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Factors determining workers' pace while conducting continuous sequential lifting, carrying, and lowering tasks

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ABSTRACT

To plan a new manual material handling work process, it is necessary to predict the times required to complete each task. Current time prediction models lack validity when the handled object's mass exceeds 2 kg. In this study, we investigated the effect of workplace design parameters on continuous sequential lifting, carrying, and lowering of boxes weighing from 2 kg to 14 kg. Both laboratory and field experiments were conducted. Results revealed that the box's weight and the lifting and lowering heights influenced the tasks' times. Further, the time to perform a task was influenced by the performance of other tasks in the same work process. New time prediction models were developed using the laboratory experiment data. Our models were found to be more accurate on average than the Maynard Operation Sequence Technique (MOST) and Methods Time Measurement (MTM-1) by 42% and 20%, respectively, for predicting the times of real workers at an actual workplace.

1. Introduction

Manual Material Handling (MMH) tasks such as lifting, lowering, and carrying are common in various industries (e.g. manufacturing, agriculture, and construction). The cost of injuries and illnesses associated with MMH is a significant factor for industry (Driscoll et al., 2014; Kim et al., 2012). In order to plan a new MMH work facility, such as a production line, it is necessary to predict the times required for the worker to complete the individual work tasks (Wells et al., 2007). These times are important for determining the expected productivity, planning staff requirements, conducting ergonomic evaluations, and simulating virtual workers in Digital Human Modeling software (Chaffin et al., 2012; Dempsey et al., 2008; Lavender et al., 1999; Mital and Ramakrishnan, 1999; Rose et al., 2013; Snook and Ciriello, 1991; Waters et al., 1993).

The worker's times in these cases are typically predicted using Predetermined Motion Time Systems (PMTS), such as the Methods Time Measurement (MTM; Maynard et al., 1948) and the Maynard Operation Sequence Technique (MOST; Zandin, 2002). PMTS are based on an independency assumption, meaning that the times of the different motions or tasks that comprise a work process do not influence each other (Freivalds and Niebel, 2013). However, the independency assumption was found to be invalid for various tasks that involved light or no mass (Abruzzi, 1956; Hall, 1956; Nadler and Denholm, 1955; Nadler and Wilkes, 1953; Sanfleber, 1967).

Moreover, to the best of our knowledge the independency assumption has never been tested in tasks that involve masses common in industry (2–14 kg).

In many cases the PMTS do not accurately consider the physiological and biomechanical aspects in the time predictions, especially for lifting, carrying, and lowering objects (Genaidy et al., 1989; Mital et al., 1987; Straker, 2002). Further, PMTS only partially consider the influence of the workplace design characteristics (e.g. height of lift, handled mass) or the worker's anthropometrics on the time standards (Garg and Saxena, 1985; Genaidy et al., 1989). Thus, in many cases PMTS predict a faster time than that which a worker is capable of performing. This might lead to errors in predictions of the worker's productivity, and to inaccuracies in the results of biomechanical, physiological, and psychophysical evaluations (Chaffin et al., 2012; Dempsey et al., 2008; Garg et al., 1978; Lavender et al., 1999; Snook and Ciriello, 1991; Waters et al., 1993). Since in many cases the expected productivity of workers is based on PMTS analysis, predicting faster times could motivate the workers to overexert themselves and thus increase their risk for injury.

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Therefore, the objective of the current study is to gain a better understanding of the time required to complete MMH tasks. We investigate the influence of the workplace design characteristics and the worker's height and weight on the required time for completion of each task. In addition, we test the PMTS′ independency assumption for the MMH work process with masses that are common in industry (2–14 kg). Finally, we offer new time prediction models for MMH tasks, and compare their accuracy to commonly-used time prediction methods.

2. Methods

2.1. Overview

In this study two experiments were conducted: a laboratory experiment and a field experiment. The aim of the laboratory experiment was to investigate the influence of the workplace design and the worker's characteristics on the task time. Since investigations based on laboratory experiments should be validated using results of real workers in real work places (Dempsey et al., 2008), we also performed a field study with the aim of comparing its results to the results of the laboratory experiment.

2.2. Laboratory experiment

2.2.1. Subjects

Twenty male college students with a mean age of 26.2 (SD = 1.2) years, height of 177.1 (SD = 6.7) cm, and weight of 74 (SD = 10) kg, participated in the experiment. All subjects filled in a screening questionnaire to ensure that they were in good health (i.e. that they did not suffer from any of the following: chronic illness, heart condition, musculoskeletal disorders, or injuries). They all signed a consent form approved by the institutional review board of the Ben-Gurion University of the Negev.

