allowed the participant to read the rating scale instructions, ensured the readiness of the participant, and initiated a new heart rate recording session.

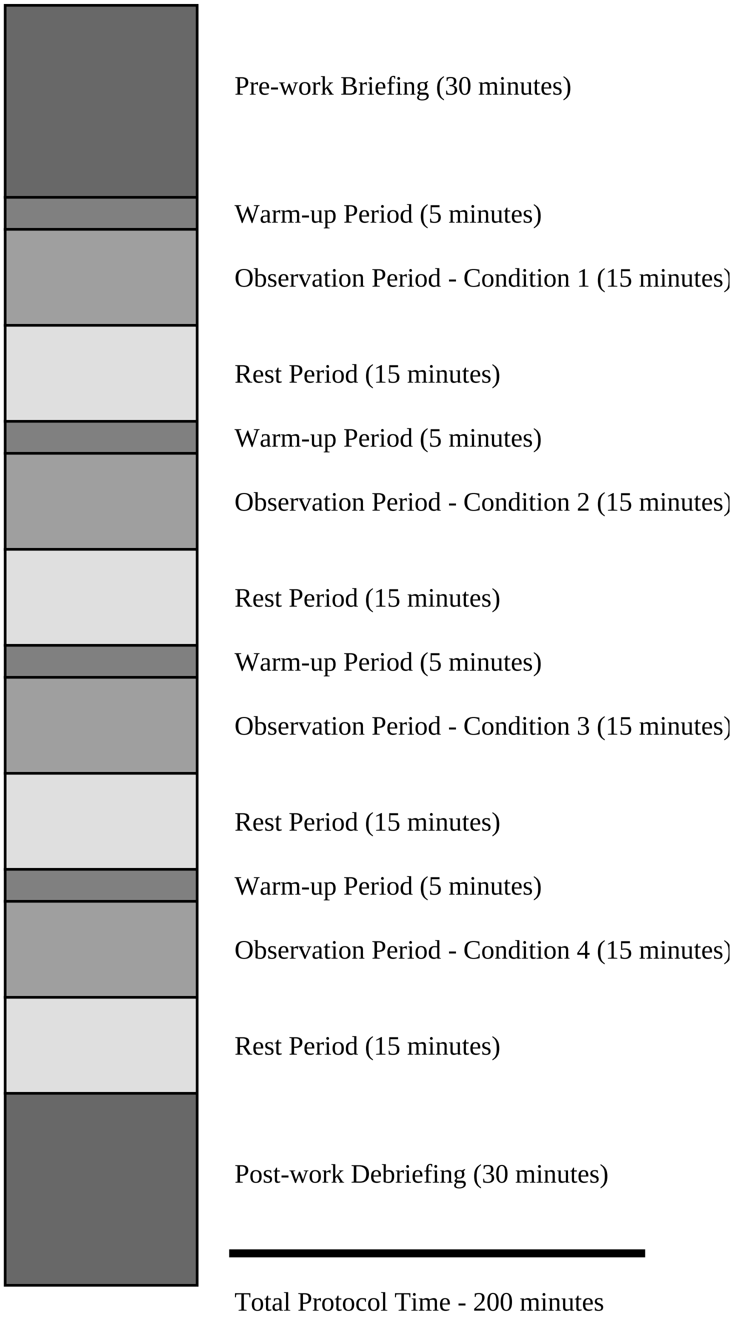


Figure 22. Experimental protocol schedule.

3.5.4 Post-observation debriefing.

Once the four conditions were complete, the observer and participant moved from the work area to debrief. In the debriefing, the observer answered any further questions the participant had and stopped the recording of resting heart rate data after 15 minutes. The observer then removed the heart rate monitor, thanked the participant for his assistance, and dismissed the participant.

3.6 Data Analysis Protocol

Following the experimental protocol, the observer retained the participant's informed consent form, physical fitness questionnaire, two video tapes recording the participant's work, the heart rate recorder with all stored data, and the completed CR-10 RPE data sheet for data analysis. Data analysis was performed over four areas: biomechanical modeling, categorical posture observation, physiological assessment, and subjective assessment. All data summary tables, descriptive statistics, and data summary graphs were generated using Microsoft Excel version 5.0. Also the Friedman Analysis of Variance and summary tables were produced using Excel. All ANOVA analyses and summary tables, Newman-Keuls analyses and tables, and graphs containing confidence intervals were generated using SuperANOVA version 1.11.

3.6.1 Biomechanical modeling.

Biomechanical modeling of lifting during the unloading task was accomplished in three parts: synchronization of the acquisition and placement scenes between the video tapes, simulation of the working posture used by the participant in the 3-D SSPM, and estimation of low-back compression forces by combining posture, load, and anthropometric data in the 3-D SSPM software.

To extract lifting posture, both lifting videos were used to capture actual posture at the point of box acquisition and at placement to the MMH system. The two videos were placed in the video cassette recorders and synchronized using a common reference frame. Following the examples of work sampling plans employed in past studies, the videos were searched for five lifting scenes meeting the following criteria:

1. The point of acquisition at the extreme from the MMH device - on the trailer floor, box side touching the trailer side wall
2. A "normal" box; i.e., a box not requiring the participant to move to the box to lift or one being liftable using only one hand
3. A "normal" lift; i.e., the lifting and MMH rhythm and motion of the operator are uninterrupted from box acquisition to release to the MMH device

The first five lifting scenes meeting these criteria were used for posture extraction.

Once a lifting scene was identified for use, the moment of box acquisition in both camera views was displayed on the video monitors for analysis. Subsequently the point of placement to the MMH device for the same box was displayed on the video monitors and analyzed.

The representations of each camera view were displayed to determine spatial locations of body segments. The 3-D SSPM was then be employed to estimate biomechanical loading on body segments. The anthropometric data taken from the participant were entered into the 3-D SSPM analysis screen. Body segment masses and moments of inertia were taken from the anthropometric data supplied in the 3-D SSPM archival data for a person of the participant's stature and weight. Then the 3-D SSPM body segment model was manipulated to mirror that of the actual posture. The 17-inch video monitor allowed a high degree of sensitivity for manipulating body segment positions in the SSPM posture entry window. The load weight used for the 3-D SSPM was 12.7 kg, the average box weight within the industrial facility. This weight was input as a distributed force magnitude of 62 N for each hand. Use of a consistent load weight between all lifting analyses was required to make valid comparisons between MMH conditions. Each set of posture images were analyzed to estimate the L5/S1 low-back compression force for that particular acquisition and particular placement in the lifting condition. The result of this analysis was an estimated low-back (L5/S1) compression force for five acquisitions and five placements in each of the four MMH conditions for each of the four subjects, a total of 160 synchronized, modeled, and analyzed postures.

The output dependent measure was a continuous, ratio-scaled measure of the estimated L5/S1 compression force on the participant. Descriptive statistics of mean, standard deviation, and standard error were computed to characterize the raw data for each acquisition and placement. The median, minimum, and maximum data points were also reported. An analysis of variance (ANOVA) was used to test for significant differences among the four conditions for both acquisition and placement. The ANOVA was conducted at the α=0.05 level of significance, following the example of similar studies cited in the Review of Literature section. Data summary, descriptive statistics, and ANOVA summary tables appear in the Results section for both acquisition and placement data.

If the ANOVA found significant difference among the four conditions, a post-hoc analysis for level differences was conducted. The Newman-Keuls Sequential Range Test was used to judge the level of difference at α=0.05 significance, following the example of similar studies cited in the Review of Literature section. This post-hoc analysis allowed comparisons between conditions to determine where significant differences arise. Output from the Newman-Keuls analysis is presented in tabular form in the Results section. Also the four computed grand means are represented graphically for each condition in acquisition and placement. Means are bounded by their 95% confidence intervals.

3.6.2 Categorical posture evaluation.

A categorical posture evaluation was conducted using the OWAS system. The video recordings of the participants' work were synchronized and played back simultaneously. Following the specified work sampling plan, the observer analyzed every tenth box moved by the participant using the OWAS forms in Appendix B. The postures assumed by the participant in the acquisition of the box and in its placement on the MMH device were categorized. Following the directions given in the OWAS forms, the action category for each acquisition and each placement was computed. This procedure was used throughout the 300 boxes unloaded in the experimental protocol. The result of this analysis was an action category for 30 acquisitions and

30 placements in each of the four experimental conditions for each of the four subjects, a total of 960 action category computations.

The output dependent measure was a discrete, ordinal-scaled measure of OWAS action category. For each set of action category data, a weighted score was derived from the 30 observations. The weighted score from each of the 4 conditions was then used to rank the conditions from lowest action category score (requiring the least immediate action) to highest action category score (requiring more immediate action). Descriptive statistics of mode, minimum, maximum, and range were also computed for each acquisition and placement. A data summary table for both acquisition and placement ratings may be found in the Results section.

Since the ranked data did not follow the parametric statistical assumptions of normal distribution and equal variance, a nonparametric statistical test was employed to examine differences among the four conditions. Given the characteristics of the experimental design, within-subjects related samples and four treatment conditions, the Friedman Two-way Analysis of Variance by Ranks was used to judge significant difference among the four conditions at $\chi \leq 0.05$.

If significant difference was found, the process of multiple comparisons in the Friedman analysis was used as a post-hoc test to allow comparisons between conditions and determine where significant differences arise. The results of the Friedman analysis and multiple comparisons for significant differences appear in tabular form in the Results section. The weighting of action categories was represented graphically for acquisition and placement in each condition over each participant. This representation allowed for qualitative judgment of action category trends for each MMH condition.

3.6.3 Physiological assessment.

The level of physiological workload was estimated from the heart rate data collected by the wrist watch data recorder during the experimental protocol. The observation period heart rate measures recorded were averaged for each participant in each experimental condition. This yielded a mean heart rate over each of the four experimental conditions for each of the four participants.

The output dependent measure was a continuous, ratio-scaled measure of estimated physiological workload. Descriptive statistics of mean, standard deviation, and standard error were computed to characterize the raw data. The median, minimum, and maximum data points were also reported. An analysis of variance (ANOVA) was used to test for significant differences among the four conditions. The ANOVA was conducted at the $\alpha=0.05$ level of significance, following the example of similar studies cited in the Review of Literature section. Data summary, descriptive statistics, and ANOVA summary tables appear in the Results section.

If the ANOVA found significant difference among the four conditions, a post-hoc analysis for level differences was conducted. The Newman-Keuls Sequential Range Test was used to judge the level of difference at $\alpha=0.05$ significance, following the example of similar studies cited in the Review of Literature section. This post-hoc analysis allowed comparisons between conditions to determine where significant differences arose. Output from the Newman-Keuls analysis is presented in tabular form in the Results section. Also the four computed grand means are represented graphically for each condition. Means are bounded by their respective 95% confidence intervals.

3.6.4 Subjective assessment.

Subjective assessment of workload was garnered from the participants' Rating of Perceived Exertion on the CR-10 RPE scale given in Appendix C. A RPE was recorded for each of the four participants over each of the four experimental conditions. The output dependent measure was a continuous, ratio-scaled measure of subjective RPE. The raw data is provided in a summary table in the Results section. An analysis of variance (ANOVA) was used to test for significant differences among the four conditions. The ANOVA was conducted at the $\alpha=0.05$ level of significance, following the example of similar studies cited in the Review of Literature section. Data summary, descriptive statistics, and ANOVA summary tables appear in the Results section.

If the ANOVA found significant difference among the four conditions, a post-hoc analysis for level differences was conducted. The Newman-Keuls Sequential Range Test was used to judge the level of difference at $\alpha=0.05$ significance, following the example of similar studies cited in the Review of Literature section. This post-hoc analysis allowed comparisons between conditions to determine where significant differences arise. Output from the Newman-Keuls analysis is presented in tabular form in the Results section. Also the four computed grand means are represented graphically for each condition. Means are bounded by their respective 95% confidence intervals.

3.6.5 Summary calculations.

Several summary representations of the data were generated to verify experimental controls and create a general presentation of the results. The effect of treatment order for each dependent measure was examined in turn. An example participant's data summary table organized with respect to treatment order is provided in the Results section. This table breaks the general data summaries down to allow a qualitative discussion of level differences within each dependent measure.

To test the assumption that the presentation of treatment conditions did not influence dependent measures, an ANOVA was conducted with respect to treatment order for each of the assessment methods. The ANOVA was conducted at the $\alpha=0.05$ level of significance. If the ANOVA found significant difference among the four conditions, the Newman-Keuls Sequential Range Test was used to judge the level of difference at $\alpha=0.05$ significance. This post-hoc analysis allowed comparisons between paired treatment orders to determine where significant differences arise. Output from the Newman-Keuls analysis is presented in tabular form in the Results section. Also the four computed grand means are represented graphically for each significant order effect. Means are bounded by their respective 95% confidence intervals.

Another control variable in the experimental design arises from production rate, an indirect indicator of motivation, working methods, and degree of worker fatigue. The production rate (in pieces unloaded per hour) is given for each subject over each condition in a data summary table. These rates are approximate, computed using physical counts of boxes unloaded from the video recordings and working times from the heart rate data recorder. However, this method provides a good general measure of production rate. A graphical representation of production rate versus MMH condition for each participant is also included to facilitate discussion of level differences.

Finally, a table providing relative rankings for the physical stress prediction of each dependent measure with respect to the MMH conditions is provided in the Discussion section. While the four assessment measures are quantitatively different, this representation facilitates discussion regarding the general, qualitative nature of the assessment method outputs. These relative rankings may be useful in identifying difference trends among the four MMH conditions and can facilitate discussion regarding the applicability of analysis methods to each working condition.

4.0 RESULTS

This section contains the results garnered from the experimental and data analysis protocols. The data analysis protocol from the Methods and Materials section was applied to the raw data to generate summary and statistical results for the data. The raw data from each assessment method may be found in Appendix D. The four hypotheses specified in the experimental objectives were used in statistical testing:

Hypothesis 1: Biomechanical stress is significantly different among the different MMH designs studied

Hypothesis 2: Working posture is significantly different among the different MMH designs studied

Hypothesis 3: Physiological stress is significantly different among the different MMH designs studied

Hypothesis 4: Rating of perceived exertion is significantly different among the different MMH designs studied

4.1 Biomechanical Modeling

The two video recordings made during the participants' work were used to extract posture for five lifting situations in each MMH condition for each participant. For each lift of interest, the posture at the point of box acquisition, specifically when the worker appeared to apply force to lift the box, and the posture at the point of box placement to the MMH device, specifically when the worker released his securing grip on the box, was modeled using the 3-D SSPM. The result of this analysis was an estimated low-back (L5/S1) compression force for five acquisitions and five placements in each of the four experimental conditions for each of the four participants, a total of 160 synchronized, modeled, and analyzed postures. Each acquisition and placement simulation required approximately five minutes to input the working posture, verify body segment locations, and analyze the posture. The total analysis time for biomechanical modeling was approximately 12 hours (three hours per participant).

The results of the acquisition and placement analyses are presented in turn, with each section containing a data summary characterizing the raw data, statistical tests of *Hypothesis 1*, and a graphical representation of the means and 95% confidence intervals for the four MMH conditions. Each analysis is also accompanied by a graph summarizing the relative data for each of the four participants.

4.1.1 Acquisition at beginning of lift.

The point at which the participant appeared to apply force to lift the box was designated the acquisition point for the lift and was estimated from the video tapes of the participant's lifting actions. An example scene used for acquisition analysis is shown in Figure 23. The posture assumed by the participant at this acquisition point was modeled using the 3-D SSPM and the output estimate of L5/S1 compression force was recorded. For each MMH condition, five estimates of L5/S1 compression force at acquisition were recorded as raw data (see Appendix D - Section I). The summary of these raw data is given in Table 2 where the mean, standard

Figure 23. Example acquisition posture used for input to SSPM and OWAS analyses.

deviation, standard error, median, minimum, and maximum values for each set of five L5/S1 force values are reported. These descriptive statistics are provided for each participant within each MMH condition.

Figure 24 provides a graphical summary of the data points for each MMH condition, giving the L5/S1 compression force changes from the means column in Table 2 by participant over each condition. This summary is useful in discussing level differences among participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph.

Following the reduction of the raw data from the video tapes and the generation of descriptive statistics, the hypothesis that "biomechanical stress is significantly different among the different MMH designs studied" was tested using inferential analysis. An ANOVA was conducted at the α=0.05 level of significance to test the hypothesis that the dependent variable indicating biomechanical stress, L5/S1 Force (N), is significantly different among levels of the independent variable, MMH Condition. Table 3 summarizes the grand means calculated from the four participants over each MMH condition and used as the inputs for the ANOVA. Table 4 provides the output of the ANOVA in a summary table. The manipulation of the source factor MMH Condition is summarized and the calculated p-value of 0.4912 reported. This p-value is not significant at the α=0.05 level, therefore *Hypothesis 1* that "biomechanical stress is significantly different among the different MMH designs studied" is rejected. In the ANOVA, the factor Subjects is separated from the MMH * Subject error term to refine the calculated error term and reduce the effect of subjects from the determination of significance in the p-value. Table 4 also includes values for the Geisser-Greenhouse (G-G) and Huynh-Feldt (H-F) multivariate adjustment factors to the p-value. Both values are provided because the Geisser-Greenhouse correction tends to be a conservative estimate of error while the Huynh-Feldt correction is more liberal.

Since no statistically significant difference among the conditions was found and *Hypothesis 1* was rejected, the Newman-Keuls post-hoc analysis was not required. A lack of significant difference in the ANOVA indicates that no significant difference exists between any of the levels of MMH condition.

Finally, Figure 25 provides a graphical depiction of the differences among the grand means used as an input to the ANOVA. Each level of MMH condition is represented on the X-axis with the corresponding mean L5/S1 force located according to the Y-axis. Also the 95% confidence intervals for each mean are represented. These confidence intervals map to the α=0.05 level of significance used in the ANOVA and give a pictorial indication of the level differences among MMH conditions.

Table 2. SSPM - Acquisition data summary (all values in Newtons - compression).

