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Working height and parts bin position effects on upper limb muscular strain for repetitive hand transfer

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ABSTRACT

The study examines the influence of workplace layout on localized muscle fatigue in a simulated repetitive seated hand transfer task. Nine task conditions were used consisting of three working heights and three parts bin positions. Six muscles in the right upper limb were monitored bilaterally using surface electromyography. Motion range data on the upper segmental joints were collected along with subjective perception data. Results showed that awkward postures due to workstation setting and high repetitiveness were the major factors affecting upper limb muscle fatigue, especially for the trapezius and anterior deltoid. The percentage of fatigued subjects generally increased when the mean working height became greater. This study suggests that working height should be organized at or below the elbow level with the parts bin position not above the working height when a repetitive hand transfer task is performed.

Relevance to industry: This experimental result should be useful in job analysis for the evaluation of muscle activities and workplace layout design for the reduction of muscular load on the upper limbs during repetitive handling of light weight in industries characterized as hand transfer.

1. Introduction

Work-related musculoskeletal disorders (WMSDs) are one of the main focuses in the area of occupational disease prevention (Colombini and Occhipinti, 2006). Across Europe and most of the industrialized world upper limb work-related musculoskeletal disorders are the most prevalent of all WMSDs (Colombini and Occhipinti, 2006; Finneran and O'Sullivan, 2013). The prevalence of upper limb disorders in the working population was 20% in the UK (Anderson, 1986) and between 20% and 30% in the USA (Larsson et al., 2007). In Taiwan, among 11,336 sampled workers in a nationwide survey 37.0% had musculoskeletal disorders (Guo et al., 2004). Lee et al. (2005) reported overall the 1-year prevalence of neck (14.8%), shoulder (16.6%), and hand (12.4%) disorders were higher than those of the upper back (7.1%) and elbow (8.3%) among those who sought medical treatment due to complaints in a nationwide study. In terms of exposure to physical risks, 62% of the respondents were exposed to repetitive hand and arm movements (Niu, 2010) in the fourth European working conditions survey in 2005. Movement repetition during work activities has been a major risk factor for upper limb musculoskeletal disorders development (Terrier and Forestier, 2009). Adverse ergonomic working conditions may play a significant role for musculoskeletal pain among workers in manufacturing industry (Lee et al., 2005; Niu, 2010).

Hand transfer tasks are usually performed from a sitting posture involving spine and lower limb positions that are static for extended periods with simultaneous manipulations performed with the upper limbs, often at a fixed repetition rate (Roman-Liu et al., 2004). Two obvious advantages of working in the seated posture were reported by Kothiyal and Kayis (2001): the physiological energy consumption demands were decreased and lower back strain can be prevented using ergonomically designed furniture. In light work conditions Strasser and Müller (1999) suggested that the breast and back muscles showed a general low activation and should not be monitored in further studies. However, repetitive hand transfer tasks may result in upper limb musculoskeletal disorders due to disadvantageous work factors. Work factors may include variation in the load magnitude, direction of movement, work rate, cycle time and precision of task intensity level for hand

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transfer tasks. The effects of these work factors were examined in the literature. For example, Kothiyal and Kayis (2001) conducted a hand transfer experiment to determine the effect of varying load magnitude, direction of movement and work rate on muscular strain in seated manual handling tasks performed with one hand. Escorpizo and Moore (2007a, b) observed the precision, speed and cycle time effects on muscle load and rest in an occupational hand transfer task. Strasser and Müller (1999) conducted a repetitive hand transfer experiment to analyse the influence of thirteen different movement directions in a horizontal plane on muscular strain in the hand-arm system when handling light weights. They all found that these work factors could mostly influence muscle load.

Elbow height is a generally accepted basis for the assessment of working heights for sedentary activities (Kroemer and Grandjean, 1997). For precision work, a working height above elbow height is generally recommended mainly due to the demand of close visual distance whereas for heavy work a working height below elbow height is required to call for great force or much freedom of movement (Sanders and McCormick, 1993; Kroemer and Grandjean, 1997; Delleman, 2003). Elbow height is a factor that may influence the work efficiency and cause upper limb disorders. Limited researches have evaluated the workplace layout with various working heights relative to elbow height of subjects for horizontal manual hand transfer tasks. For example, Delleman (2003) examined the effects of working height and reach distance on working postures (using an opto-electronic motion system) and workers' perceptions (using a questionnaire) during light-weight manual handling in the metal industry. In his study, only the working heights equal to individual elbow height and elbow height +10 cm were examined. He did not assess the effect of working height below elbow height. Magnusson and Örtengren (1987) applied the subjective ranking scale and interview methods to investigate the optimal working height and surface angle in meat cutting. In the above studies no muscle activities were examined on the associated muscles to observe the working height effect. Upper limb work-related musculoskeletal disorders for hand transfer tasks were studied by Kothiyal and Kayis (2001) and Escorpizo and Moore (2007a, b), involving electromyographic data to observe muscle activities. They set the working heights at the subject's elbow height in their experiments, with the effects of various working heights not examined.

