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The effects of cycle time on the physical demands of a repetitive pick-and-place task

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Abstract

This study seeks to elucidate the effects of the cycle time of a pick-and-place task on muscle activity, grip force, posture, and perception-based measures (discomfort and difficulty). Six healthy adults (3 males, 3 females) participated. A 4×2 repeated measures design was used with cycle time (1, 2, 5, and 10 s) and grip (power and chuck) as independent variables. The task consists of repetitively picking a 0.7 kg part and placing it into a bin. A reduction in cycle time (CT) resulted in both a decrease of task time and physical rest time ($p<0.001$). The physiological muscle rest was much lower than the physical rest time ($p<0.05$). An increase in static muscle loading ($p<0.01$), grip force ($p<0.001$), and discomfort ($p<0.001$) were also observed. These results suggest that a pace threshold (between 2 and 5 s for this task) is reached at a higher CT than that defined by the ability to perform the task.

Keywords: Pick-and-place; Cycle time; Work-related musculoskeletal disorders

1. Introduction

The prevalence and incidence of work-related musculoskeletal disorders (WMSDs) among industrial workers have been well recognized. There have been documented work-related problems in the manufacturing industries such as electronics assembly (Neumann et al., 2002; Silverstein et al., 1986); materials picking and assembly tasks (Nordander et al., 2004); parts assembly, cashiering, and packaging (Ranney et al., 1995), laminate industry (Hansson et al., 2000), and garment sewing and printing (Seth et al., 1999). Many of these jobs involve grasping and moving objects. The US Bureau of Labor Statistics reported that repetitive placing, grasping, and moving objects accounted for 31% of nonfatal occupational injuries in private industry workplaces in the year 2003 that were associated with repetitive movement (BLS, 2005). Of these cases, 65% affected the fingers, hands, and the wrists; and 11% make up shoulder-related complaints. In a cross-sectional study among sewing, assembly, cashiering, and packaging workers, muscle pain and tenderness of the neck and shoulder areas, and forearm extensors constituted the largest problem (Ranney et al., 1995). It was suggested that muscle tissue is highly vulnerable to overuse and the force of muscle contraction has also been implicated in tendon pathology. Further, industrial jobs characterized predominantly by static or highly repetitive loads resulted in neck and shoulder complaints (Veiersted et al., 1990).

Generally in industry, tasks can be characterized as: (1) fully automated, where a task is done by a machine, a motor, or equipment; (2) semi-automated or machine-paced, where a task is shared by a machine (i.e. conveyor) and a worker; and (3) manual, in which the task is done by the worker. Pace-wise, both fully automated and manual tasks are not as problematic and physically demanding as a semi-automated task where machines determine the pace that the worker must adhere to, possibly making the risk for WMSDs greater. In a review by Muggleton et al. (1999), it was stated that reducing loads so that the worker may operate faster increases the repetition rate among semi-automated jobs. This situation may also potentially

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worsen other co-existing risk factors such as posture, forcefulness, or muscle activity while doing the task.

In the context of industrial jobs, manually transferring an object from one point to another (pick-and-place or hand transfer tasks) occurs frequently in the retail trades, manufacturing, and production assembly (Krawczyk and Armstrong, 1991) and is a common component for many machine-paced tasks. The time available to do one transfer (pick then place) will be referred to as cycle time (CT). The general purpose of this exploratory study was to quantify the effects and physical demands of speeding up the demands of the job by reducing the CT. There were three specific objectives of the study: (1) to profile the rest time taken based on the task and rest time taken based on the muscles of interest, (2) to determine the level of grip force in vertical power and five-finger chuck grip types, and (3) to investigate error count, and perceived discomfort level and difficulty of the task.