		Mean	Std. Dev.	Std. Error	Median	Min	Max
Flat-floor Trailer Roller Conveyor	Participant 1	2009.20	810.84	362.62	1875	1191	2904
	Participant 2	2747.80	570.08	254.95	2521	2071	3399
	Participant 3	4584.60	306.03	136.86	4493	4265	5056
	Participant 4	4653.80	493.79	220.83	4452	4151	5223
Flat-floor Trailer Power Conveyor	Participant 1	2393.60	539.29	241.18	2138	1896	3144
	Participant 2	2862.20	644.82	288.37	2879	1891	3577
	Participant 3	3558.00	365.57	163.49	3765	3135	3903
	Participant 4	3999.40	1266.64	566.46	4701	2364	5217
Drop-frame Trailer Floor Rollers	Participant 1	2660.80	517.81	231.57	2506	2292	3573
	Participant 2	3139.80	239.60	107.15	3093	2829	3477
	Participant 3	3419.60	635.46	284.18	3402	2788	4220
	Participant 4	4002.40	1071.19	479.05	4605	2467	4877
Drop-frame Trailer Suspended Rollers	Participant 1	2540.20	550.85	246.35	2539	1753	3158
	Participant 2	3331.20	565.41	252.86	3277	2564	3924
	Participant 3	3981.80	242.66	108.52	4005	3669	4338
	Participant 4	4473.20	548.38	245.25	4374	3827	5181

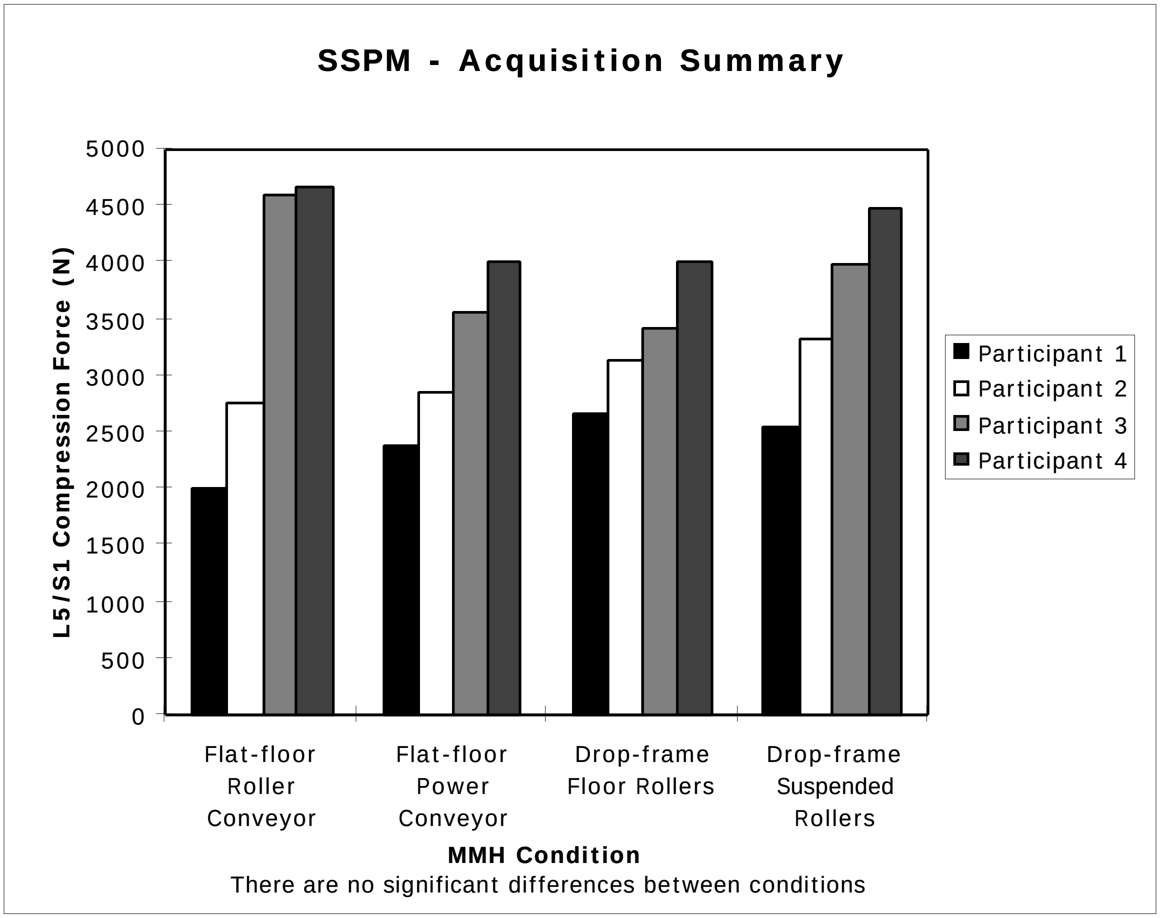


Figure 24. Summary graph for SSPM - Acquisition.

Table 3. ANOVA calculation for SSPM - Acquisition.

Means Table
Effect: MMH Condition
Dependent: L5/S1 Force (N)

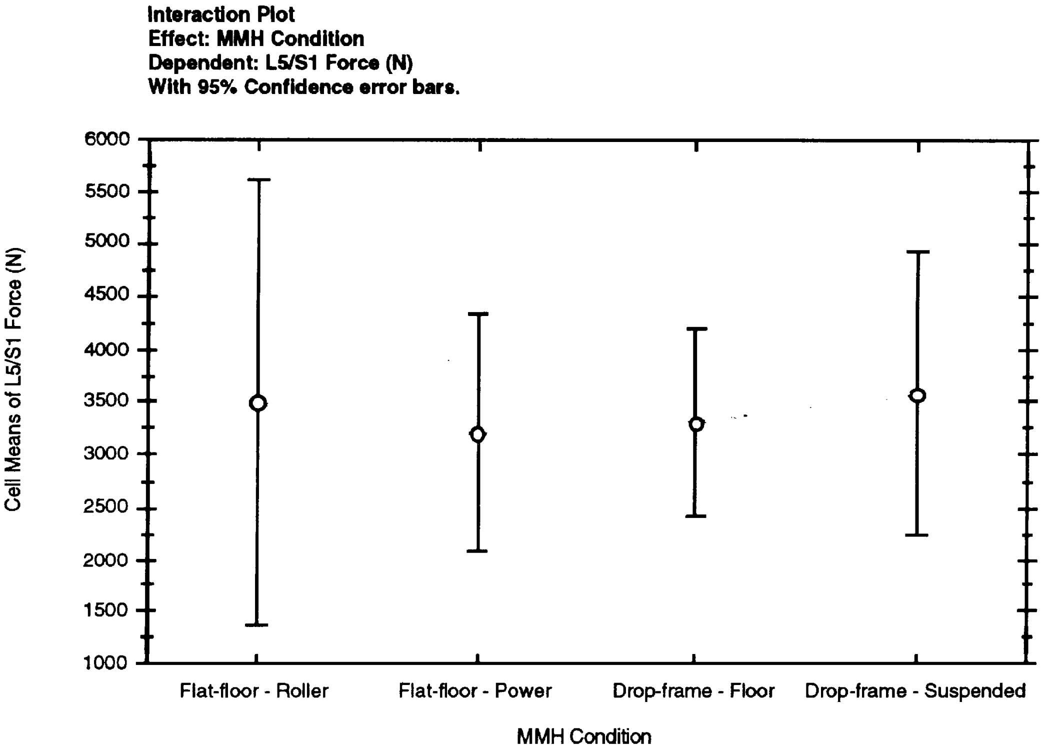
	Count	Mean	Std. Dev.	Std. Error
Flat-floor - Roller	4	3498.850	1328.645	664.323
Flat-floor - Power	4	3203.300	714.505	357.252
Drop-frame - Floor	4	3305.650	560.292	280.146
Drop-frame - Suspended	4	3581.600	837.123	418.561

Table 4. ANOVA summary table for SSPM - Acquisition output.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	8627022.860	2875674.287				
MMH Condition	3	361258.420	120419.473	.871	.4912	.4226	.4271
MMH Condition * Subject	9	1244531.160	138281.240				

Dependent: L5/S1 Force (N)



There are no significant differences between conditions

Figure 25. Graphical representation of SSPM - Acquisition means and 95% confidence intervals.

4.1.2 Placement at end of lift.

The point at which the participant appeared to release the securing force necessary to lift and move the box was designated the placement point for the lift and was estimated from the video tapes of the participant's lifting actions. An example scene used for placement analysis is shown in Figure 26. The posture assumed by the participant at this placement point was modeled using the 3-D SSPM and the output estimate of L5/S1 compression force generated was recorded. For each MMH condition five estimates of L5/S1 compression force at placement were recorded as raw data (see Appendix D - Section II). The summary of these raw data is given in Table 5 where the mean, standard deviation, standard error, median, minimum, and maximum values for each set of five L5/S1 force values are reported. These descriptive statistics are provided for each participant within each MMH condition.

Figure 27 provides a graphical summary of the data points for each MMH condition, giving the L5/S1 compression force changes from the means column in Table 5 by participant over each condition. This summary is useful in discussing level differences among participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph. A noticeable level difference is evident with the Drop-frame - Floor MMH condition.

Following the reduction of the raw data from the video tapes and the generation of descriptive statistics, *Hypothesis 1* that "biomechanical stress is significantly different among the different MMH designs studied" was tested using inferential analysis. An ANOVA was conducted at the $\alpha=0.05$ level of significance to test the hypothesis that the dependent variable indicating biomechanical stress, L5/S1 Force (N), is significantly different among levels of the independent variable, MMH Condition. Table 6 summarizes the grand means calculated from the four participants over each MMH condition and used as the inputs for the ANOVA. Table 7 provides the output of the ANOVA in a summary table. The manipulation of the source factor MMH Condition is summarized and the calculated p-value of 0.0008 reported. This p-value is significant at the $\alpha=0.05$ level, thus *Hypothesis 1* that "biomechanical stress is significantly different among the different MMH designs studied" is accepted and a statistically significant difference does exist between one or more of the MMH conditions. In the ANOVA, the factor Subjects is separated from the MMH Condition * Subjects error term to refine the calculated error term and reduce the effect of subjects from the determination of significance in the p-value. Table 7 also includes values for the Geisser-Greenhouse (G-G) and Huynh-Feldt (H-F) multivariate adjustment factors to the p-value. Both values are provided because the Geisser-Greenhouse correction tends to be a conservative estimate of error while the Huynh-Feldt correction is more liberal. Here the p-value has a high degree of significance and neither corrected value contradicts this conclusion

Since a statistically significant difference among the conditions was found and *Hypothesis 1* was accepted, the Newman-Keuls post-hoc analysis was required to determine between which conditions the difference occurs. Table 8 provides the results of the Newman-Keuls paired

Figure 26. Example placement posture used for input to SSPM and OWAS analyses.

Table 5. SSPM - Placement data summary (all values in Newtons - compression).

		Mean	Std. Dev.	Std. Error	Median	Min	Max
Flat-floor Trailer Roller Conveyor	Participant 1	1455.00	553.74	247.64	1192	1074	2399
	Participant 2	2129.20	648.76	290.13	2261	1168	2869
	Participant 3	2405.40	781.12	349.33	2040	1767	3544
	Participant 4	2401.60	910.86	407.35	1961	1726	3929
Flat-floor Trailer Power Conveyor	Participant 1	1021.20	514.50	230.09	1007	503	1823
	Participant 2	1616.80	331.57	148.28	1506	1367	2171
	Participant 3	1794.60	279.83	125.14	1670	1523	2232
	Participant 4	2037.80	349.21	156.17	2064	1628	2435
Drop-frame Trailer Floor Rollers	Participant 1	2206.60	957.37	428.15	2322	908	3415
	Participant 2	3192.80	819.50	366.49	3525	2256	4174
	Participant 3	3655.00	496.10	221.86	3794	2999	4184
	Participant 4	4268.20	1008.39	450.96	4874	2851	5047
Drop-frame Trailer Suspended Rollers	Participant 1	972.80	328.28	146.81	999	558	1458
	Participant 2	2538.80	628.92	281.26	2428	1704	3453
	Participant 3	2043.00	395.31	176.79	1853	1723	2702
	Participant 4	1441.20	141.78	63.41	1464	1208	1560

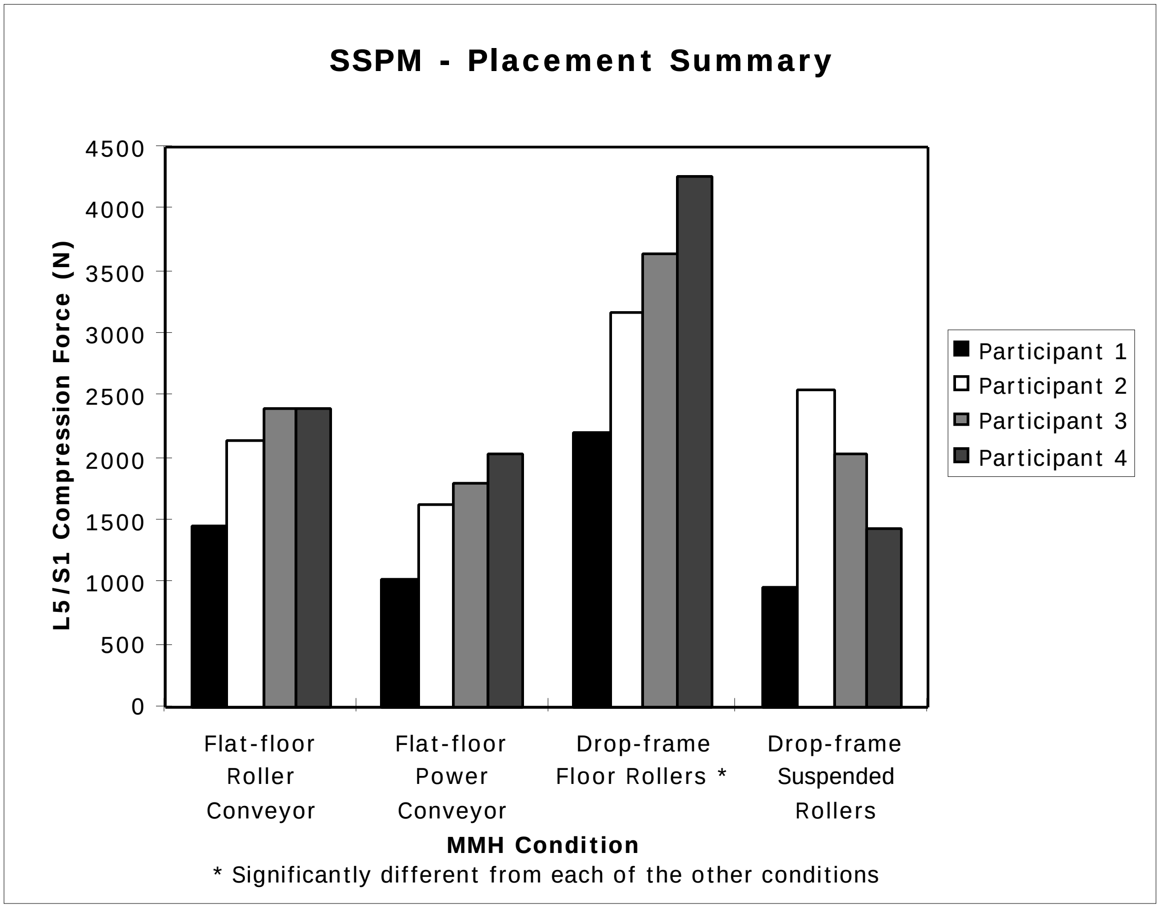


Figure 27. Summary graph for SSPM - Placement.

Table 6. ANOVA calculation for SSPM - Placement.

Means Table
Effect: MMH Condition
Dependent: L5/S1 Force (N)

	Count	Mean	Std. Dev.	Std. Error
Flat-floor - Roller	4	2097.800	447.620	223.810
Flat-floor - Power	4	1617.600	433.432	216.716
Drop-frame - Floor	4	3330.650	869.232	434.616
Drop-frame - Suspended	4	1748.950	684.945	342.472

Table 7. ANOVA summary table for SSPM - Placement output.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	3342789.640	1114263.213				
MMH Condition	3	7325775.500	2441925.167	14.690	.0008	.0176	.0059
MMH Condition * Subject	9	1496032.260	166225.807				

Dependent: L5/S1 Force (N)

comparisons for the SSPM - Placement analysis. In the summary table, statistically different factor levels of MMH condition are indicated by a “S”. The paired comparisons show a significant difference between the Drop-frame - Floor condition and all other MMH conditions.

Finally, Figure 28 provides a graphical depiction of the differences among the grand means used as an input to the ANOVA. Each level of MMH condition is represented on the X-axis with the corresponding mean L5/S1 force located according to the Y-axis. Also the 95% confidence intervals for each mean are represented. These confidence intervals map to the $\alpha=0.05$ level of significance used in the ANOVA and give a pictorial indication of the level differences among MMH conditions. The Drop-frame - Floor condition shows a significantly higher L5/S1 compression force for the SSPM - Placement analysis at the $\alpha=0.05$ level, with all other means lying outside the Drop-frame - Floor 95% confidence interval.

4.2 Categorical Posture Evaluation

The two video recordings made during the participant’s work were used to extract OWAS posture classifications for thirty lifting situations in each MMH condition for each participant. For each lift the posture at the point of box acquisition, specifically when the worker appeared to apply force to lift the box, and the posture at the point of box placement to the MMH device, specifically when the worker released his securing grip on the box, was analyzed using the OWAS system. The result of this analysis was an action category for 30 acquisitions and 30 placements in each of the four experimental conditions for each of the four participants, a total of 960 action category computations. Each condition required approximately 30 minutes of analysis time to generate action categories from the videos. The total OWAS analysis time was approximately 8 hours (two hours per participant).

The results of the acquisition and placement analyses are presented in turn, with each section containing a data summary characterizing the raw data, a graph summarizing the relative data for each of the four participants, and statistical tests of *Hypothesis 2.*

4.2.1 Acquisition at beginning of lift.

The point at which the participant appeared to apply force to lift the box was designated the acquisition point for the lift and was estimated from the video tapes of the participant’s lifting actions. An example scene used for acquisition analysis is shown in Figure 23. The posture assumed by the participant at this acquisition point was analyzed using the OWAS system and a corresponding action category for the lift was recorded. For each MMH condition thirty action category scores were recorded as raw data (see Appendix D - Section III). The summary of these raw data is given in Table 9 where the weighted score, mode, range, minimum, and maximum values for each set of thirty action category scores are reported. These descriptive statistics are provided for each participant within each MMH condition.