When the parts bin position is not arranged at the working height level, i.e., the starting point for hand transfer is above or below the working height, the muscle load on the upper limb may vary due to the anatomical structure of the hand-arm-shoulder system. Reaching at different heights may influence both the muscle activities and the kinematics of the shoulder and elbow. Mamaghani et al. (2002) found that the shoulder and elbow angle had a significant effect on the root mean square (RMS) and mean power frequency (MPF) sEMG value during sustained isometric contraction. Lin et al. (2010) investigated the arm reaching and holding factors effect on subjective discomfort rating when subjects vertically transferred an in-line pneumatic screwdriver between the home position and several specific positions. They found that the arm reaching over shoulder height was the main factor affecting the discomfort rating for the whole body. Vandenberghe et al. (2010) confirmed that reaching to higher targets was initiated by the shoulder joint, but the adaptations compared to lower reaching occurred primarily at the elbow level. Reaching height modulation induced an immediate elbow flexion adaptation followed by a shoulder elevation adaptation.

Work physiology is an appropriate approach to use for analysis with repetitive motion at worksites. Some measures of physiological strain such as heart rate, oxygen consumption, and electromyography (EMG) can be obtained from workers. The measures of heart rate and oxygen consumption usually relate to overall level of physical work and stress placed on the body. Surface EMG (sEMG) technique is often used to measure physiological strain of individual muscles or muscle groups and considered to be a good indicator of muscle fatigue in occupational field studies (Chesler and Durfee, 1997; Cacioppo et al., 2000; Luttmann et al., 2000; Stern et al., 2001). It has been observed that the frequency content of the surface myoelectric signals continuously changed over time under dynamic conditions (Ebenbichler et al., 1998; Bonato et al., 2001; Hostens et al., 2004; Roman-Liu et al., 2004). Typical changes in sEMG during repetitive muscle contractions, such as a significant increase in the amplitude and a shift in the frequency spectrum towards lower frequencies, can be commonly interpreted as signs of localized muscle fatigue and used to establish the occurrence of fatigue.

In real work situations workstation layout associated with working heights and parts bin positions for repetitive hand transfer tasks depends mostly on the original default setup (no adjustment while in use), previous working experiences, the individual preference of the facility designer, supervisor or operators themselves. The muscle fatigue influence of working heights in conjunction with various parts bin positions on the upper limb for repetitive hand transfer tasks has not yet been examined in the literature. Many literature studies observed the muscle activities for a repetitive handling task over a prolonged period. This study conducted an experiment to explore the upper limb activities while the working heights and parts bin positions were varied in a seated repetitive hand transfer task during a short period. This study hypothesized that the upper limb muscle strain would be different when both the working heights and parts bin positions were changed at worksites with a high repetition rate.

2. Materials and methods

2.1. Subjects

Ten male subjects were recruited to participate for the experiment as paid volunteers in this study. Their ages ranged from 22.9 to 27.9 years (mean 25.2 yr/SD 1.5 yr), body height from 163.3 to 180.2 cm (mean 171.8 cm/SD 4.6 cm), and body weight from 60.1 to 115.1 kg (mean 78.7 kg/SD 18.5 kg). The anthropometric data of 10 subjects are shown in Table 1. All subjects were free of known musculoskeletal injuries and described themselves as right-handed. A written consent was obtained from the subjects after they were given a clear explanation of the objectives and procedures of the experiment. They were also given the opportunity to ask any question on the study and had the option to withdraw any time during the experiment. This study was approved by the Institutional Review Board for Ergonomics Experiment of Chaoyang University of Technology.

2.2. Tasks

A banana plug was picked up by subjects with their dominant hand from a parts bin located at designated level relative to the working height and then plugged into a banana jack located on a board at the work surface. Banana plugs, typically an electrical connector for insertion into a banana jack, were used in this study as the objects for hand transfer to simulate a repetitive seated manual assembly task. The banana plug was about 3 g in weight. Five pieces of acrylic jack boards with 180 × 180 mm^2 were prepared and 36 (i.e., 6 × 6) banana jacks were installed on each board. Fig. 1 shows the plugs and the jack for hand transfer and the layout of the simulated assembly task.