Validating Optical Motion Capture Assessments of the Dynamic Aspects of Work

Jackie Sutherland[1] and Vincent Duffy[1,2]

Purdue University
[1] School of Industrial Engineering, 315 N. Grant Street
[2] Regenstrief Center for Healthcare Engineering and Agricultural and Biological Engineering
West Lafayette, IN 47907 USA
{jasuther,duffy}@purdue.edu

Abstract The objective of this study is to validate two three-dimensional motion systems used capture human movement; the Lumbar Motion Monitor (LMM) and optical motion capture. Marras et al. captured the accuracy and reliability of optical motion capture and the LMM in a 1992 validation study, and found several benefits of using the LMM for ergonomic evaluations. However, since 1992, several advances have been made in the field of digital human modeling and optical motion capture, and it is believed that a modern validation of the two systems could serve others in academic and industry alike when choosing a methodology toward capturing ergonomic data. The purpose of this research is to validate the methods of collecting dynamic data and predicting injury risk in humans during lifting procedures.

Keywords: optical motion capture, lumbar motion monitor, dynamic lifting, digital human modeling, ergonomics, validation.

1 Introduction

Low-back disorders (LBDs) continue to serve as detrimental components of health and safety in the workplace [1]. In 2005, the occupational incidence rate of nonfatal injuries remained around 6 total recordable cases per 100 full-time workers in the manufacturing sector. Manufacturing alone consisted of 20.2% of all nonfatal workplace industries in 2005, with health care and social assistance following with 15.7% of all industry injuries. Nonfatal injuries to the back in industry reached 270,890 in 2005 [2].

2 Early Lifting Guidelines

Numerous efforts have been made to modify work practices and the methods of which industrial tasks are performed. As early as 1930, laws limited the weights that women and children could handle. In 1962 the International Labour Organization published a listing of suggested limits for “occasional weight lifting” for both women and men. These weight restrictions were based on previous injury statistics of manual materials

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handling (MMH) tasks that had led to increased injuries in the spinal, knee, shoulder, elbow, and hip injuries [3].

2.1 Risk Factors for Lifting Injury

In 1974, Herrin, et al. identified seven risk factors towards lifting injury. These factors included:

Weight of material lifted.
Position of the center of gravity of the load relative to the worker.
Frequency, duration, and pace of lifting.
Stability of the load.
Coupling of the load.
Workplace geometry, including direction of movement and distance.
Environmental factors such as temperature, humidity, vibration, and stability [4].

Herrin's work was influential for its time, and paved the way for research in the field of industrial safety and dynamic lifting. However, a more explicit method was required to identify specific lifting procedures that were detrimental to the worker.

2.1 NIOSH Work Practices Guide and Lifting Equation

Later, more quantified research led to the 1981 publication of the Work Practices Guide for Manual Lifting (WPG) by the National Institute for Occupational Safety and Health (NIOSH). The NIOSH WPG was generated by a team of scientists, engineers, and physicians, based on several investigations of the human physiological system. In addition, the team relied upon research from countless others in the areas of neurology, physical therapy, biomechanics, musculoskeletal surgery, industrial hygiene, and beyond. In the 1981 WPG, NIOSH stressed the susceptibility of the lower-back to overstress and injury from flawed lifting procedures. NIOSH utilized previous studies to draw knowledge about compressive and shear forces on the spine, disc moments, and other psychological measurement of the musculoskeletal system to develop the NIOSH lifting guidelines [3].