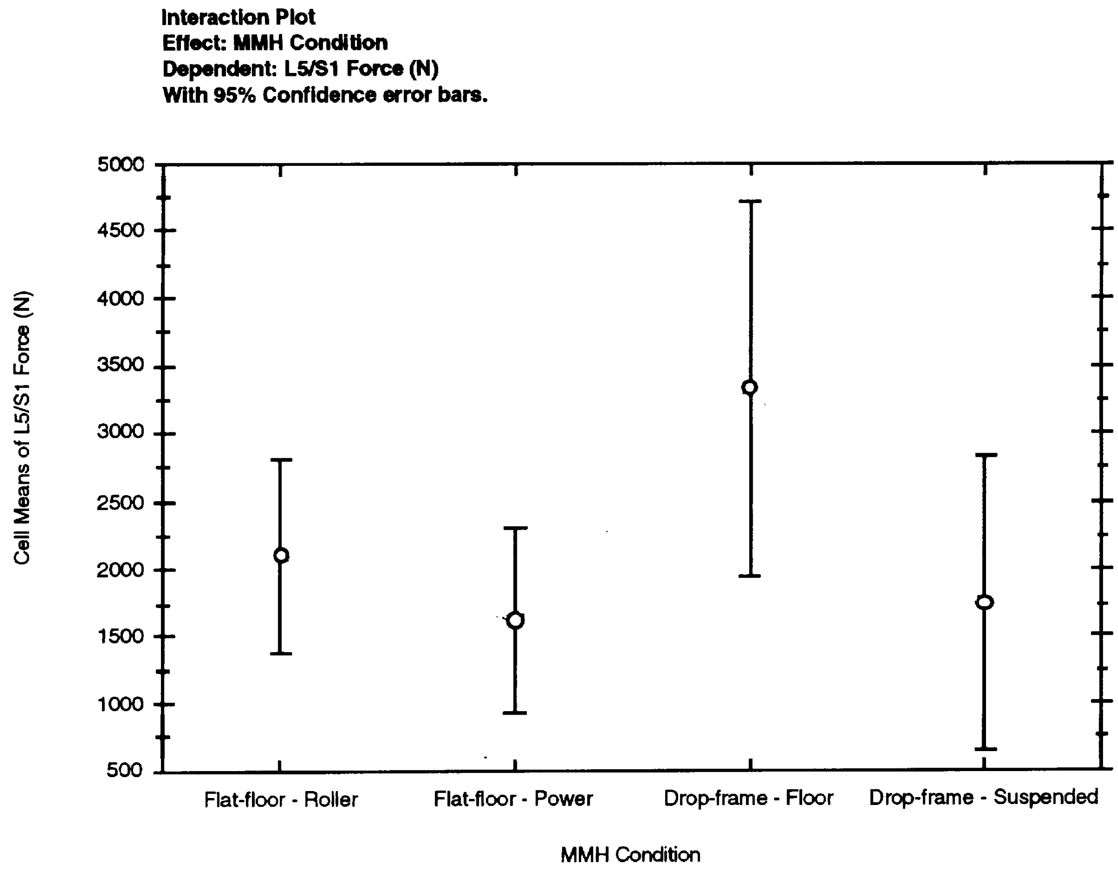
Figure 29 provides a graphical summary of the data points for each MMH condition, giving the weighted action category score changes from the weighted score column in Table 9 by participant over each condition. This summary is useful in discussing level differences among

Table 8. Results of Newman-Keuls post-hoc paired comparisons for SSPM - Placement.

Student-Newman-Keuls
Effect: MMH Condition
Dependent: L5/S1 Force (N)
Significance level: .05

	Vs.	Diff.	Crit. diff.	
Flat-floor - Power	Drop-frame - Suspended	131.350	652.333	
	Flat-floor - Roller	480.200	805.223	
	Drop-frame - Floor	1713.050	901.035	S
Drop-frame - Suspended	Flat-floor - Roller	348.850	652.333	
	Drop-frame - Floor	1581.700	805.223	S
Flat-floor - Roller	Drop-frame - Floor	1232.850	652.333	S

S = Significantly different at this level.



The Drop-frame Floor condition is significantly different from each of the other conditions

Figure 28. Graphical representation of SSPM- Placement means and 95% confidence intervals.

Table 9. OWAS - Acquisition data summary (values represent OWAS Action Category Scores).

		Weighted Score	Mode	Range	Min	Max
Flat-floor Trailer Roller Conveyor	Participant 1	1.87	2	2	1	3
	Participant 2	1.90	2	2	1	3
	Participant 3	1.77	2	2	1	3
	Participant 4	1.77	2	2	1	3
Flat-floor Trailer Power Conveyor	Participant 1	1.50	1	2	1	3
	Participant 2	1.67	2	2	1	3
	Participant 3	1.47	1	2	1	3
	Participant 4	1.73	2	3	1	4
Drop-frame Trailer Floor Rollers	Participant 1	1.93	2	2	1	3
	Participant 2	1.93	2	3	1	4
	Participant 3	1.80	1	3	1	4
	Participant 4	1.80	1	2	1	3
Drop-frame Trailer Suspended Rollers	Participant 1	2.30	2	3	1	4
	Participant 2	2.10	2	3	1	4
	Participant 3	2.13	2	2	2	4
	Participant 4	2.40	2	2	1	3

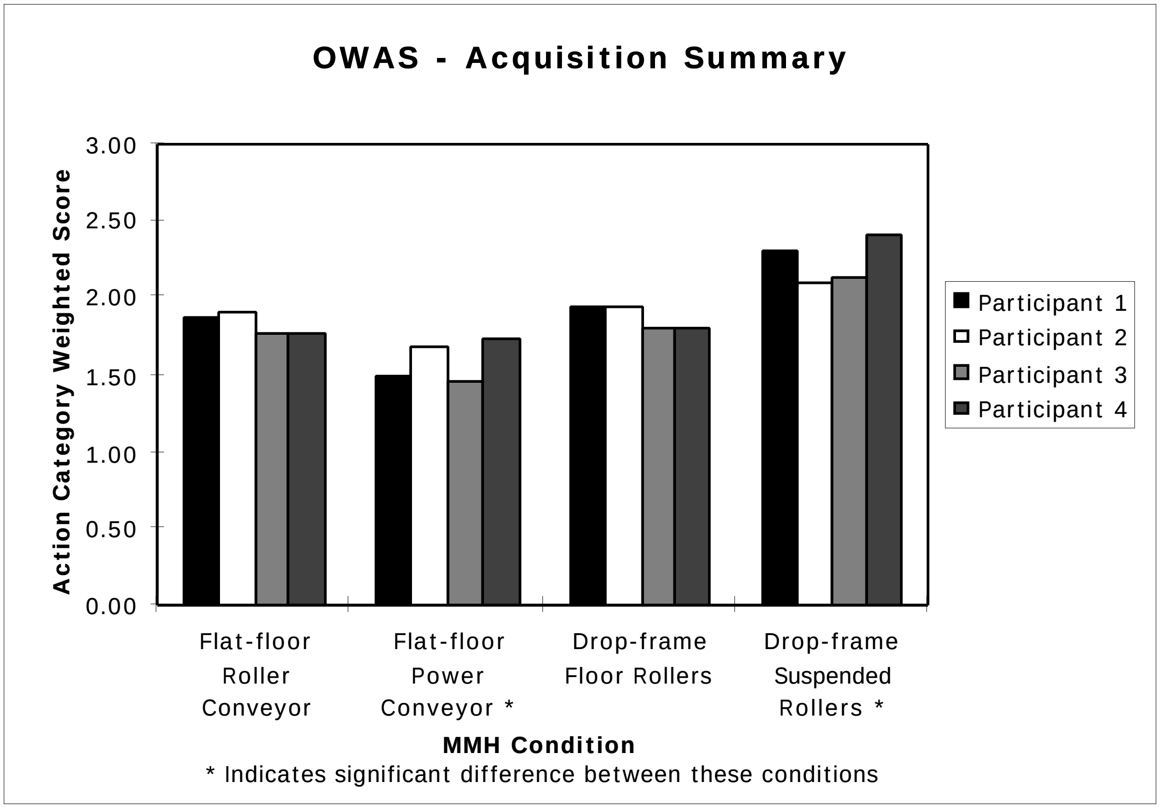


Figure 29. Graphical representation of OWAS - Acquisition weighted scores.

participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph.

Following the reduction of the raw data from the video tapes and the generation of descriptive values, *Hypothesis 2* that “working posture is significantly different among the different MMH designs studied” was tested using inferential analysis. Since OWAS action category data represent an ordinal-scaled measure, a nonparametric inferential technique was required. The Friedman Two-way Analysis of Variance by Ranks was conducted at the $\chi \leq 0.05$ level of significance to test the hypothesis that the dependent variable indicating use of working posture, the Action Category Score, is significantly different among the levels of the independent variable, MMH condition. Table 10 provides the output of the Friedman Two-way Analysis in a summary table. The F_r (observed) value of 12.00 computed from the column rank sums is greater than the critical F_r (table) value of 7.80 at the $\chi \leq 0.05$ level, therefore *Hypothesis 2* that “working posture is significantly different among the different MMH designs studied” is accepted and statistically significant difference does exist between one or more of the MMH conditions at acquisition.

Since a statistically significant difference among the conditions was found and *Hypothesis 2* was accepted, the post-hoc Friedman Two-way multiple comparisons analysis was required to determine between which conditions the difference occurs. Table 11 provides the results of the Friedman paired comparisons for the OWAS - Acquisition analysis. In the summary table, statistically different factor levels of MMH condition are indicated by a “S”. The paired comparisons show a significant difference between the Flat-floor Power Conveyor condition and the Drop-frame - Suspended Rollers condition.

4.2.2 Placement at end of lift.

The point at which the participant appeared to release the securing force necessary to lift and move the box was designated the placement point for the lift and was estimated from the video tapes of the participant’s lifting actions. An example scene used for placement analysis is shown in Figure 26. The posture assumed by the participant at this placement point was analyzed using the OWAS system and a corresponding action category for the placement was recorded. For each MMH condition thirty action category scores were recorded as raw data (see Appendix D - Section IV). The summary of these raw data is given in Table 12 where the weighted score, mode, range, minimum, and maximum values for each set of thirty action category scores are reported. These descriptive statistics are provided for each participant within each MMH condition.

Figure 30 provides a graphical summary of the data points for each MMH condition, giving the weighted action category score changes from the weighted score column in Table 12 by participant over each condition. This summary is useful in discussing level differences among participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph.

Following the reduction of the raw data from the video tapes and the generation of descriptive statistics, *Hypothesis 2* that “working posture is significantly different among the

Table 10. Friedman Two-way Analysis of Variance by Ranks summary table for OWAS - Acquisition.

Weighted Action Category Scores for each condition

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	1.87	1.50	1.93	2.30
Participant 2	1.90	1.67	1.93	2.10
Participant 3	1.77	1.47	1.80	2.13
Participant 4	1.77	1.73	1.80	2.40

Relative ranks between the four MMH conditions

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	2	1	3	4
Participant 2	2	1	3	4
Participant 3	2	1	3	4
Participant 4	2	1	3	4
Column Rank Sums =	8	4	12	16

F_r (observed) = 12.00

F_r (table) = 7.80 ($\chi \leq 0.05$)

F_r (observed) > Fr (table), therefore the difference between conditions is significant

Table 11. Results of Friedman Analysis of Variance post-hoc multiple comparisons for OWAS - Acquisition.

Friedman Multiple Comparisons
Effect: MMH Condition
Dependent: OWAS Rating
Significance level: .05

	Vs.	Diff.	Crit. Diff.	
Flat-floor Power Conveyor	Drop-frame Suspended Rollers	12	9.63	S
	Flat-floor Roller Conveyor	4	9.63	
	Drop-frame Floor Rollers	8	9.63	
Drop-frame Suspended Rollers	Flat-floor Roller Conveyor	8	9.63	
	Drop-frame Floor Rollers	4	9.63	
Flat-floor Roller Conveyor	Drop-frame Floor Rollers	4	9.63	

S=Significantly different at this level ($\chi \leq 0.05$)

Table 12. OWAS - Placement data summary (values represent OWAS action categories).

		Weighted Score	Mode	Range	Min	Max
Flat-floor Trailer Roller Conveyor	Participant 1	1.53	1	2	1	3
	Participant 2	2.00	1	2	1	3
	Participant 3	2.07	2	2	1	3
	Participant 4	1.90	1	2	1	3
Flat-floor Trailer Power Conveyor	Participant 1	1.20	1	2	1	3
	Participant 2	1.73	1	2	1	3
	Participant 3	1.60	1	2	1	3
	Participant 4	1.47	1	2	1	3
Drop-frame Trailer Floor Rollers	Participant 1	2.13	2	1	2	3
	Participant 2	2.17	2	2	2	4
	Participant 3	1.93	2	2	1	3
	Participant 4	2.23	2	2	1	3
Drop-frame Trailer Suspended Rollers	Participant 1	1.67	2	1	1	2
	Participant 2	2.20	2	3	1	4
	Participant 3	1.73	2	3	1	4
	Participant 4	1.97	2	2	1	3

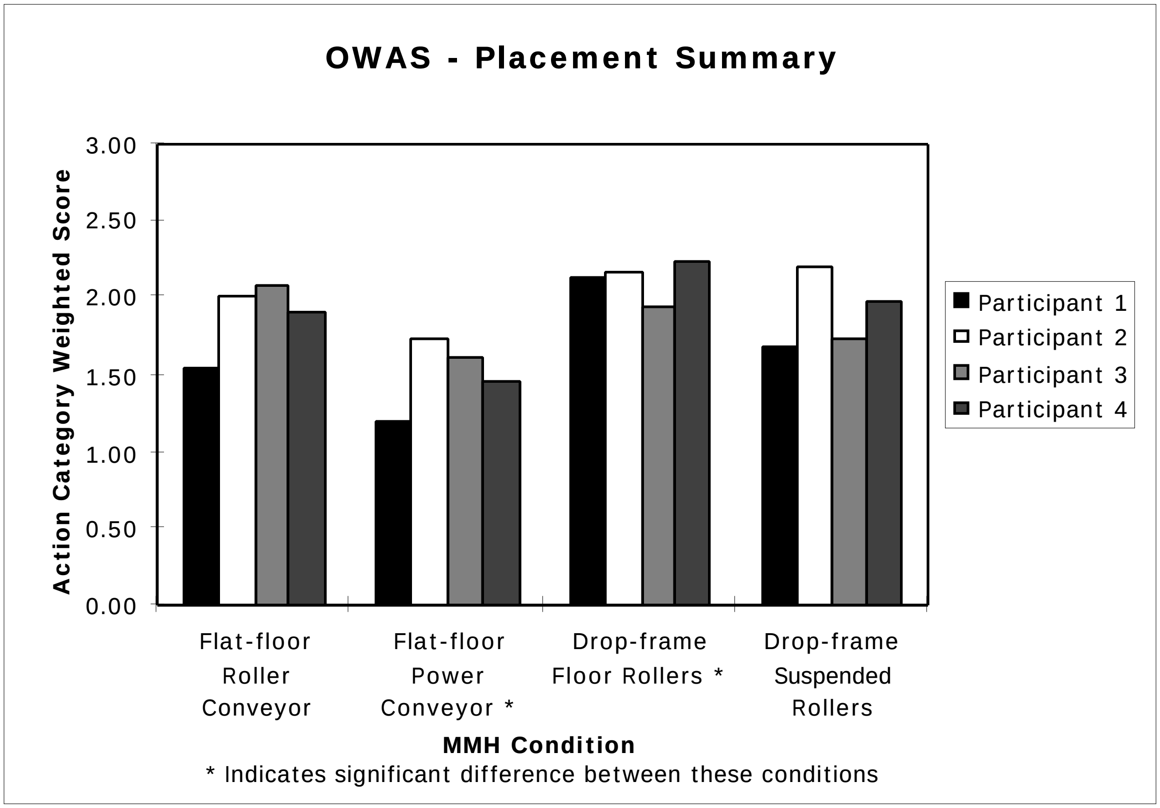


Figure 30. Graphical representation of OWAS - Placement weighted scores.

different MMH designs studied" was tested using inferential analysis. Again, since the OWAS action category data represent an ordinal-scaled measure, a nonparametric inferential technique was required. The Friedman Two-way Analysis of Variance by Ranks was conducted at the $\chi \leq 0.05$ level of significance to test the hypothesis that the dependent variable indicating use of working posture, the Action Category Score, is significantly different among levels of the independent variable, MMH condition. Table 13 provides the output of the Friedman Two-way Analysis in a summary table. The F_r (observed) value of 8.40 computed from the column rank sums is greater than the critical F_r (table) value of 7.80 at the $\chi \leq 0.05$ level, therefore *Hypothesis 2* that "working posture is significantly different among the different MMH designs studied" is accepted and statistically significant difference does exist between one or more of the MMH conditions during placement.

Since a statistically significant difference among the conditions was found and *Hypothesis 2* was accepted, the post-hoc Friedman Two-way multiple comparisons analysis was required to determine between which conditions the difference occurs. Table 14 provides the results of the Friedman paired comparisons for the OWAS - Placement analysis. In the summary table statistically different factor levels of MMH condition are indicated by a "S". The paired comparisons show a significant difference between the Flat-floor Power Conveyor condition and the Drop-frame - Floor Rollers condition.

4.3 Physiological Assessment

The recorded and stored data from the heart rate monitor were used to analyze the physiological response of the participant during work for each of the MMH conditions. These results are presented by a data summary characterizing the raw data, a statistical test of *Hypothesis 3*, and a graphical representation of the means and 95% confidence intervals for the four MMH conditions. The analysis is also accompanied by a graph summarizing the relative data for each of the four participants.