2.2.2. Experiment apparatus

The subjects handled a plastic box with the dimensions of 20 × 55 × 36 cm (height × width × depth). Handles were located on both sides of the box, 15 cm from the bottom. During the experiment the subjects lifted the box from a wooden platform and lowered the box on a wooden platform, using the handles. The subjects lifted and lowered three different masses which were distributed equally at the bottom of the box. A video camera with a rate of 29 frames per second recorded the subjects while they performed the tasks, and a time study was conducted by applying direct measurements on the video recordings using the video time stamp.

2.2.3. The experimental design

The subjects performed a box-conveying work process, which is a common task in packinghouses and warehouses. This work process consisted of the following tasks (Fig. 1A–D): 1) lifting the box from a platform; 2) carrying the box in front of the body for 3.7 meters; 3) lowering the box on a platform; 4) returning to the lifting platform (starting point).

The following task definitions are used in the experiment. The lifting task starts when the worker begins to reach with his hands toward the box and ends when the worker's hands reach a steady height at which they will carry the box. The lowering task starts when the worker begins to lower the box toward the platform and ends when the worker's hands return to the sides of his body. The carrying task is defined as the time between the end of the lifting and the start of the lowering. The returning task is defined as the time between the end of lowering and the beginning of the lifting again.

We investigated the influence of the box mass, the initial height of the lifting, and the final height of the lowering (i.e. independent variables) on the time for performing each of the lifting, carrying, lowering and returning tasks (i.e. dependent variables). The possible values of each of the independent variables are presented in Table 1. The values of the box mass were determined according to the acceptable mass limit for 75% of male workers (Snook and Ciriello, 1991). In order to determine this limit, we calculated the acceptable mass limit for all lifting and lowering heights (Table 1) and considered the most conservative value, which was the result of lifting the box from 20 cm above the floor. For this height the

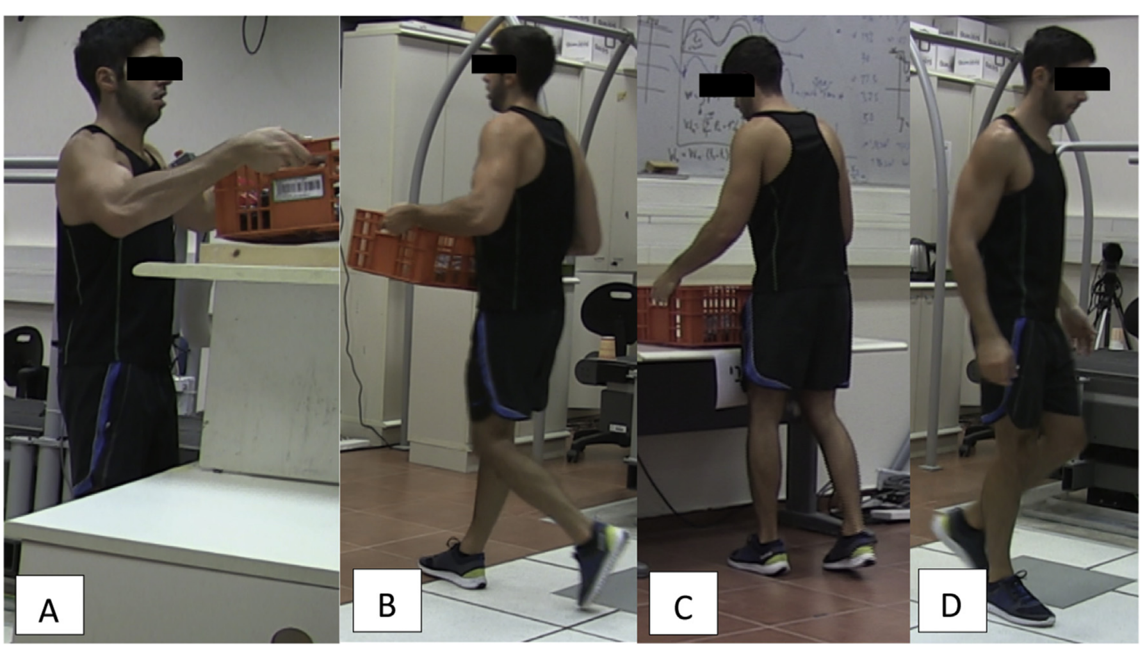

Fig. 1. The box conveying work process: A) lifting, B) carrying, C) lowering, D) returning.