Since its development in 1981, NIOSH has revised its original lifting guidelines to include asymmetrical lifting tasks and lifts with varying coupling levels. This resulted in the Revised NIOSH Lifting Equation and its principal component, the Recommended Weight Limit (RWL). The RWL, as defined by NIOSH, is the maximum load weight that a healthy worker should be able to utilize over an eight-hour work day without increasing their risk of lift-related lower back pain (LBP). NIOSH defined the RWL as the multiples of the load constant, horizontal multiplier, vertical multiplier, distance multiplier, asymmetric multiplier, frequency multiplier, and coupling multiplier. Each multiplier has specific definitions and methods of measurement as defined by NIOSH. In addition, application of the lifting equation is limited to certain conditions, specifically, two-handed lifting tasks which do not require more energy expenditure than can be handled repetitively from day to day. NIOSH also assumes that lifting occurs in workplaces that provide adequate lifting space, stable objects, adequate temperature and humidity, and a sufficient coefficient of friction between the worker's shoes and the floor [1].

3 Marras' Lumbar Motion Monitor

Despite NIOSH's previous efforts, the sources for low-back injuries in the workplace are not always easy to identify. Other analytical methods have therefore been developed to assess the risk of lumbar injury in the workplace. One such tool is the Lumbar Motion Monitor (LMM), a triaxial electrogoniometer worn on the back and used to measure an individual's three-dimensional angular position in space. Developed by William Marras and colleagues at the Ohio State University Biodynamics Laboratory, the LMM can be considered for predictions of back injury based on the type of movement performed. This exoskeleton of the spine has the capability to process lumbar position, velocity, and acceleration in the frontal, sagittal, and transverse planes by differentiating the value of the subject's position in space [5]. Figures of the LMM can be found on the Ohio State Biodynamics Laboratory website [6].

By utilizing the lumbar motion monitor, Marras was able to quantify LBD injury rates by creating a LBD risk model. Marras' model approximates the probability that a particular lifting task could be classified as a 'high risk' task. In addition, Marras validated his model in 2000 by measuring the trunk movement of 142 employees and judging this against their LBD incident rates. Marras found a statistically significant correlation between the changes in LBD incident rates and LBD risk values predicted by the Marras LBD risk model [7].

3.1 Incorporation of Electromyography

Other physical systems have been integrated into lumbar injury prevention studies as well. Marras, Granata, Davis, Allread, and Jorgensen incorporated an electromyograph (EMG) into their analysis of low back disorder risk using the LMM. Electromyographic activity was measured through bipolar electrodes spaced 3 cm apart at ten major trunk muscle sites. By including an EMG into their analysis, Marras was able to calculate internal moments and forces for specific lumbar muscles, and determine the specific exertion of lumbar muscles when a downward force was applied [8].

4 Optical Motion Capture

Although NIOSH and others have developed helpful tools used to evaluate possible risk found in the workplace, digital human modeling methods propose innovative and accurate approaches for examining the musculoskeletal system and possible risks to the spine during lifting and movement. This research aims to test the validity and accuracy of two biodynamic systems during pre-defined lifting and movement techniques, the lumbar motion monitor, and optical motion capture**.** This study utilizes the LMM and updated, three-dimensional optical motion capture technology in efforts to capture a comparison between the two systems.

4.1 Envision Center

Purdue University's Envision Center for Data Perception (Envision Center) provides the opportunity for students, faculty, and industry professionals to utilize cutting-edge facilities in the field of human computer interaction [9]. Partially funded by a National Science Foundation grant, Envision Center features an extensive list of both hardware and software technologies [10]. Current hardware resources include the FLEX™ Virtual Reality Theater, a 12’ x 7’ tiled display wall, an Access Grid which allows participants to collaborate with others from distant geographical areas quickly and easily, and several haptic devices including the CyberGlove®. Recent projects include incorporating tactile feedback into terrain modeling, development of virtual learning environments for hearing impaired children, and creating bio-terror communication training modules for public relations students [11]. In 2006 Purdue’s Envision Center received a national award from Campus Technology magazine as a winner in its annual Innovators Competition [10].

Motion capture technology is commonly thought of as a tool found in the entertainment industry to capture and incorporate human movement into films. However, motion capture is proving to have a valuable impact in commercial industry in the areas of industrial safety and ergonomics. By capturing human movement during lifting techniques involving various loads and twisting motions, industries can determine the safe limit that can be performed in a typical work setting. In addition, industries can utilize motion capture in the design and development of future lifting procedures and work tasks.