The heart rate monitor sampled and recorded heart rate in five second intervals for the 20 minute duration of the work task (a five minute warm-up period and 15 minutes of observation time). The raw observation data, 180 heart rate samples in beats per minute, were analyzed and reduced to generate a set of descriptive statistics for each participant over each MMH condition (see Appendix D - Section V). Example output graphs from the heart rate monitoring equipment are given in Figures 31 and 32. Both graphs are from the same participant. Figure 31 shows the response of heart rate at the beginning of MMH work. The first five minutes of graph data represent the participant's warm-up period and the subsequent 15 minutes of data represent the observation period. Figure 32 shows the recovery of the heart rate measure to a steady state during the rest period. These two graphs typify the physiological responses of all four participants in each of the MMH conditions.

Approximately two hours were required for the heart rate data reduction and analysis (about 30 minutes per participant). The summary of these raw data can be found in Table 15 where the mean, standard deviation, standard error, median, minimum, and maximum values for

Table 13. Friedman Two-way Analysis of Variance by Ranks summary table for OWAS - Placement.

Weighted Action Category Scores for each condition

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	1.53	1.20	2.13	1.67
Participant 2	2.00	1.73	2.17	2.20
Participant 3	2.07	1.60	1.93	1.73
Participant 4	1.90	1.47	2.23	1.97

Relative ranks between the four MMH conditions

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	2	1	4	3
Participant 2	2	1	3	4
Participant 3	4	1	3	2
Participant 4	2	1	4	3
Column Rank Sums =	10	4	14	12

F_r (observed) = 8.40

F_r (table) = 7.80 ($\chi \leq 0.05$)

F_r (observed) > Fr (table), therefore the difference between conditions is significant

Table 14. Results of Friedman Analysis of Variance post-hoc multiple comparisons for OWAS - Placement.

Friedman Multiple Comparisons
Effect: MMH Condition
Dependent: OWAS Rating
Significance level: .05

	Vs.	Diff.	Crit. Diff.	
Flat-floor Power Conveyor	Drop-frame Suspended Rollers	8	9.63	
	Flat-floor Roller Conveyor	6	9.63	
	Drop-frame Floor Rollers	10	9.63	S
Drop-frame Suspended Rollers	Flat-floor Roller Conveyor	2	9.63	
	Drop-frame Floor Rollers	2	9.63	
Flat-floor Roller Conveyor	Drop-frame Floor Rollers	4	9.63	

S=Significantly different at this level (χ≤0.05)

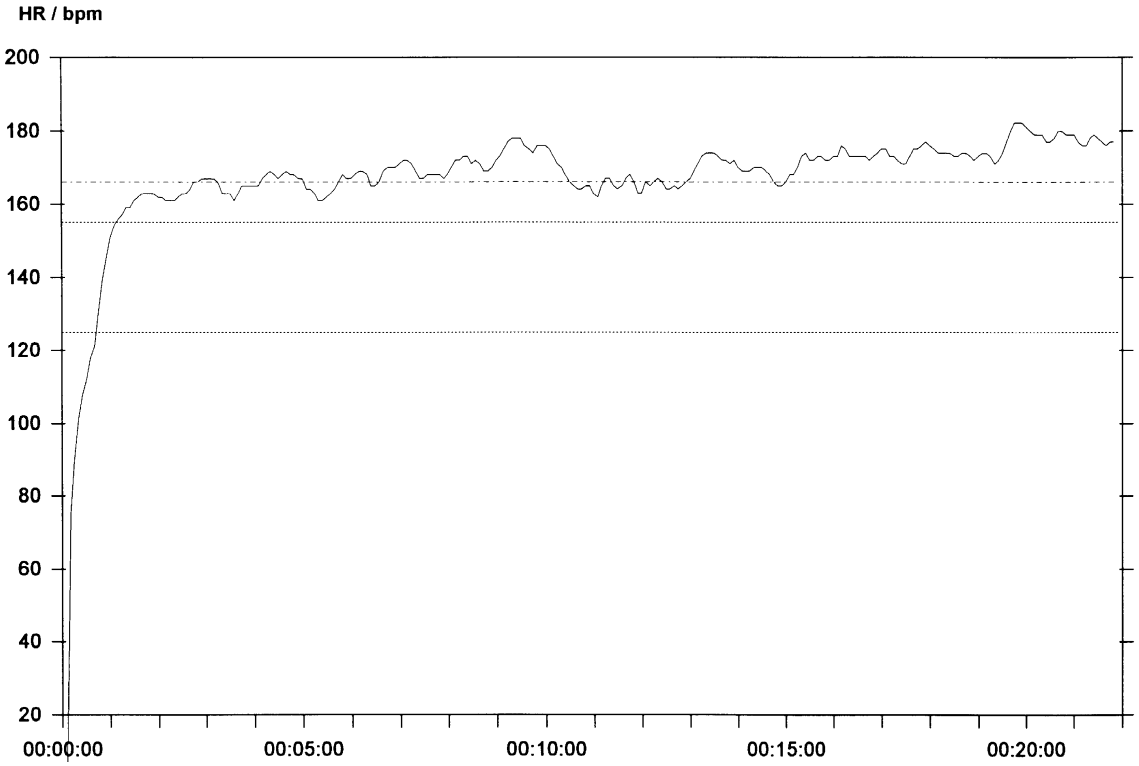


Figure 31. Output graph of heart rate response to MMH work.

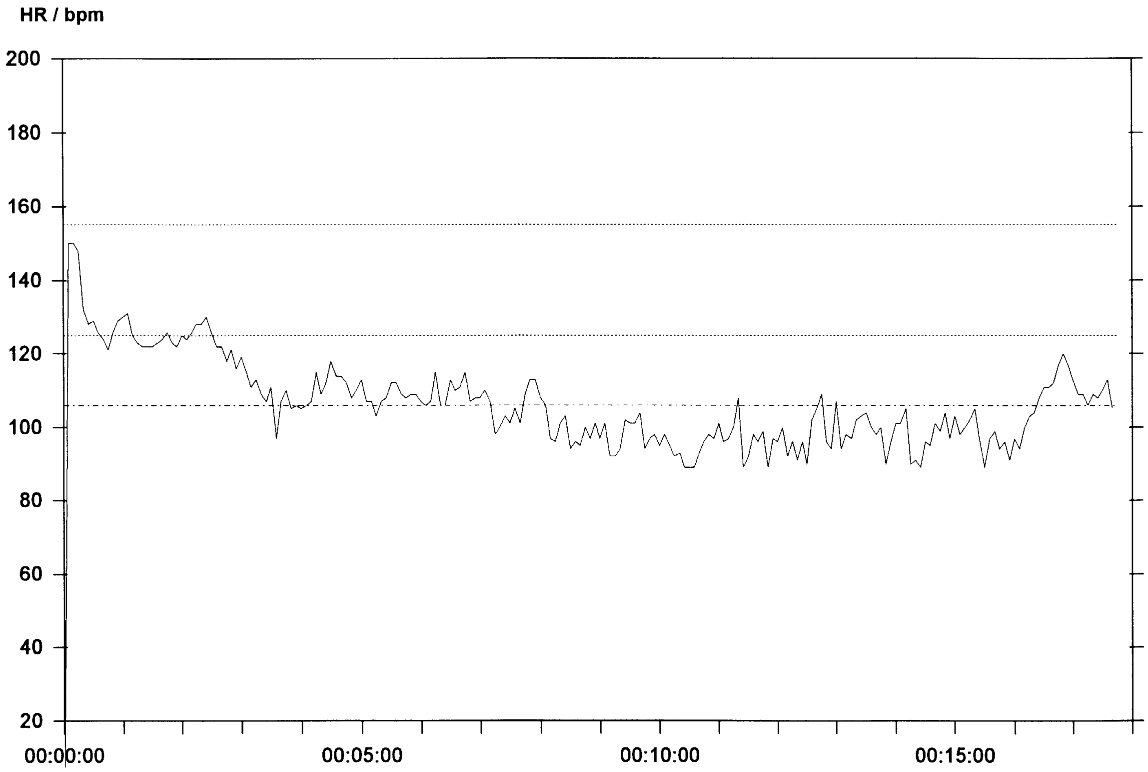


Figure 32. Output graph of heart rate recovery during rest.

Table 15. Heart rate data summary (all values in beats per minute).

		Mean	Std. Dev.	Std. Error	Median	Min	Max
Flat-floor Trailer Roller Conveyor	Participant 1	168.98	5.29	0.39	169	158	182
	Participant 2	170.33	4.34	0.32	171	161	182
	Participant 3	182.44	4.35	0.32	183	171	191
	Participant 4	182.66	3.89	0.29	183	173	189
Flat-floor Trailer Power Conveyor	Participant 1	161.14	4.87	0.36	161	147	173
	Participant 2	167.00	4.52	0.34	168	156	176
	Participant 3	163.61	5.19	0.39	164	149	174
	Participant 4	189.26	2.68	0.20	189	183	195
Drop-frame Trailer Floor Rollers	Participant 1	165.67	11.96	0.89	171	135	179
	Participant 2	159.08	4.32	0.32	159	145	168
	Participant 3	167.92	7.78	0.58	169	147	183
	Participant 4	186.90	2.59	0.19	187	181	194
Drop-frame Trailer Suspended Rollers	Participant 1	177.79	4.72	0.35	178	168	187
	Participant 2	167.22	5.97	0.45	168	151	177
	Participant 3	190.22	2.93	0.22	190	181	196
	Participant 4	176.51	2.74	0.20	176	170	186

each set of heart rate samples are reported. These descriptive statistics are provided for each participant within each MMH condition.

Figure 33 provides a graphical summary of the data points for each MMH condition, giving the heart rate changes from the means column in Table 15 by participant over each condition. This summary is useful in discussing level differences among participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph.

Following the reduction of the data from the heart rate monitor and the generation of descriptive values, *Hypothesis 3* that "physiological stress is significantly different among the different MMH designs studied" was tested using inferential analysis. An ANOVA was conducted at the $\alpha=0.05$ level of significance to test the hypothesis that the dependent variable indicating physiological stress, Heart Rate (bpm), is significantly different among levels of the independent variable, MMH Condition. Table 16 summarizes the grand means calculated from the four participants for each MMH condition and used as the inputs for the ANOVA. Table 17 provides the output of the ANOVA in a summary table. The manipulation of the source factor MMH Condition is summarized and the calculated p-value of 0.4188 reported. This p-value is not significant at the $\alpha=0.05$ level, therefore *Hypothesis 3* that "physiological stress is significantly different among the different MMH designs studied" is rejected. In the ANOVA, the factor Subjects is separated from the MMH Condition * Subject error term to refine the calculated error term and reduce the effect of subjects from the determination of significance in the p-value. Table 17 also includes values for the Geisser-Greenhouse (G-G) and Huynh-Feldt (H-F) multivariate adjustment factors to the p-value. Both values are provided because the Geisser-Greenhouse correction tends to be a conservative estimate of error while the Huynh-Feldt correction is more liberal.

Since no statistically significant difference among the conditions was found and *Hypothesis 3* was rejected, the Newman-Keuls post-hoc analysis was not required. A lack of significant difference in the ANOVA indicates that no significant difference exists between any of the levels of MMH condition.

Finally, Figure 34 provides a graphical depiction of the differences among the grand means used as an input to the ANOVA. Each level of MMH condition is represented on the X-axis with the corresponding mean heart rate located according to the Y-axis. Also the 95% confidence intervals for each mean are represented. These confidence intervals map to the $\alpha=0.05$ level of significance used in the ANOVA and give a pictorial indication of the level differences among MMH conditions.

4.4 Subjective Assessment

The data garnered from the participants' responses to the Borg CR-10 RPE scale were used to analyze the subjective assessment of the participant during work for each of the MMH conditions. The result of this analysis is presented by a data summary characterizing the raw data, statistical test of *Hypothesis 4*, and a graphical representation of the means and 95%

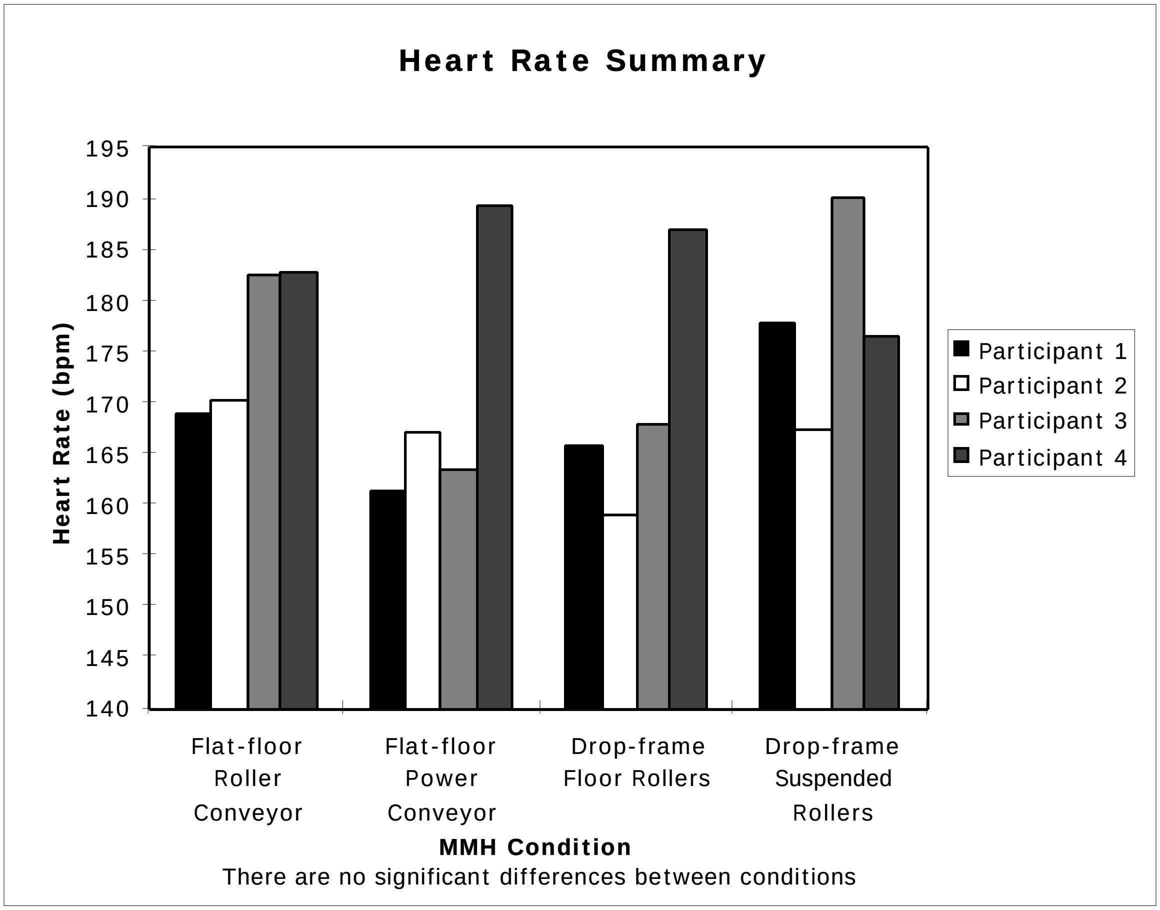


Figure 33. Summary graph for Heart Rate.

Table 16. ANOVA calculation for Heart Rate.

Means Table
Effect: MMH Condition
Dependent: Heart Rate (bpm)

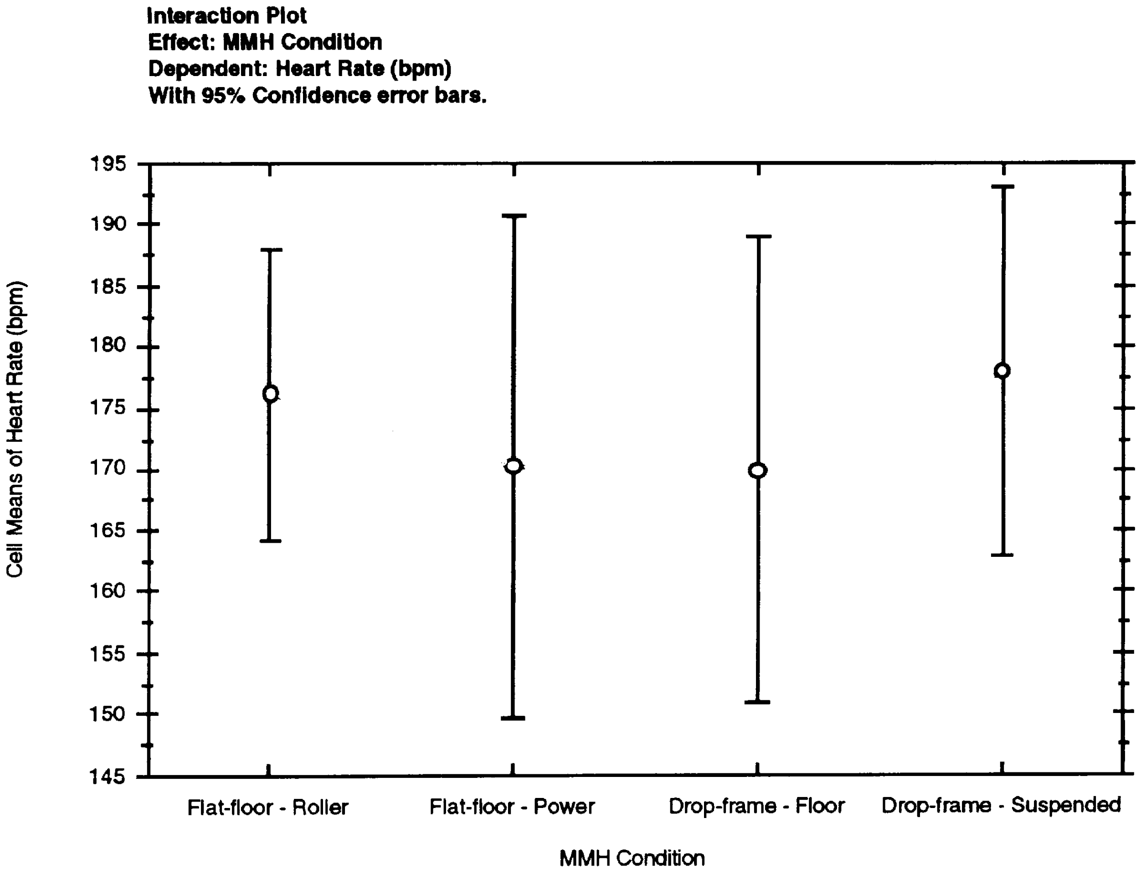
	Count	Mean	Std. Dev.	Std. Error
Flat-floor - Roller	4	176.102	7.466	3.733
Flat-floor - Power	4	170.253	12.897	6.449
Drop-frame - Floor	4	169.893	11.943	5.971
Drop-frame - Suspended	4	177.935	9.448	4.724

Table 17. ANOVA summary table for Heart Rate.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	787.796	262.599				
MMH Condition	3	199.977	66.659	1.045	.4188	.3898	.4000
MMH Condition * Subject	9	574.114	63.790				

Dependent: Heart Rate (bpm)



There are no significant differences between conditions

Figure 34. Graphical representation of Heart Rate means and 95% confidence intervals.

confidence intervals for the four MMH conditions. The analysis is also accompanied by a graph summarizing the relative data for each of the four participants.