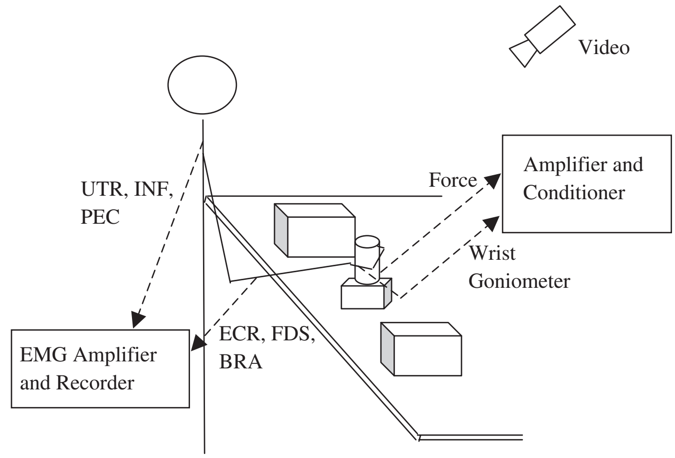

Fig. 1. During the task, subjects were instructed to pick the instrumented tool on the right, and placed to a similar square bin to the left. Headset was used for auditory pacing.

2. Methodology

2.1. Subjects

Three males and 3 females ($N = 6$) from the university population were recruited. All participants were right-handed and were free from any injury to the upper limb in the past year. Participants had a mean age of 28 years (± 6.9) and mean body mass index (BMI) of 24.2 kg/m^2 (± 2.8). Each participant signed an informed consent form for the experiment, as approved by the ethics review board of York University, Toronto, Ontario, Canada.

2.2. Experimental design

A repeated measures factorial design (2×4) was utilized. The independent variables included grip type (power, chuck) and CT (1, 2, 5, and 10 s). Outcome measures included muscle activity, grip force, wrist posture, perceived discomfort and ease, and error count. CT was paced using a computer-generated auditory metronome. Trials were randomized and all took place in a single day. Participants were asked to lift a part instrumented with a force transducer (MLP-500-CO, Transducer Technique, Temecula, CA) from a bin 9.5 cm $\times$ 9.5 cm $\times$ 4.7 cm on the right side to a similar bin on the left side, and back (i.e. pick-and-place or get-and-put). A cycle was considered a movement in one direction. The inter-bin distance was 0.5 m. The weight of the part was 0.7 kg, with a height of 19.4 cm, base diameter of 5 cm and a grip diameter of 4.1 cm. The participants were instructed to orient the part within the plastic square bin by use of a positioning rod mounted 1 cm from the base (length = 13.4 cm) which has to fit into the target (Fig. 1). Working height was adjusted such that the elbow angle was 100° during the power grip when the part was in the bin.

Prior to the experiment, participants were oriented and trained to do the task. The attachment of the recording instrumentation, workstation set-up, and calibration trials were also done at this time.

2.3. Work time and task rest time

Work time (WT) was calculated from every sampled cycle, from the onset of the grip as indicated by the grip force ($GF > 0$) to its offset ($GF = 0$); the time the part was picked up until it was placed down. Fifteen equally spaced cycles were sampled from each trial. For the purpose of this paper, only samples moving from right to left were used. Task rest time (R_T) which was expressed in percentage and referred to the time that the hand was not in contact with the part ($GF = 0$) was calculated based on the WT using the equation: $R_T = [(CT - WT)/CT] \times 100$.

2.4. Electromyography

Root mean square (RMS) muscle activity was recorded using a portable electromyography (EMG) unit (ME3000P8 Mega Electronics Ltd, Kuopio, Finland), with a sampling frequency of 10 Hz, a total gain of 412, and common mode rejection ratio of 110 dB. EMG signals were collected from six muscles—the upper fibers of the trapezius (UTR), infraspinatus (INF), pectoralis major (PEC), brachioradialis (BRA), extensor carpi radialis (ECR), and flexor digitorum superficialis (FDS). The EMG signal was recorded using disposable Ag/AgCl surface electrodes (Kendall Meditrace 130) with a pickup area diameter of 20 mm, at a spacing of 30 mm placed parallel to the muscle fibers. Standard electrode placement and individual test performance of the muscles were observed (Cram et al., 1998). A silent trial was collected to determine any noise intrinsic to the system or the laboratory environment. Maximum voluntary contractions (MVC) of each muscle were done against resistance from the investigator, or using a shoulder-sling restraint board for the upper trapezius muscle. MVCs were performed