4.2 Motion Capture Configuration

Motion capture technology uses multiple STT Motion Captor cameras to capture human position and movement in space to create a 3D simulation. A typical motion

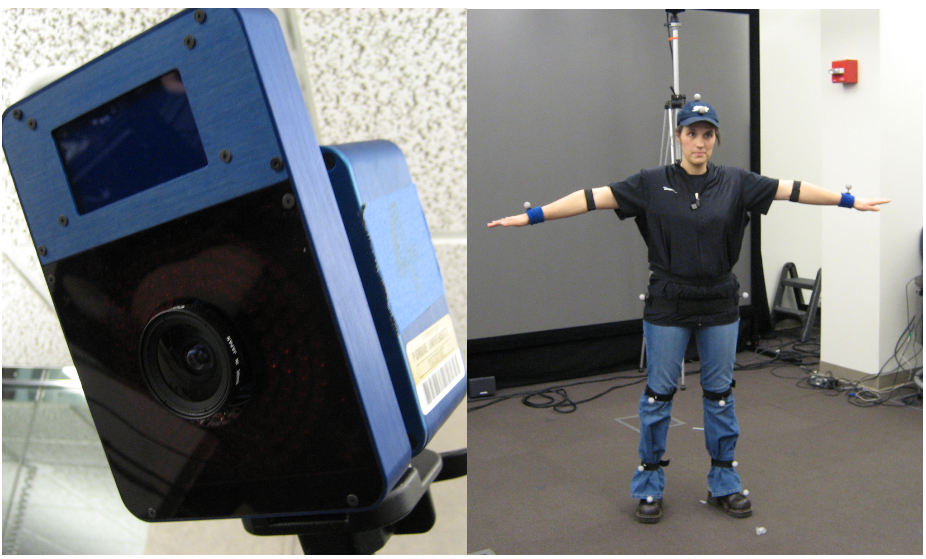

Fig. 1. One of six infrared cameras used in Envision Center’s STT Motion Captor optical motion capture system (left) and a participant demonstrating a basic LED configuration (right)

capture setup includes the placement of nineteen markers, or LEDs placed on pre-specified areas of the body, and uses a circular four- or six-camera configuration to capture all degrees of the subject's movement. One of the cameras used during optical motion capture is shown in the left image in Figure 1. The LED configuration includes placing markers on the foot, ankle, knee, hip, wrist, elbow, shoulder, waist, neck, and head, as shown in the right image in Figure 1 [12]. Markers are essentially LEDs whose brightness point is over a specified value. Therefore, it is recommended that bright clothes, jewelry, and reflective material be avoided during the capture process [13].

5 Previous LMM Validation

This research was inspired by previous work by Marras concerning the accuracy and repeatability of a LMM. In his 1992 publication, subjects moved in one of three angular ranges of motion while wearing the LMM and motion capture equipment. To capture human movement through motion capture, several LEDs were placed on the upper and lower plate of the LMM. The values recorded by both the LMM and LEDs were then compared to the actual position in space. Marras used the deviation between actual position in space and specified position for both the LMM and motion capture system to indicate their accuracy. The data taken by Marras verified that deviations between the actual and predicted range of motions in the optical motion capture system were twice that of the LMM. This research demonstrated that the LMM can assess the risk of low back disorders more accurately and effectively than optical motion capture, and serves as a reliable and cost-effective means to monitor lumbar motion [5]. In fact, the Ohio State Biodynamics Laboratory states that the LMM boasts three times the predictive power of that given by the original NIOSH lifting guide [6].