Following each MMH condition the participant was prompted to rate his perceived exertion following the CR-10 RPE scale. The raw data were comprised of a RPE rating for each MMH condition. These raw data are outlined in Table 18 for each participant within each MMH condition.

Figure 35 provides a graphical summary of the data points for each MMH condition, giving the RPE from the RPE column in Table 18 by participant over each condition. This summary is useful in discussing level differences among participants and in examining similarities in trends among the conditions. Any conditions showing significant level differences are indicated in the summary graph.

Following the tabulation of the data, *Hypothesis 4* that "rating of perceived exertion is significantly different among the different MMH designs studied" was tested using inferential analysis. An ANOVA was conducted at the $\alpha=0.05$ level of significance to test the hypothesis that the dependent variable indicating perceived exertion, RPE, is significantly different among levels of the independent variable, MMH Condition. Table 19 summarizes the grand means calculated from the four participants for each MMH condition and used as the inputs for the ANOVA. Table 20 provides the output of the ANOVA in a summary table. The manipulation of the source factor MMH Condition is summarized and the calculated p-value of 0.2412 reported. This p-value is not significant at the $\alpha=0.05$ level, therefore *Hypothesis 4* that "rating of perceived exertion is significantly different among the different MMH designs studied" is rejected. In the ANOVA, the factor Subjects is separated from the MMH Condition * Subject error term to refine the calculated error term and reduce the effect of subjects from the determination of significance in the p-value. Table 20 also includes values for the Geisser-Greenhouse (G-G) and Huynh-Feldt (H-F) multivariate adjustment factors to the p-value. Both values are provided because the Geisser-Greenhouse correction tends to be a conservative estimate of error while the Huynh-Feldt correction is more liberal.

Since no statistically significant difference among the conditions was found and *Hypothesis 4* was rejected, the Newman-Keuls post-hoc analysis was not required. A lack of significant difference in the ANOVA indicates that no significant difference exists between any of the levels of MMH condition.

Finally, Figure 36 provides a graphical depiction of the differences among the grand means used as an input to the ANOVA. Each level of MMH condition is represented on the X-axis with the corresponding RPE located according to the Y-axis. Also the 95% confidence intervals for each mean are represented. These confidence intervals map to the $\alpha=0.05$ level of significance used in the ANOVA and give a pictorial indication of the level differences among MMH conditions.

Table 18. CR-10 RPE output data summary (values represent CR-10 scaling).

		RPE
Flat-floor Trailer Roller Conveyor	Participant 1	2.00
	Participant 2	2.50
	Participant 3	4.00
	Participant 4	6.00
Flat-floor Trailer Power Conveyor	Participant 1	2.00
	Participant 2	3.00
	Participant 3	5.00
	Participant 4	3.00
Drop-frame Trailer Floor Rollers	Participant 1	3.00
	Participant 2	3.00
	Participant 3	3.00
	Participant 4	5.00
Drop-frame Trailer Suspended Rollers	Participant 1	3.50
	Participant 2	3.00
	Participant 3	5.00
	Participant 4	8.00

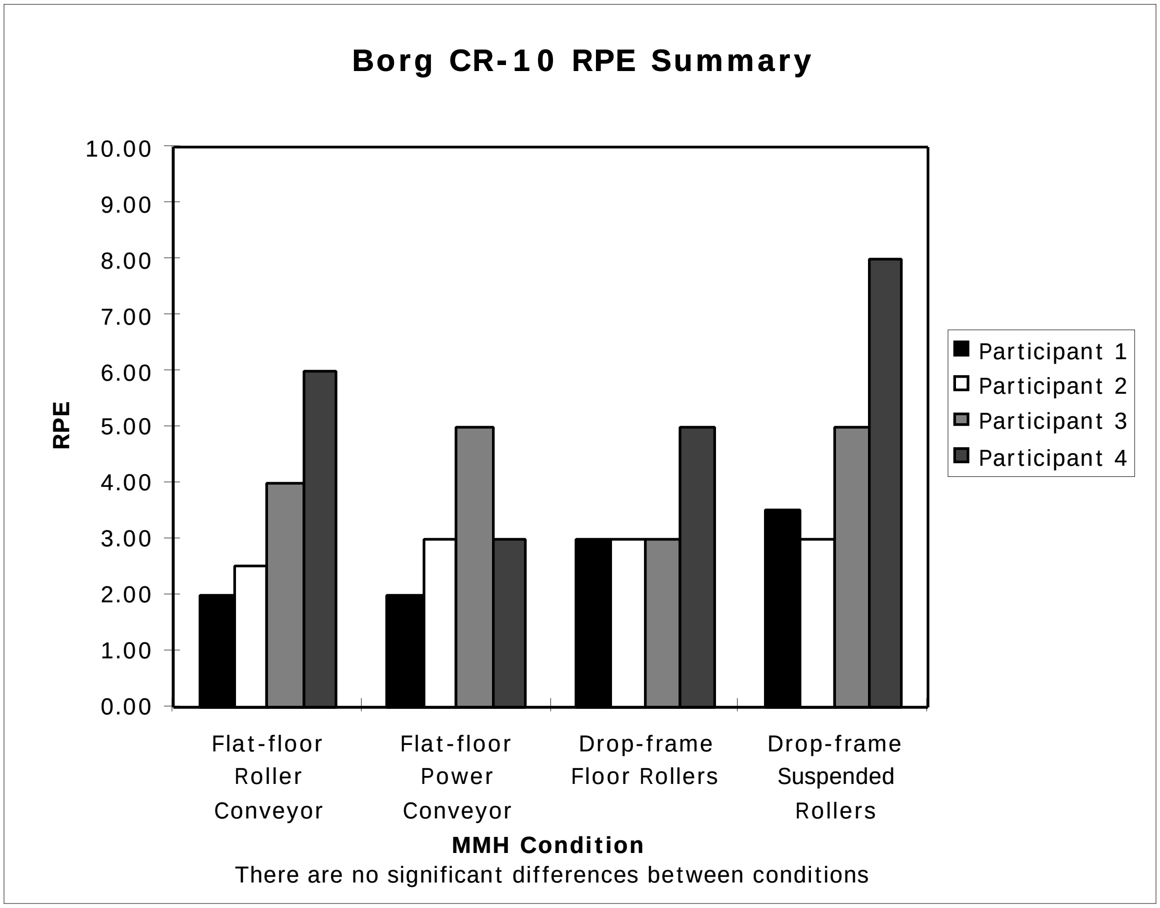


Figure 35. Summary graph for Borg CR-10 RPE.

Table 19. ANOVA calculation for RPE.

Means Table
Effect: MMH Condition
Dependent: RPE

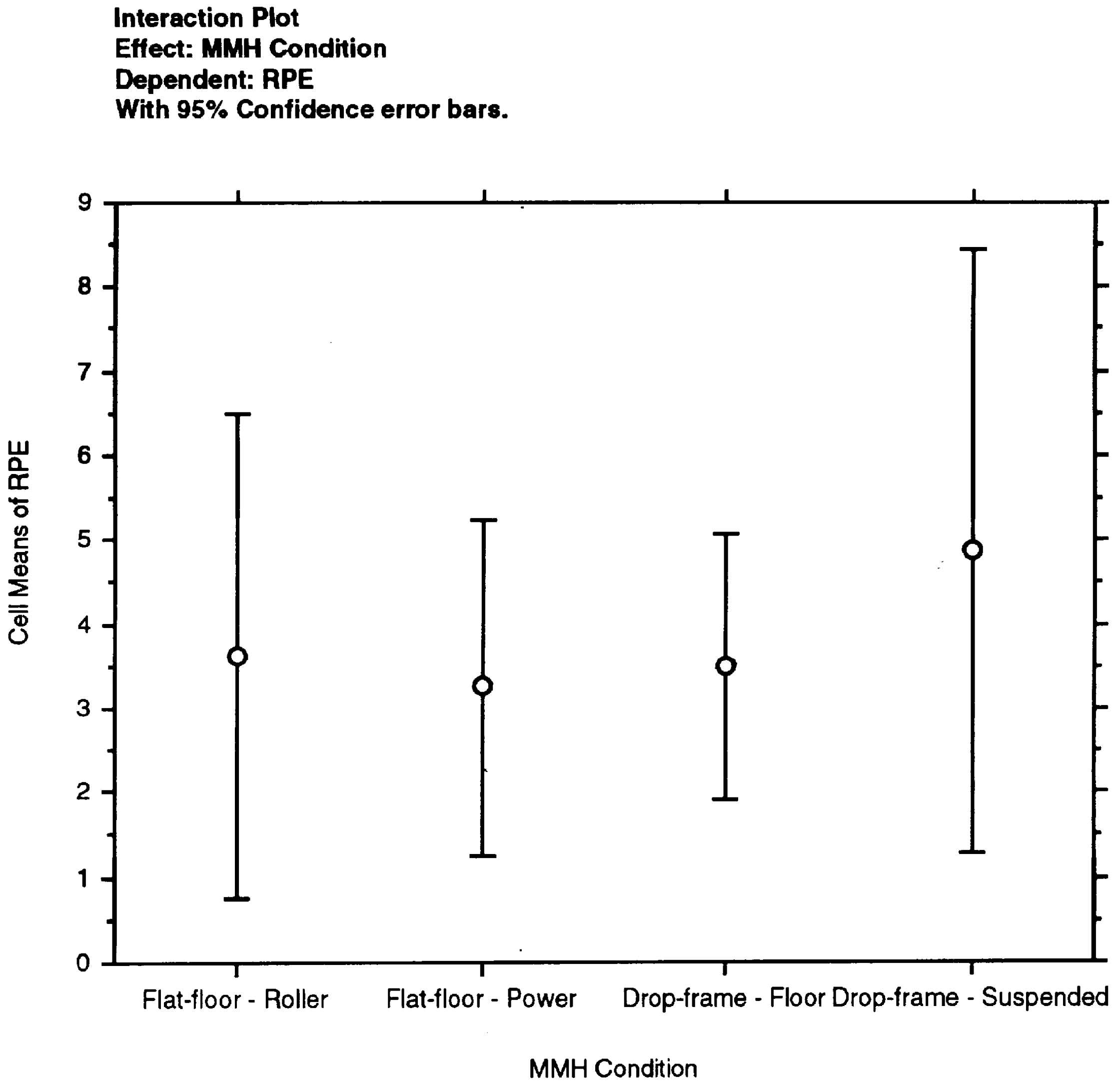
	Count	Mean	Std. Dev.	Std. Error
Flat-floor - Roller	4	3.625	1.797	.898
Flat-floor - Power	4	3.250	1.258	.629
Drop-frame - Floor	4	3.500	1.000	.500
Drop-frame - Suspended	4	4.875	2.250	1.125

Table 20. ANOVA summary table for RPE output.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	21.312	7.104				
MMH Condition	3	6.312	2.104	1.674	.2412	.2767	.2511
MMH Condition * Subject	9	11.313	1.257				

Dependent: RPE



There are no significant differences between conditions

Figure 36. Graphical representation of RPE means and 95% confidence intervals.

4.5 Experimental Controls

The use of a within-subjects experimental design created the potential for a confounding effect arising from the repetition of conditions for each participant. This potential effect was controlled by ordering the treatment conditions using a balanced Latin Square presentation, thus having each condition to proceed and follow every other condition an equal number of times. To test the assumption that treatment order did not affect the results for the biomechanical, categorical, physiological, and subjective analyses, the data for each participant were summarized in a table ordered by the actual presentation of conditions. Then an ANOVA test was conducted to examine significant differences with respect to treatment order. A sample data summary table representing Participant 1 is given in Table 21. The mean of each dependent measure is presented for all four of the MMH conditions in the order in which the conditions were completed by the participant.

The ANOVA was conducted at the $\alpha=0.05$ level of significance to test the hypothesis that treatment order had no significant effect on the dependent measures. This hypothesis held true for the SSPM - Acquisition (p=0.9062), SSPM - Placement (p=0.4909), OWAS - Acquisition (p=0.2342), OWAS - Placement (p=0.6257), and RPE (p=0.5646) measures. However, a significant effect of treatment order was found in the Heart Rate measure (p=0.0253). To determine where this order effect occurred, the Newman-Keuls Sequential Range Test was used to judge the level differences in treatment order at the $\alpha=0.05$ level of significance (see Table 22). A significant ordering effect was found between the second and third Heart Rate measures and between the first, second, and fourth Heart Rate measures (indicated by a “S” in the Table). Figure 37 provides a graphical representation of this significant ordering effect with means bounded by their respective 95% confidence intervals. The mean Heart Rate levels generally decreased as the participants completed the four conditions. This effect is probably due to the fact that the worker’s body is physiologically better prepared to perform aerobic work following each subsequent condition. This finding is consistent with findings by Stegemann and Skinner (1981).

In specifying the experimental procedure, three central confounding variables were identified (section 3.3.3). These were: size and weight of the materials used, participant variance in experience and working methods, and the motivational level of participants. During the observations, the number and rate of materials unloaded made collection of size and weight data impossible. However, the working methods and motivation of the participant may be inferred from the production rate used in unloading materials. Table 23 provides a summary of the estimated production rates for each participant over each condition in pieces moved per hour. Table 23 also includes a matrix of relative rankings within each participant for the four MMH conditions. The Drop-frame Suspended Rollers condition consistently had the lowest relative production rate of the four MMH systems. The bar graph in Figure 38 provides a graphical representation of the relative production rates between participants over each condition.

Table 21. Participant 1 data summary (ordered by MMH condition presentation).

	Drop-frame Floor Rollers	Drop-frame Suspended Rollers	Flat-floor Power Conveyor	Flat-floor Roller Conveyor
L5/S1 - Acq.	2660.80	2540.20	2393.60	2009.20
L5/S1 - Place.	2206.60	972.80	1021.21	1455.00
OWAS - Acq.	1.93	2.30	1.50	1.87
OWAS - Place.	2.13	1.67	1.20	1.53
Heart Rate	165.67	177.79	161.14	168.98
RPE	3.00	3.50	2.00	2.00

Table 22. Results of Newman-Keuls post-hoc paired comparisons for the heart rate order effect.

Student-Newman-Keuls
Effect: Order
Dependent: Heart Rate (bpm)
Significance level: .05

	Vs.	Diff.	Crit. diff.	
4	3	2.690	8.180	
	2	11.488	10.260	S
	1	11.825	11.584	S
3	2	8.798	8.180	S
	1	9.135	10.260	
2	1	.337	8.180	

S = Significantly different at this level.

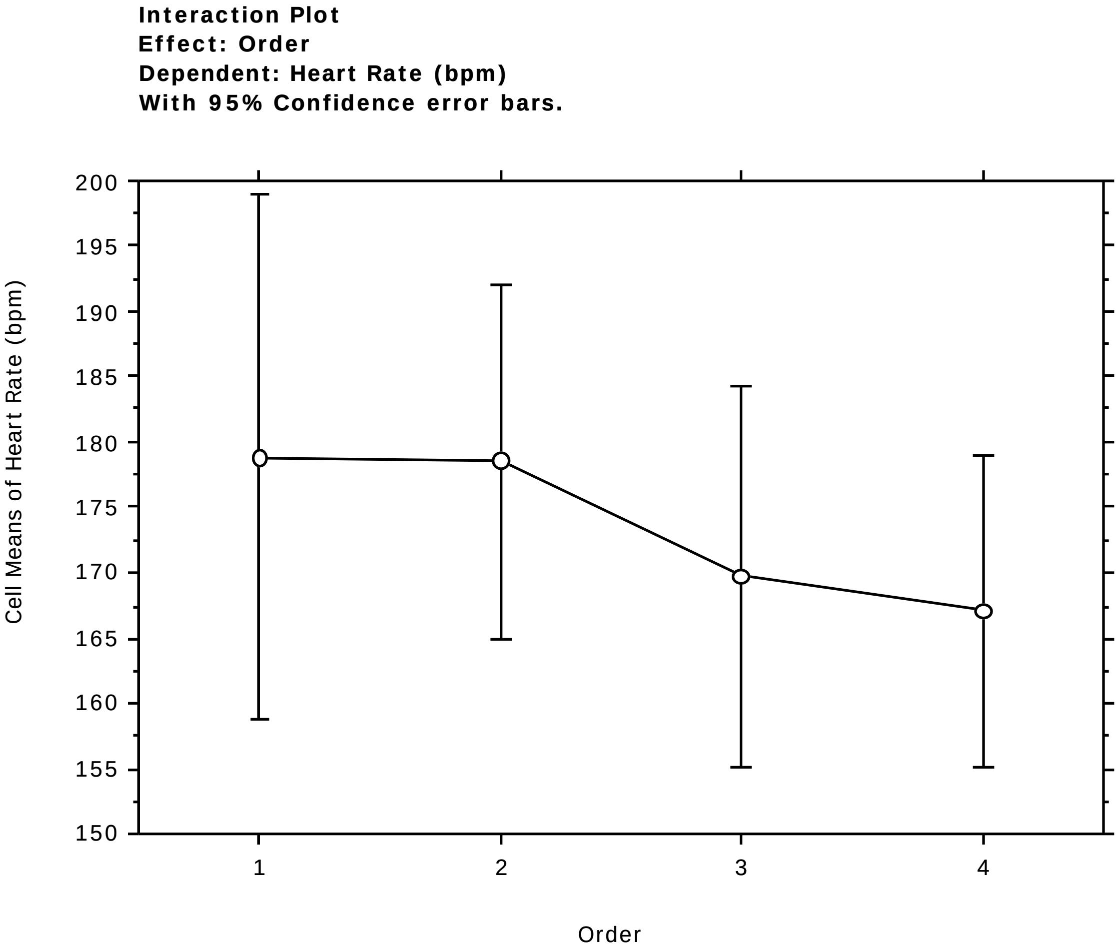


Figure 37. Graphical representation of Heart Rate means with respect to treatment order and 95% confidence intervals.

Table 23. Estimated MMH production rate for each condition (pieces per hour).

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	1080	901	956	873
Participant 2	1198	1342	1414	1153
Participant 3	1257	1107	1050	898
Participant 4	1096	1238	1173	892

Relative ranks between the four MMH conditions

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
Participant 1	1	3	2	4
Participant 2	3	2	1	4
Participant 3	1	2	3	4
Participant 4	3	1	2	4

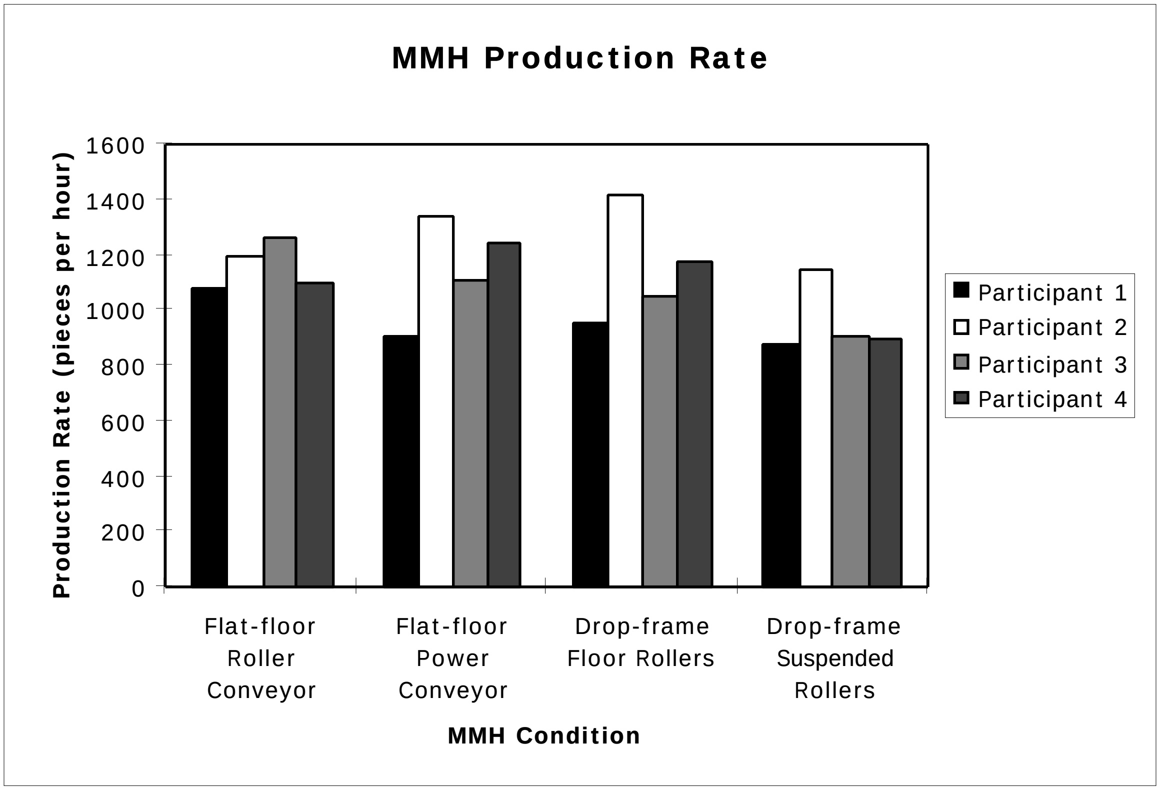


Figure 38. Estimated MMH production rate for each condition (pieces per hour).

5.0 DISCUSSION

This section is a discussion of the results garnered from the experimental and data analysis protocols. Discussion includes methods used for results generation, results found through summary or statistical analyses, and possible confounds in the protocols. Significant results are discussed in turn for each analysis method. Each of the following experimental hypotheses were addressed and either validated or contradicted:

Hypothesis 1: Biomechanical stress is significantly different among the different MMH designs studied

Hypothesis 2: Working posture is significantly different among the different MMH designs studied

Hypothesis 3: Physiological stress is significantly different among the different MMH designs studied

Hypothesis 4: Rating of perceived exertion is significantly different among the different MMH designs studied

A qualitative assessment was made regarding the relative application effort, cost, and equipment required for each of the four assessment methods. The ease of data reduction and applicability of "standard" statistical analyses is discussed. Also, the ability of each dependent measure to be sensitive to changes in experimental condition is evaluated.

A central element of interest in this study arises from the applicability of the results to other "field study" assessments. Pursuant to this interest, a section entitled "Discussion for the Practitioner" is included. In this section the sensitivity of each analysis method to differences in experimental condition is discussed. A trade-off analysis was conducted to determine which method should be used in future "field" assessments. Finally, an aggregate of quantitative results and qualitative rankings was used to recommend a MMH design that minimizes physical stress during trailer unloading.

5.1 Biomechanical Modeling

The elements of interest in applying biomechanical modeling to the assessment of trailer MMH systems arise from three central issues: the application of the method, the results garnered in the data analysis, and the effect of confounding factors on the final assessment. The summary result of the analysis was to provide support or refutation of *Hypothesis 1* that "biomechanical stress is significantly different among the different MMH designs studied". Each of these discussion points is presented in turn.

5.1.1 Application of method.

The 3-D SSPM method for biomechanical modeling was by far the most complex of the four assessment techniques employed. The method required a substantial amount of equipment support in the form of video displays, computing resources, and the actual software from the University of Michigan. These base equipment requirements make the SSPM the most costly of the four methods to employ.

The SSPM method also required the most analysis effort to reduce raw data into final output, from captured posture images on video to modeled, analyzed postures. The SSPM was the most time consuming method employed, requiring three hours of analysis time per participant to generate results. The SSPM also required a substantial training period for the analyst to become proficient in the use and application of the program to model diverse working situations.

During data reduction, limitations of the modeling software created problems in generating the most accurate depiction of the participant's actual working posture. The stick figure editor was often difficult to manipulate and match to actual body postures. One noticeable shortcoming for modeling whole-body lifting postures arose from the inability to move the legs laterally away from the body, as a worker might do in a partial crouching posture with the body weight supported on one bent leg (see Figure 23). Also the SSPM software would not accept certain extreme locations of body segments when the program predicted that the body would not support itself in a particular posture. Such situations occur when a participant works with some external support such as a wall. No method of inputting external forces or supports on the body was available.

Although the stick figure editor had a low degree of fidelity for visually matching postures, the 3-D Graphic Human Model provided a high degree of visual representation for actual body segment positions in space. However, the graphic model could not be manipulated. This resulted in additional analysis time as the SSPM was switched between posture input in the stick figure editor and validation using the graphic human model.

The SSPM did provide an excellent data output interface with detailed and intensive prediction information for body segment forces. The L5/S1 dependent measure was input into standard ANOVA tests to determine level differences among conditions. However, the output analysis generated from this method failed to produce consistent level differences among the four MMH conditions. In the data summary graph (Figure 24) level differences can be seen among the four participants over the conditions, but the large degree of variability exhibited in the data (see Figure 25) precludes judgment regarding differences among conditions.

The large degree of subjectivity associated with inputting posture by visually matching the SSPM stick figure with video images contributed to the lack of sensitivity and validity of the SSPM. The SSPM would probably increase in sensitivity if coupled with a more precise posture capture system such as those discussed in the Review of Literature (section 2.2). However, more advanced posture capture systems are often difficult, if not impossible, to apply in field assessments. This would limit the valid SSPM to more controlled laboratory assessments.

5.1.2 Results of data analysis.

In modeling body posture and predicting L5/S1 compression force at the initiation of a lift, the SSPM failed to show significant difference among the four MMH conditions (Table 4). However, the model did show a substantial sensitivity to level differences between participants (Figure 24). This would indicate that the model as employed is indeed a good predictor of working posture since it consistently showed level differences among all participants. The confounding effect of differing lifting methods among participants appears to affect the ability of the model to show level differences among MMH conditions.

In the placement posture used during lifting, the SSPM found a significant difference between the Drop-frame Floor Rollers condition and all others (Table 7). This difference probably arises from the tendency of the worker to use a back-bent, twisting posture to place materials down on the floor rollers when unloading. However, the model still showed a high degree of variability within each of the four conditions (Figure 28). Again the model showed sensitivity to level differences between individual participants, although not as markedly as with the acquisition analysis (Figure 27).

5.1.3 Confounding factors.

The SSPM appears to be influenced by differences in participants. Different lifting techniques could be applied by a range of the population of MMH workers, but the methods used by the participants in this study had been standardized and gauged by regular training and follow-up. Comparing participants' L5/S1 compression force level differences with level differences in production rate, an inferential for use of proper working methods and work pace (Figure 38), there appears to be no correlation between the subjects work pace and the output of the SSPM. This effect coupled with the lack of fidelity inherent in the SSPM input resulted in a lack of salient information from the 3-D SSPM output and analysis.

The application of the SSPM was also potentially confounded by the fact that actual box weights were not used for the materials being unloaded. The use of the average box weight in the industrial environment facilitated comparisons among the four conditions but may have influenced the goodness of the model's predictive ability by removing pertinent information from the analysis.

5.1.4 Assessment summary.

The end result of this analysis is that some substantive cause is found to accept *Hypothesis 1* that "biomechanical stress is significantly different among the different MMH designs studied". The model shows a significant difference between the Drop-frame Floor Rollers condition and all others in material placement. However, it fails to provide evidence for any further conclusions regarding the MMH conditions.

5.2 Categorical Posture Evaluation

The elements of interest in applying categorical posture observation to the assessment of trailer MMH systems arise from three central issues: the application of the method, the results garnered in the data analysis, and the effect of confounding factors on the final assessment. The summary result of the analysis was to provide support or refutation of *Hypothesis 2* that "working posture is significantly among between the different MMH designs studied". Each of these discussion points is presented in turn.

5.2.1 Application of method.

The OWAS assessment method for categorical posture evaluation required the same video equipment as the SSPM method, but used only paper-and-pencil reference and scoring sheets for data capture. The OWAS method also required substantially less observer time to reduce the raw data from recorded video postures to the dependent action category scores. Approximately two hours were required per participant to reduce the video data to the action category scores. This method did require some analyst training in the rating methods and use of action category scales, but the time requirements were significantly less that those of the SSPM.

Though the OWAS system was cost and time effective to apply, the tools and underlying method were not without shortcomings. Most notably, the OWAS references for the position of the back and legs treat bending as a binary condition. The back and legs are either considered bent or not. This inability to discriminate between degrees of bending is especially important in assessing the position of the back, which can range from slightly bent to doubled over. The OWAS system could greatly increase in predictability and sensitivity with a one or two choice discrimination for degree of bending, much like that included in the RULA technique (see section 2.3).

OWAS also has the drawback of presenting the output action category scores as ordinal-scaled data. This greatly limits the range and discriminatory ability of statistical tests on the output data. If the action category scale were to be validated by cross-methodological comparison with other assessment techniques and shown to have or scaled to have interval properties, this would greatly improve the statistical range of the method. As the system stands, the Friedman Analysis of Variance presents an easy to apply, interpretable means for judging the level differences among conditions by assessing differences in relative rankings (see Tables 10 and 13) but lacks the robust statistical qualities of parametric techniques.

5.2.2 Results of data analysis.

In assessing the level differences among MMH conditions, the OWAS system showed a significant difference in both the acquisition and placement analyses (Tables 11 and 14). At acquisition, the singular significant difference found was between the Flat-floor Power Conveyor condition and the Drop-frame Suspended Rollers condition. At placement the single level difference found was between the Flat-floor Power Conveyor condition and the Drop-frame Floor Rollers condition. As in the SSPM results, these two conditions are the most likely ones to involve a worker using a back-bent, twisting posture to acquire materials from the floor or to place materials down to the floor when unloading using floor rollers.

Examining the graphical summaries of the acquisition and placement conditions (Figures 29 and 30), the OWAS output lacks the marked level differences between participants that were exhibited by the SSPM output. Here the participants have similar action category scores for each condition.

5.2.3 Confounding factors.

As in the SSPM, the OWAS analysis is probably confounded by the choice of a consistent box weight to facilitate comparisons among the MMH conditions. The inclusion of varied box weights may create a wider dispersion of action category scores and thus allow for greater level differences among working conditions. The limited, forced values of the ordinal OWAS action category scores also create a tendency toward centralization in the output data.

OWAS was probably the assessment technique most susceptible to observer bias in this project. In some observations, the degree of bending in the back or legs or the application of force to one or both legs was a matter of subjective opinion. In this project, care was taken to use a single analyst for all data reduction. However, in larger applications inter-observer biases and a lack of standardized and careful training could create a confounding influence in the assessment method.

5.2.4 Assessment summary.

The end result of this analysis is that some substantive cause is found to accept *Hypothesis 2* that "working posture is significantly different among the different MMH designs studied". The model shows a significant difference between the Flat-floor Power Conveyor and Drop-frame Suspended Rollers conditions at acquisition and the Flat-floor Power Conveyor and Drop-frame Floor Rollers conditions at placement. However, it fails to provide evidence for any further conclusions regarding the relative MMH conditions.

5.3 Physiological Assessment

The elements of interest in applying physiological assessment to the study of trailer MMH systems arise from three central issues: the application of the method, the results garnered in the data analysis, and the effect of confounding factors on the final assessment. The summary result of the analysis was to provide support or refutation of *Hypothesis 3* that "physiological stress is significantly different among the different MMH designs studied". Each of these discussion points is presented in turn.

5.3.1 Application of method.

The heart rate measure used for physiological assessment presented the widest range of equipment possibilities among the four assessment methods. Heart rate data can be collected using nothing more than palpation, a wrist watch, and a pencil-and-paper form or it can be collected using sophisticated telemetried monitoring and recording equipment. Obviously some lesser degree of invasiveness and a greater ability to collect valid data is inherent in more sophisticated equipment such as the monitor, data recorder, and analysis interface used in this project. As the capability of the heart rate data collection and analysis equipment increases, the time required for analysis generally decreases. With the higher capability equipment used in this project the analysis time for each subject was approximately 30 minutes.

The heart rate data also have the advantage of offering a continuous, sensitive measure of physical workload during dynamic work. Heart rate data may be analyzed using standard statistical descriptors and tests. However, the heart rate data are also the most susceptible of the four techniques to individual physical predispositions between participants. Better conditioned participants show marked difference in their sensitivity and reactivity to situational work changes. This makes any assessment comparisons between participants difficult unless they are made relative to some baseline condition.

5.3.2 Results of data analysis.

The heart rate data failed to show any significant difference among the levels of MMH condition (see Table 17). In the data summary graphs (Figures 33 and 34) a large degree of inter-participant variability is evident. An interesting point arises from the fact that the heart rate data do not follow consistent trends for each of the four participants across the four conditions as the SSPM and OWAS analyses did. The only similar trend exhibited is the marked maximum mean Heart Rate of the Drop-frame Suspended Rollers condition in Participants 1-3. However, the data for Participant 4 contradicts this apparent trend. The variability of the heart rate data among participants is too great to allow for any substantive findings in level differences among the MMH conditions.

5.3.3 Confounding factors.

The central confounding factor arising from the heart rate measure was that of treatment ordering. As the participants completed subsequent MMH conditions, their relative mean heart rates showed a significant decrease. This decrease is probably due to the fact that the worker's body is physiologically better prepared to perform aerobic work following each subsequent condition. This finding is consistent with findings by Stegemann and Skinner (1981).

Any confounding influence of work methods and motivation would be expected to have an effect on heart rate levels during work. However, no correlation appears to exist between the heart rate summary graph trends (Figure 33) and the production rate levels (Figure 38) for the individual participants. The largest confound to the heart rate analysis procedure appears to stem from the inter-participant differences in physiological reaction to physical work. These differences could only be controlled by standardizing the individual participant's heart rate reactions with respect to some baseline and comparing the subsequent data as a relative change in level rather than as an absolute measure.

5.3.4 Assessment summary.

The end result of this analysis is that no substantive cause is found to accept *Hypothesis 3* that "physiological stress will be significantly different among the different MMH designs studied". The data presented fail to provide evidence for any conclusions regarding the relative MMH conditions.

5.4 Subjective Assessment

The elements of interest in applying subjective assessment to the study of trailer MMH systems arises from three central issues: the application of the method, the results garnered in the data analysis, and the effect of confounding factors on the final assessment. The summary result of the analysis was to provide support or refutation of *Hypothesis 4* that "rating of perceived exertion is significantly different among the different MMH designs studied". Each of these discussion points is presented in turn.

5.4.1 Application of method.

The CR-10 RPE method used for subjective assessment of physical workload required the least equipment and cost of the four methods employed. All CR-10 RPE materials were paper-and-pencil forms and instruction sheets. However, this method captured only one data point for each MMH condition.

The RPE method has the distinct shortcoming of being the only method that can be affected by the psychological predispositions of the participant. Even though participants were given specific instructions to report RPE based only on physical sensations, the opportunity for psychological interpretation of working situations and subsequent confounding of responses is great.

Since the CR-10 scale is considered a ratio-scaled measure, standard descriptive and inferential statistical analyses may be conducted. However, like the heart rate data, the RPE ratings are susceptible to individual physical predispositions between participants. Better conditioned participants may show marked difference in their reactivity to working conditions. This makes RPE comparisons difficult unless they are made relative to some baseline condition for each participant.

5.4.2 Results of data analysis.

The RPE data failed to show significant difference among the levels of MMH condition (see Table 20). In the data summary graphs (Figures 35 and 36) a large degree of inter-participant variability is evident. The only trend exhibited by all four participants is the increased rating or consistent rating between the Drop-frame Suspended Rollers condition and all other conditions. However, this increase lacks statistical significance in the pooled participant ratings. The variability of the RPE data among participants is too great to allow for any substantive findings in level differences among the MMH conditions.