5.1 Other Model Validation

Research has also been performed to validate the models used to measure and prevent injuries in the workplace. In 2001, Robson, Shannon, Goldenhar, and Hale described validity and reliability as it applies to injury statistics and analytical equipment measures. They believe that experimental control has a significant impact on the results of a biomechanical experiment using analytical equipment, particularly calibration and maintenance of equipment, the equipment's interaction with the environment, and the proper use of the equipment by the operator. It has been shown that validity and reliability of collecting data with analytical equipment can be improved by minimizing variation in equipment operation, and, if the cost of measuring allows, by taking multiple measurements [14]. It is therefore believed that this experiment will cover multiple repetitions of each trial in order to assess the equipment's accuracy.

5.2 Assessment of the LMM and Optical Motion Capture

Marras' development of the job risk classification model has sparked additional research in the area of classifying lifting kinematics. In 2005, a study by Tara

Cappelli examined two- and three-plane lifts through the use of motion capture in relation to the Marras *et al. 1993* Model (Marras model). Cappelli found that motion capture technology and the LMM were capable of collecting similar types of data. One major aspect of Cappelli's research was the calculation of a participant's angular velocity and acceleration by differentiating the position data points with respect to time [15].

However, since Marras' 1992 validation of the LMM and optical motion capture system, there have been several advances in the area of optical motion capture, including the reliability, accuracy, and ease of capturing detailed three dimensional motion data. Although Marras' work is thorough and comprehensive, it compares the LMM to the version of optical motion capture that was available in 1992. In addition, Marras' capture of motion using optical motion equipment consisted of LEDs placed on the LMM; one on the top, dynamic portion, and another on the bottom, static portion. It is believed that a more recent and detailed validation of the LMM and optical motion capture would be useful in the context of current research on the measurement of lumbar movements and prediction of lower back disorders.

5.3 Experimental Method

With a modern assessment of the validity and accuracy of the LMM and optical motion capture, a comparison can be made between the two systems. It is not currently known whether one system is clearly superior to the other; however, it is believed that both systems offer effective measurements in various dimensions of human movement. Additional insights into the use of optical motion capture for industrial ergonomic assessments can be found in [16]. One goal of this research is to determine the varying degrees of accuracy, reliability, and practicality in determining lumbar movements. For example, while one system may exhibit lower error rates when determining subject position in space, another system may demonstrate superiority for velocity and acceleration measurements. This research hopes to capture an impartial analysis of the accuracy and validity of the LMM compared to optical motion as well as their practicality in industrial settings.

In order to capture the accuracy of the LMM and motion capture systems, the reported position value from the LMM and motion capture can be compared to a frame of reference that restricts the subject through a clamp. By restricting the subject to pre-specified ranges of motion, it is possible to measure the 'error' of the position value recording by either system. In addition to measuring the accuracy through error rates, the reliability of each system will be determined by performing several repetitions for each specified range of motion [5].

Testing will be somewhat similar to that of Marras et al., but may include EMG data in order to standardize lifting and lumbar movements. Independent variables will include the angular range of motion (ROM) in degrees specified by the experiment, as well as vertical position in space (also pre-specified). In addition,. Task candidates will be considered such that different levels of velocity and acceleration can be monitored and reported in relation to validity. Dependent variables include the ROM and area in space reported by the LMM and motion capture equipment. For each trial, an error will be reported for the difference between the subject's actual position in space specified by the clamp, and the reported position in space given from the LMM and motion capture systems.

5.4 Results

Preliminary results from this study will be presented at the HCI International Conference in Beijing, China in 2007.

5.5 Future Work

A considerable range of future research could be performed in the study of lifting procedures and the tools used to evaluate them. One area of research is the study of lifts in non-standard postures, such as one-handed lifts and those performed more infrequently. In addition, it would be beneficial to utilize the LMM and optical motion capture in an industrialized setting to test the system's compatibility with their environment. The LMM has already been tested and applied in industrial settings, and by further incorporating the LMM or motion capture system into a factory environment, the practicality of either system will be greater recognized. Possibilities also exist for further study of lifting procedures in health-care settings such as the task of lifting and transporting patients. Use of the LMM and motion capture systems promise rewarding benefits in these and many other commercial settings, particularly where standard repetitive strain related models may not be sufficient.

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