5.4.3 Confounding factors.

Any confounding influence of work methods and motivation would be expected to impact RPE levels for physical work. However, no correlations appear to exist between the RPE summary graph trends (Figure 35) and the production rate levels (Figure 38) for the individual participants. The largest confound to the RPE data and analysis procedure stems from the inter-participant differences in physiological and psychological reactions to the work conditions. These differences could only be controlled by standardizing the individual participant’s reactions with respect to some baseline and comparing the subsequent data as a relative change in level rather than as an absolute measure.

5.4.4 Assessment summary.

The end result of this analysis is that no substantive cause is found to accept *Hypothesis 4* that “rating of perceived exertion is significantly different among the different MMH designs studied”. The data presented fail to provide evidence for any conclusions regarding the relative MMH conditions.

5.5 Discussion for the Practitioner

In this section the sensitivity of each analysis method to differences in experimental conditions is discussed. A trade-off analysis was conducted to determine which method should be used in future "field" assessments. Finally, an aggregate of quantitative results and qualitative rankings was used to recommend a design that minimizes physical stress during trailer unloading.

5.5.1 Relative Sensitivity to MMH Differences.

The premise underlying this discussion supposes that one of the four dependent assessment measures detects differences among the MMH conditions with greater sensitivity than the other measures. Given the data, results, and discussion of the general findings, no method appears to be "most sensitive" to MMH condition differences. Of the four methods, the SSPM provided the greatest number of level differences, but the differences were only in SSPM - Placement between one condition and all others.

5.5.2 Trade-off analysis of Assessment Methods.

A trade-off analysis was conducted to determine which assessment method may be useful for examining similar types of work in the industrial environment. This trade-off analysis considered each method's equipment requirements, experimental protocols, and data analysis protocols (see sections 3.4 - 3.6) and the results garnered from the application of the method (sections 4.1 - 4.4)

The OWAS method offers an intervention that is easy to apply, utilizes relatively inexpensive and easily obtainable equipment, and requires marginal data reduction. This method has the shortcomings of lacking an interval scale for relative comparisons and parametric inferential analyses and of lacking sensitivity to degrees of posture deviations. However, the basic OWAS technique could be developed further to incorporate these attributes and thus offer a better assessment tool to the field researcher. Even without these changes, the OWAS technique provides good insight into level differences among MMH conditions and can be applied rapidly to any manner of dynamic whole-body work.

5.5.3 Evaluation of the MMH Designs.

The final objective of this research arises from the supposition that one or more of the four trailer MMH designs will produce significantly lower physical stress on the worker during trailer unloading. Using the data, results, and discussion presented, no single analysis technique provides a clear answer to this point. However, taking a more qualitative approach, the relative ranking of each dependent measure among the four MMH conditions provides an interesting finding.

The results outlined in Table 24a rank the MMH conditions from 1 to 4 within each dependent measure, with 1 being the MMH condition presenting the lowest overall predicted physical stress and 4 being the MMH condition with the highest predicted physical stress. A summary of dependent measures where significance was found is given in Table 24b for comparison. Interestingly, even though significant differences were found only in specific comparisons in the L5/S1 - Placement and OWAS measures, the Flat-floor Power Conveyor

Table 24a. Relative rankings for each condition over each dependent measure.

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
L5/S1 - Acq.	3	1	2	4
L5/S1 - Place.	3	1	3	2
OWAS - Acq.	2	1	3	4
OWAS - Place.	2	1	4	3
Heart Rate	3	2	1	4
RPE	3	1	2	4

1 = Lowest ranking condition for dependent measure

4 = Highest ranking condition for dependent measure

Table 24b. Summary of statistical significance findings over each dependent measure.

	Flat-floor Roller Conveyor	Flat-floor Power Conveyor	Drop-frame Floor Rollers	Drop-frame Suspended Rollers
L5/S1 - Acq.	-	-	-	-
L5/S1 - Place.	B	B	A	B
OWAS - Acq.	-	C	-	D
OWAS - Place.	-	E	F	-
Heart Rate	-	-	-	-
RPE	-	-	-	-

A/B Indicates significant difference between conditions A and B

C/D Indicates significant difference between conditions C and D

E/F Indicates significant difference between conditions E and F

- Indicates no significant difference between conditions condition provided the lowest predicted physical stress over all dependent measures, with the single exception of heart rate where it was the second lowest.

While there are no statistical or quantitative data to recommend the Flat-floor Power Conveyor MMH design over the other three designs, this qualitative representation of the data may prove useful to the practitioner in examining design attributes for future MMH systems. These relative rankings, while not representing statistically significant differences in all cases, indicate that the MMH design causing the least physical stress on the human operator unloading materials is the Flat-floor Power Conveyor design.

6.0 CONCLUSIONS

The content of the Methods and Materials, Results, and Discussion sections were used to generate conclusions for each of the experimental objectives specified in section 3.1.1:

1. Determine which trailer MMH design minimizes biomechanical loading during trailer unloading

The 3-D SSPM model shows a significant difference between the Drop-frame Floor Rollers condition and all others in material placement. However, it fails to provide evidence for any further conclusions regarding the relative MMH conditions.

2. Determine which trailer MMH design minimizes poor working postures during trailer unloading

OWAS shows a significant difference between the Flat-floor Power Conveyor and Drop-frame Suspended Rollers conditions at acquisition and the Flat-floor Power Conveyor and Drop-frame Floor Rollers conditions at placement. However, it fails to provide evidence for any further conclusions regarding the relative MMH conditions.

3. Determine which trailer MMH design minimizes physiological stress during trailer unloading

The data presented fail to provide statistically significant differences to support any conclusions regarding the relative MMH conditions.

4. Determine which trailer MMH design minimizes rating of perceived exertion during trailer unloading

The data presented fail to provide statistically significant differences to support any conclusions regarding the relative MMH conditions.

5. Determine which method of assessment shows the greatest sensitivity to differences in experimental conditions

Given the data, results, and discussion of the general findings, no method appears to be clearly “most sensitive” to MMH condition differences. Of the four methods, the SSPM provided the greatest number of level differences, but the differences were only in SSPM - Placement between one condition and all others.

6. Make recommendations for an assessment method useful in the field for evaluating similar MMH work

The OWAS method offers an intervention that is easy to apply, utilizes relatively inexpensive and easily obtainable equipment, and requires marginal data reduction. The OWAS technique provides good insight into level differences among MMH conditions and can be applied rapidly to dynamic whole-body work.

7. Make recommendations for a MMH design that minimizes physical stress during trailer unloading

While no quantitative findings were evident, the relative rankings among all dependent measures provide a qualitative indication that the MMH design causing the least physical stress on the human operator unloading materials is the Flat-floor Power Conveyor design.

7.0 SUMMARY

While no single assessment method provided a clear means for quantifying level differences in physical stress among MMH conditions, the methods employed here provide insight into what techniques and protocols might be useful in studying similar working situations. Based on relative sensitivity, ease of application, and administrative and equipment costs, the OWAS method was recommended as an assessment method useful for evaluating similar MMH work. The summary results of the four methods provided information to meet the experimental goals of this research and allowed conclusions to be drawn for the major areas of interest. Specifically, statistically significant difference was found between the Drop-frame - Floor Rollers condition and all other conditions in the SSPM - Placement analysis, between the Flat-floor - Power and the Drop-frame - Suspended Rollers conditions in the OWAS - Acquisition analysis, and between the Drop-frame - Suspended Rollers and the Drop-frame - Floor Rollers conditions in the OWAS - Placement analysis.

Future work or modifications that could be made following this research include:

- Development and use of a posture registering system applicable to field research situations
- Further development of the OWAS technique to allow greater sensitivity to postural changes and to allow more salient quantitative analyses
- Development of a protocol to normalize the heart rate scores with respect to a baseline measure for each participant, thus providing relative rather than absolute differences
- Further development of the CR-10 RPE scale to test validity and application procedures for longer term dynamic work
- Application of the four assessment methods used in this study to different types of MMH situations, such as materials sorting or stacking work

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APPENDICES

APPENDIX A

Participants' Informed Consent

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Assessing Trailer Material Handling Tasks: Biomechanical Modeling, Posture Categorization, Physiological Measure, and Subjective Rating

Investigator(s): Ronald E. Honaker and Dr. Karl Kroemer, Faculty Advisor

I. The Purpose of this Research / Project

You are invited to participate in a study investigating the differences in unloading different types of trailers. The purpose of this research is to examine different methods for analyzing working situations. A total of four participants will be included.

II. Procedures

You will be asked to work during your assigned shift in a normal manner, following all instructions and training provided by your employer. While you are working, your actions will be video-taped using two cameras, one behind you and the other to the side. The video tapes will be viewed by no one other than the investigator and will not be available to your employer.

While working you will be asked to wear a device around your chest that monitors heart rate. The device will provide a constant measure of your heart rate throughout the work shift.

After working in a trailer you will be asked to complete a short questionnaire related to fatigue. The answers you provide will be kept confidential and will not be available to your employer.

You will be asked to take part in a briefing session before your work shift and a debriefing session following the day's work. All questions you have will be answered in a forthright manner by the investigator.

III. Risks

The possible risks or discomfort to you as a participant are the same as those for a normal work shift. You will be working in the same environment and manner as in a regular work day. There is no risk of electric shock from the heart rate monitor or any other part of the testing apparatus.

Safeguards that will be used to minimize your risk or discomfort are screening of your health history, close monitoring by the observer, and following the normal safe working methods of your employer.

IV. Benefits of this Project

Your participation in this project will provide information regarding the differences in unloading different types of trailers. This type of information can provide guidance to engineers in assessing different working situations.

No guarantee of benefits has been made to encourage you to participate.

You may receive a synopsis or summary of this research when it is completed. Please leave (or bring back) a self-addressed envelope.

V. Extent of Anonymity and Confidentiality

The results of this study will be kept strictly confidential. At no time will the researchers release the results of this study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only a participant number will identify you during analyses and any written reports of this research.

The experiment will be video-taped. These video tapes will be viewed only by Ronald E. Honaker and will be erased after the research has been completed.

VI. Compensation

Monetary.

You will be compensated by your employer at your normal hourly rate for all time spent during this experiment.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty. If you chose to withdraw, you will be compensated for the portion of the time of the study in which you participated.

There may be circumstances under which the investigator may determine that you should not continue as a participant in this project. These circumstances might include excessive fatigue or discomfort. If this occurs, you will be compensated for the portion of the project completed.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I understand that I will be asked to complete the physical fitness questionnaire.

X. Participant's Permission

I have read and understand the informed consent form and the conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

______________________________	______________________________
Signature	Date

Should I have any questions about this research or its conduct, I may contact:

Name	**Phone**
Ronald E. Honaker, Investigator	540.231.5359
Dr. Karl Kroemer, Faculty Advisor	540.231.5677
H. T. Hurd Chair, Institutional Review Board, Research Division	540.231.5281

XI. Participant Physical Fitness Questionnaire

Participant Name :____________________________________ SSN :_______________

Address :____

Telephone Number :___________________ Date of Birth :____________________

** Height :________________ ** Weight :______________________

Which describes your present physical condition (circle one):

Poor Fair Good Excellent

Please describe any physical activities you presently participate in on a regular basis:
Sports (name):
____:____________(times per week)
____:____________(times per week)
Other (name):
____:____________(times per week)
____:____________(times per week)
Have you ever had a hernia (Yes or No)?:______________
Have you ever had a serious back injury (Yes or No)?:______________
Have you had any noticeable back pain in the last year (Yes or No)?:______________
Have you had any joint dislocations, broken bones, or other physical injuries in the last year (Yes or No)?:______________
Have you ever had any serious musculoskeletal injury (Yes or No)?:______________
Are you presently taking any medication or drugs (Yes or No)?:______________
Do you have any physical impairment or injury worth noting (Yes or No)?:____________
Can you think of any injury or illness you might have which could be aggravated by physical activity or participation in this experiment (Yes or No)?:______________
If you answered yes to any of the above or have any other remarks you feel are pertinent to your participation, please elaborate in the space below or on the back of the page.

____

Signature and Date

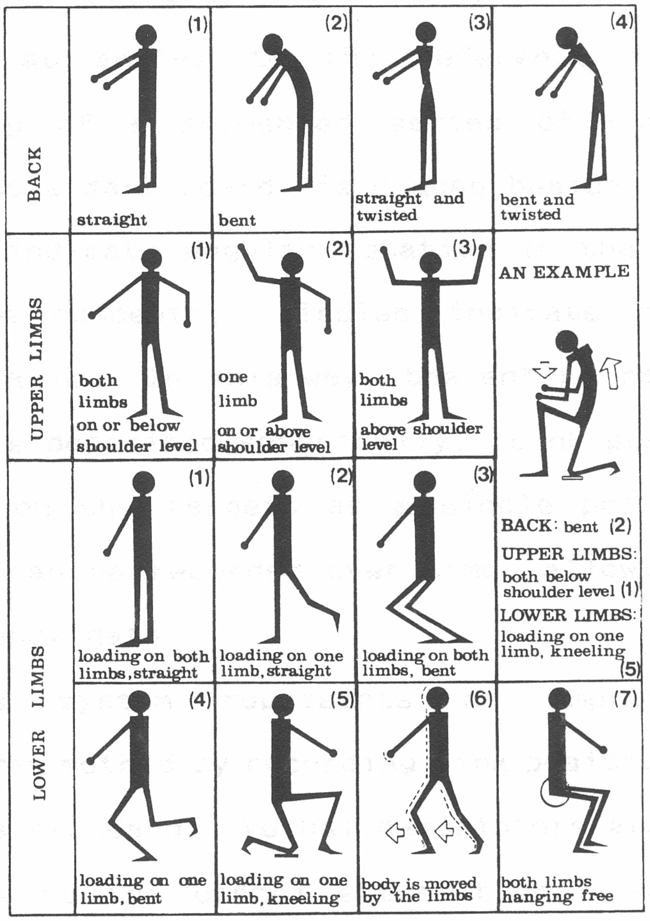
** **Note:** Height and weight data will be used in experimental calculations. These data will be collected by the observer and recorded here.

APPENDIX B

OWAS Analysis Reference

I. Posture Classification Table

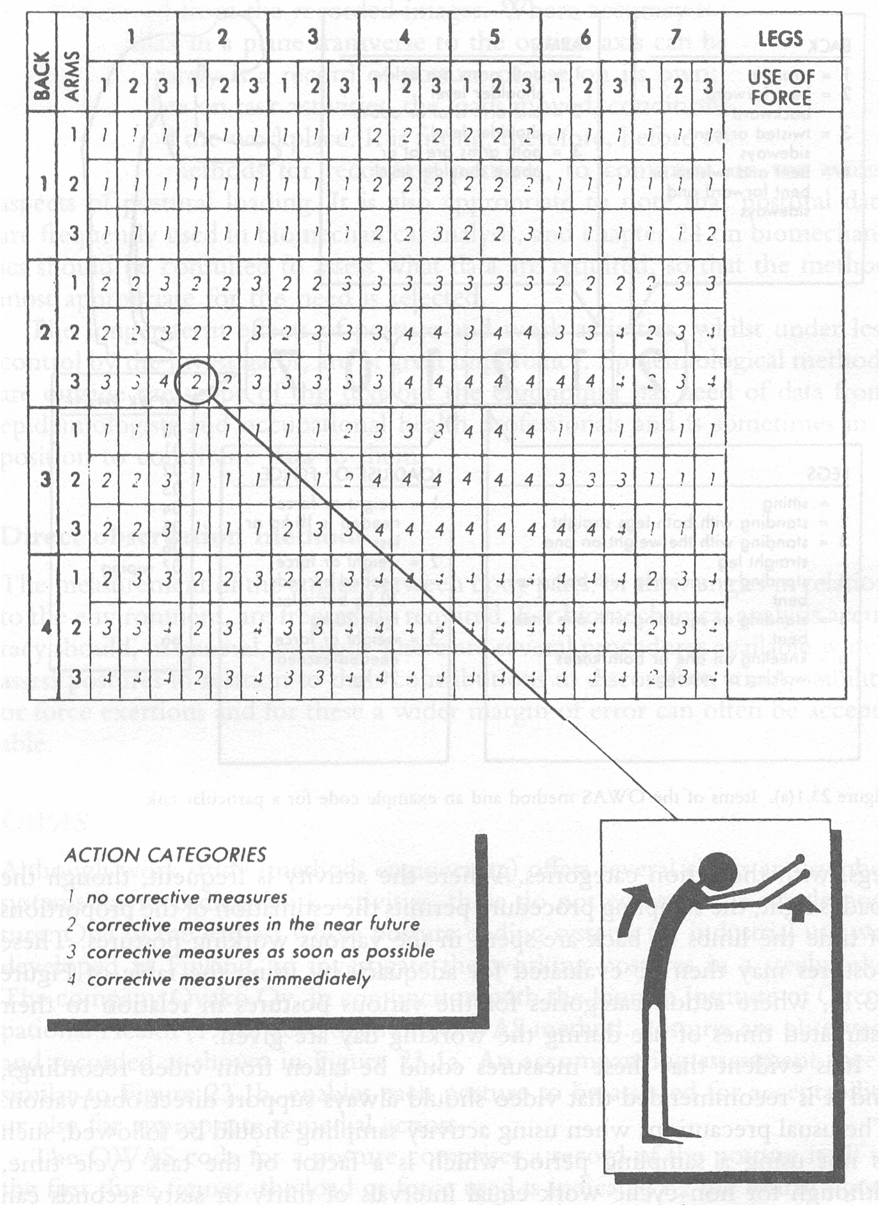
Using the figures in the table below as a reference, determine the codes for the position of the back, upper limbs, and lower limbs. Record these codes on the OWAS data collection sheet in Part III.



List of items classified by OWAS (the Ovako Working Posture Analysing System). A code number is given for each item. Each posture can be described with a three-digit code.

II. Action Category Table

Using the table below as a reference, determine the action category given the posture codes determined in Part I. Record the action category on the OWAS data collection sheet in Part III.



BACK	ARMS	1			2			3			4			5			6			7			LEGS
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	USE OF FORCE
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

ACTION CATEGORIES

1 no corrective measures
2 corrective measures in the near future
3 corrective measures as soon as possible
4 corrective measures immediately

III. OWAS Data Recording Sheet

Participant Number:____________________

Observation Date:______________________

Condition: Flat-floor / Roller Flat-floor / Power

Drop-frame / Floor Drop-frame / Suspended

Analysis of: Acquisition / Placement (circle one)

Obs. No.	Back	Upper Limb	Lower Limb	Load	Action Cat.
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Comments:____

____

APPENDIX C

Borg CR-10 Data Reference

I. Participant Instructions

The observer will take you to a trailer and ask you to start unloading it. You will work for about 20 minutes (long enough to unload 300 boxes). Please work at your normal pace and follow all training and safe working methods of your employer. If you have any problems or questions while working, please tell the observer immediately.

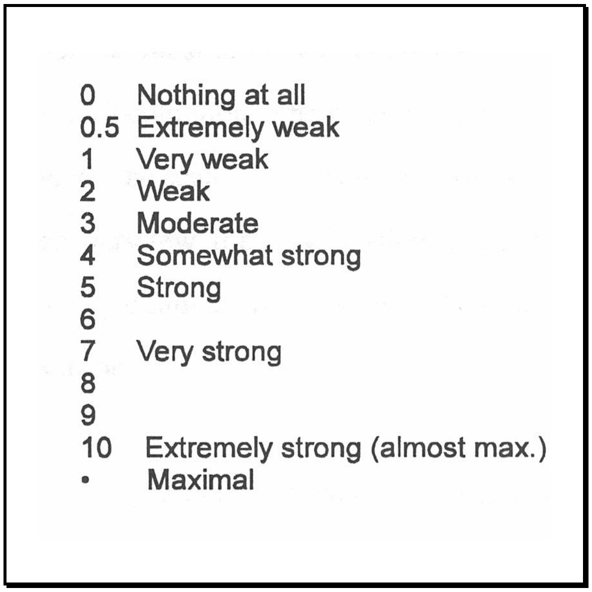
When the observer tells you to stop working, you will be asked for a rating. You will use the rating scale attached to tell how strongly you feel your whole body was worked. This rating should include all feelings of being “tired” and any mild pain in your body. The scale starts at “Nothing at all” and goes to “Maximal”. “Nothing at all” is 0 and means that your whole body feels as if you have done no work at all. “Extremely strong” is 10 and is “Almost maximum”. For most people this is the most worked their whole body has ever been. However, you might think of a feeling that is just a little more than what you yourself have experienced, this would be the “**.**” (bold dot) placed a little farther down the scale.

When you use the rating scale:

1. Always start by looking at the words to the right of the numbers and picking the word that describes how hard your whole body was worked
2. Then choose a number that goes with the word you picked

If you say “Very weak”, then the number is “1”. If you say “Moderate” then the number is “3”, and so on. You may use any numbers you want, including half values (like 1.5) or decimals (like 0.08, 1.7, or 2.3). It is very important that you answer what you feel and not what you think you should answer. Be as honest as possible and try not to overestimate or underestimate the numbers.

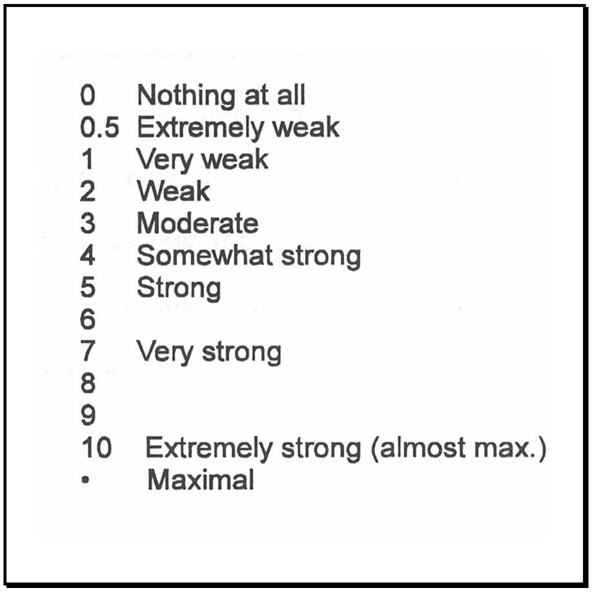
Rating scale



0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Extremely strong (almost max.)
•	Maximal

II. Rating Scale Instructions

You have just finished unloading and may feel like your whole body has been worked. The observer will ask you for a number from the rating scale for how you feel. This rating should include all feelings of being “tired” and any mild pain in your body. There are no right or wrong answers, only how you feel. Use the scale below and remember to pick the word first, then chose the number that goes with that word. You may use half values (like 1.5) or decimals (like 0.08, 1.7, or 2.3).



0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Extremely strong (almost max.)
•	Maximal

III. Borg CR-10 Data Recording Sheet

Participant Number:____________________

Observation Date:______________________

Condition 1

Condition:	Flat-floor / Roller	Flat-floor / Power
	Drop-frame / Floor	Drop-frame / Suspended

Perceived Exertion:_________________

Condition 2

Condition:	Flat-floor / Roller	Flat-floor / Power
	Drop-frame / Floor	Drop-frame / Suspended

Perceived Exertion:_________________

Condition 3

Condition:	Flat-floor / Roller	Flat-floor / Power
	Drop-frame / Floor	Drop-frame / Suspended

Perceived Exertion:_________________

Condition 4

Condition:	Flat-floor / Roller	Flat-floor / Power
	Drop-frame / Floor	Drop-frame / Suspended

Perceived Exertion:_________________

APPENDIX D

Participants' Raw Data

I. SSPM - Acquisition (L5/S1 Compression Force - (N))

Participant 1

1. Flat-floor Roller Conveyor - 1875 / 1191 / 1283 / 2793 / 2904
2. Flat-floor Power Conveyor - 3144 / 2016 / 2774 / 1896 / 2138
3. Drop-frame Floor Rollers - 3573 / 2506 / 2417 / 2516 / 2292
4. Drop-frame Suspended Rollers - 2311 / 3158 / 1753 / 2940 / 2539

Participant 2

1. Flat-floor Roller Conveyor - 2465 / 3399 / 2071 / 2521 / 3283
2. Flat-floor Power Conveyor - 2682 / 2079 / 1891 / 3282 / 3577
3. Drop-frame Floor Rollers - 3058 / 3093 / 2829 / 3242 / 3477
4. Drop-frame Suspended Rollers - 3924 / 3052 / 3277 / 2564 / 3839

Participant 3

1. Flat-floor Roller Conveyor - 5056 / 4493 / 4696 / 4265 / 4413
2. Flat-floor Power Conveyor - 3189 / 3135 / 3903 / 3798 / 3765
3. Drop-frame Floor Rollers - 3402 / 3875 / 2788 / 2813 / 4220
4. Drop-frame Suspended Rollers - 4005 / 4338 / 4012 / 3669 / 3885

Participant 4

1. Flat-floor Roller Conveyor - 5139 / 4304 / 4151 / 5223 / 4452
2. Flat-floor Power Conveyor - 4787 / 2364 / 5217 / 4701 / 2928
3. Drop-frame Floor Rollers - 4774 / 4877 / 3289 / 2467 / 4605
4. Drop-frame Suspended Rollers - 5181 / 3827 / 4862 / 4374 / 4122

II. SSPM - Placement (L5/S1 Compression Force - (N))

Participant 1

1. Flat-floor Roller Conveyor - 1500 / 1110 / 2399 / 1074 / 1192
2. Flat-floor Power Conveyor - 651 / 503 / 1122 / 1007 / 1823
3. Drop-frame Floor Rollers -2322 / 2697 / 1691 / 908 / 3415
4. Drop-frame Suspended Rollers - 1458 / 558 / 1020 / 829 / 999

Participant 2

1. Flat-floor Roller Conveyor - 1865 / 2261 / 2869 / 1168 / 2483
2. Flat-floor Power Conveyor - 1380 / 1506 / 2171 / 1660 / 1367
3. Drop-frame Floor Rollers - 2428 / 3581 / 3525 / 4174 / 2256
4. Drop-frame Suspended Rollers - 2428 / 2419 / 3453 / 2690 / 1704

Participant 3

1. Flat-floor Roller Conveyor - 1793 / 2883 / 3544 / 2040 / 1767
2. Flat-floor Power Conveyor - 1900 / 1648 / 2232 / 1523 / 1670
3. Drop-frame Floor Rollers - 2999 / 3292 / 4006 / 4184 / 3794
4. Drop-frame Suspended Rollers - 1723 / 1853 / 2112 / 1825 / 2702

Participant 4

1. Flat-floor Roller Conveyor - 3929 / 2550 / 1961 / 1726 / 1842
2. Flat-floor Power Conveyor - 1747 / 2315 / 2064 / 1628 / 2435
3. Drop-frame Floor Rollers - 4874 / 5047 / 2851 / 5021 / 3548
4. Drop-frame Suspended Rollers - 1547 / 1560 / 1464 / 1208 / 1427

III. OWAS - Acquisition (Action Category Score)

Participant 1

1. Flat-floor Roller Conveyor - 2/3/3/2/2/1/2/2/2/3/2/3/1/1/2/2/2/2/1/1/3/2/2/1/1/1/1/1/3/2
2. Flat-floor Power Conveyor - 3/2/1/1/2/1/1/2/1/1/2/1/3/1/2/1/2/1/1/1/1/2/1/2/2/1/2/2/1/1
3. Drop-frame Floor Rollers - 3/3/2/2/2/3/2/3/2/2/3/2/2/2/2/2/2/2/2/2/2/4/4/2/2/4/2/2/1/1
4. Drop-frame Suspended Rollers - 2/2/3/2/2/2/2/2/2/2/3/3/1/2/2/2/1/2/1/2/1/1/2/2/2/2/2/ 2/2/2

Participant 2

1. Flat-floor Roller Conveyor - 2/1/1/1/1/2/1/1/2/2/1/2/2/2/2/3/4/2/2/2/2/2/3/1/2/2/2/1/1/4
2. Flat-floor Power Conveyor - 3/1/2/2/2/2/2/2/2/2/4/4/2/2/1/2/2/1/2/2/3/2/1/2/2/1/3/2/3/2
3. Drop-frame Floor Rollers - 2/1/3/2/1/1/2/2/1/3/2/2/2/1/1/1/2/1/2/1/1/2/2/3/3/2/3/3/3/2
4. Drop-frame Suspended Rollers - 2/1/1/3/2/2/2/1/1/1/2/3/1/1/1/2/2/1/2/2/2/2/3/2/2/1/1/ 1/1/2

Participant 3

1. Flat-floor Roller Conveyor - 1/2/3/1/1/1/1/2/1/1/1/2/2/1/1/2/1/2/2/1/1/2/2/1/2/1/1/2/1/2
2. Flat-floor Power Conveyor - 1/1/2/2/2/2/2/1/1/1/2/2/3/2/2/1/2/1/2/2/2/3/2/1/2/1/1/2/3/2
3. Drop-frame Floor Rollers - 3/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2/3/4/2/2/2/2/2/2/2/2/2/2/2
4. Drop-frame Suspended Rollers - 2/1/2/3/1/2/2/3/2/3/2/2/2/3/3/1/1/1/1/2/2/1/1/1/1/1/2/ 2/1/1

Participant 4

1. Flat-floor Roller Conveyor - 2/2/2/2/1/1/2/1/3/2/2/1/2/3/1/1/1/2/2/2/1/2/2/1/1/2/1/2/2/3
2. Flat-floor Power Conveyor - 3/2/2/2/3/3/2/2/1/1/1/1/2/2/1/2/3/1/2/2/1/2/1/1/1/1/2/3/1/1
3. Drop-frame Floor Rollers - 1/2/2/2/3/2/1/1/2/2/1/1/1/3/2/2/2/1/2/2/2/1/1/2/2/3/2/2/2/1
4. Drop-frame Suspended Rollers - 2/3/3/3/1/3/2/3/3/3/2/2/2/3/2/3/3/1/3/3/3/3/2/2/2/2/2/ 2/2/2

IV. OWAS - Placement (Action Category Score)

Participant 1

1. Flat-floor Roller Conveyor - 1/2/3/1/2/1/1/1/1/1/1/1/1/2/3/2/1/1/1/3/3/2/1/1/1/1/1/3/2
2. Flat-floor Power Conveyor - 1/3/1/1/1/1/1/1/2/1/2/1/1/1/1/1/1/1/1/1/1/1/3/1/1/1/1/1/1
3. Drop-frame Floor Rollers -1/1/2/1/2/2/1/1/2/2/2/2/2/2/2/21/2/2/1/2/2/2/1/2/2/2/1/2/1/2
4. Drop-frame Suspended Rollers -2/2/2/2/2/2/2/2/2/2/23/2/2/2/2/36/2/2/2/2/2/2/3/3/2/2/ 2/2/2

Participant 2

1. Flat-floor Roller Conveyor - 2/4/2/2/2/2/2/2/2/2/2/2/2/2/2/3/2/2/2/2/2/3/2/2/2/2/3/2/2
2. Flat-floor Power Conveyor - 2/2/2/1/3/4/1/1/3/3/4/4/2/1/4/3/2/2/2/2/2/2/1/1/2/2/2/2/2/2
3. Drop-frame Floor Rollers - 2/1/3/1/3/1/3/3/1/3/1/1/2/1/1/3/3/2/2/3/3/1/3/3/1/2/2/1/3/1
4. Drop-frame Suspended Rollers - 2/1/2/3/2/3/3/1/3/1/3/3/1/1/1/1/3/3/1/1/2/3/1/1/1/1/ 1/1/1

Participant 3

1. Flat-floor Roller Conveyor - 2/2/2/2/2/1/1/3/1/1/1/1/3/1/1/2/1/3/2/1/1/1/3/1/2/1/1/2/1/2
2. Flat-floor Power Conveyor - 1/1/2/3/3/3/3/1/1/2/1/2/2/3/2/2/2/2/2/2/3/2/3/1/3/1/1/3/2/3
3. Drop-frame Floor Rollers - 2/2/2/2/2/2/1/1/1/1/2/2/1/1/1/2/3/2/4/4/1/2/1/1/2/2/1/1/1/2
4. Drop-frame Suspended Rollers - 2/2/2/2/3/3/2/2/2/2/2/2/2/2/2/2/3/3/1/2/2/1/1/2/1/1/3/ 2/1/1

Participant 4

1. Flat-floor Roller Conveyor - 1/2/2/1/1/2/2/1/1/1/2/1/2/2/2/1/1/3/1/2/1/1/1/1/1/3/1/2/1/1
2. Flat-floor Power Conveyor - 2/3/2/2/2/2/2/2/2/3/3/2/2/3/2/1/3/2/2/2/2/2/3/3/1/2/3/2/3/2
3. Drop-frame Floor Rollers - 1/2/2/2/2/2/1/3/2/2/1/1/1/3/3/1/1/1/2/3/1/1/3/2/1/3/3/3/3/1
4. Drop-frame Suspended Rollers - 3/2/2/2/2/2/1/2/2/2/3/2/3/3/2/2/2/1/2/2/1/1/2/2/1/2/1/ 2/3/2

V. Mean Heart Rate (beats per minute)

Participant 1

1. Flat-floor Roller Conveyor - 168.98
2. Flat-floor Power Conveyor - 161.14
3. Drop-frame Floor Rollers - 165.67
4. Drop-frame Suspended Rollers - 177.79

Participant 2

1. Flat-floor Roller Conveyor - 170.33
2. Flat-floor Power Conveyor - 167.00
3. Drop-frame Floor Rollers - 159.08
4. Drop-frame Suspended Rollers - 167.22

Participant 3

1. Flat-floor Roller Conveyor - 182.44
2. Flat-floor Power Conveyor - 163.61
3. Drop-frame Floor Rollers - 167.92
4. Drop-frame Suspended Rollers - 190.22

Participant 4

1. Flat-floor Roller Conveyor - 182.66
2. Flat-floor Power Conveyor - 189.26
3. Drop-frame Floor Rollers - 186.9
4. Drop-frame Suspended Rollers - 176.51

VI. CR-10 Rating of Perceived Exertion (RPE)

Participant 1
1. Flat-floor Roller Conveyor - 2.00
2. Flat-floor Power Conveyor - 2.00
3. Drop-frame Floor Rollers - 3.00
4. Drop-frame Suspended Rollers - 3.50

Participant 2
1. Flat-floor Roller Conveyor - 2.50
2. Flat-floor Power Conveyor - 3.00
3. Drop-frame Floor Rollers - 3.00
4. Drop-frame Suspended Rollers - 3.00

Participant 3
1. Flat-floor Roller Conveyor - 4.00
2. Flat-floor Power Conveyor - 3.00
3. Drop-frame Floor Rollers - 3.00
4. Drop-frame Suspended Rollers - 5.00

Participant 4
1. Flat-floor Roller Conveyor - 6.00
2. Flat-floor Power Conveyor - 3.00
3. Drop-frame Floor Rollers - 5.00
4. Drop-frame Suspended Rollers - 8.00

VITA

RONALD E. HONAKER (*Assessing Trailer Material Handling Tasks: Biomechanical Modeling, Posture Categorization, Physiological Measure, and Subjective Rating*) was born on January 5, 1970, in Roanoke, Virginia. He received his Bachelor of Science in Industrial and Systems Engineering from Virginia Polytechnic Institute and State University in May 1993. He received his Bachelor of Science in Psychology from Virginia Polytechnic Institute and State University in August 1993.

From May 1992 to August 1994 he was employed by United Parcel Service as an Industrial Engineering Supervisor. His work included facilities design and development, work methods design and assessment, and safety and ergonomics programs development.

Following his work with United Parcel Service, he returned to Virginia Polytechnic Institute to develop his interests in Human Factors Engineering and Ergonomics. While pursuing a Master of Science degree in Industrial Engineering, he performed research work in the Industrial Ergonomics Laboratory. He is a current member of the Institute of Industrial Engineers, Human Factors and Ergonomics Society, American Society of Safety Engineers, and Alpha Pi Mu.

Ronald E. Honaker