International Journal of Industrial Ergonomics 68 (2018) 290–296

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

On-body personal assist suit for commercial farming: Effect on heart rate, EMG, trunk movements, and user acceptance during digging

Nugrahaning Sani Dewi[a], Masakazu Komatsuzaki[a,b,*]

[a] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Saiwaicho 3-5-8, Fuchu, Tokyo, 183-8509, Japan
[b] Center for International Field Agriculture Research & Education, Ibaraki University, 3-21-1, Ami, Inashiki, Ibaraki, 300-0393, Japan

ARTICLE INFO

Keywords:
On-body personal assist suit
Digging task
sEMG

ABSTRACT

Personal "protective" equipment has been recommended in agricultural tasks. The plastic mulching process is often required in commercial farming. On-body personal assist suits (PAS) affect heart rate, muscles, trunk movement, and user acceptance. In this study, 8 male and 6 female subjects performing 3-min digging tasks were evaluated. Electrocardiograph, electromyography of the right and left upper trapezius and (L3) lumbar erector spinae, and motion data were simultaneously recorded using a multichannel telemetry system. In the task's final minute, the workload was decreased using PAS in males, although the average workload did not change. Males achieved a more stable acceleration pattern using PAS as compared to females. 86% females experienced discomfort in the crotch area; therefore, we recommend that hip straps be modified to increase user acceptance. For a typical agricultural forward-bending task, such as digging, PAS can significantly reduce strain ($p < 0.05$) on lower back muscles (L3).

1. Introduction

Workers in the agricultural sector, in general, especially in labor-intensive agriculture, are at high risk of musculoskeletal disorders (Palmer; 1996; Meyers et al. 2000; Jin et al. 2009; Fathallah, 2010; Kirkhorn et al. 2010; Keawduangdee et al. 2015; Thetkathuek et al., 2018). Although farm machinery and mechanization have greatly diminished the manual labor required for field preparation, the use of such equipment is not fully mechanized. Manual tasks such as digging often require in the plastic mulching process in commercial farming. Digging involves repetitive forward flexion, and is targeted as a priority task for health intervention.

On-body ergonomic aid devices such as personal lift-assist devices (PLADs) and personal weight-transfer devices have been shown to reduce lower back muscular activity during lifting (Abdoli-e et al., 2006; Abdoli-e and Stevenson, 2008; Lotz et al. 2009; Godwin et al. 2009; Ulrey and Fathallah, 2013) and the static forward bending that is executed by workers in the automotive industry (Graham et al. 2009). PLADs use elastic bands in a passive system mounted on the upper back to transfer force and moment from the spinal column to the shoulders, pelvic girdle, and knees (Lotz et al. 2009). Another option is the on-body personal assist suit (PAS), which has recently become commercially available. Similar to the PLAD, a PAS has an elastic system for the upper back. PAS weighs only 1.04 pound which is lighter than PLAD and similar to a normal suit. Such on-body ergonomic aid devices are often evaluated in simulated laboratory or industrial settings but have yet to be evaluated in the field for agricultural tasks. A few studies have investigated trunk movement while performing manual handling in industrial farming. Graham et al. 2009 has investigated trunk inclination using an accelerometer during static forward bending in the automotive industry.

Thus, the aim of the present study is to evaluate how PAS affect the heart rate, muscles, and trunk movement and whether users accept to wear them while digging for a period of 3 min, which is a repetitive dynamic forward bending task commonly encountered in agriculture. In previous works (Godwin at al. 2009; Lotz et al., 2009), the effect of PLAD was found to be statistically similar for women and for men. However, men and women have different trunk motion and knee-angle ranges, which need to be considered separately when evaluating work technique in manual-handling tasks (Lindbeck and Kjellberg, 2001). Thus, the present study monitors how PASs affect both male and female subjects and also records the acceleration pattern. PASs could prove to be a simple safety intervention in field-related applications. The hypothesis of this study is that wearing a PAS reduces the demand on back muscles during digging.

* Corresponding author. Center for International Field Agriculture Research & Education, Ibaraki University, 3-21-1, Ami, Inashiki, Ibaraki, 300-0393, Japan.
E-mail addresses: nugrahaningsani@gmail.com (N.S. Dewi), masakazu.komatsuzaki.fsc@vc.ibaraki.ac.jp (M. Komatsuzaki).

https://doi.org/10.1016/j.ergon.2018.08.013
Received 22 May 2018; Received in revised form 24 July 2018; Accepted 27 August 2018

Abbreviations

ANOVA	Analysis of variance
BMI	Body-mass index
CA	Conservation agriculture
HR	Heart rate
HRR	Heart rate reserved
IUCAM	Ibaraki university cooperation between agriculture and medical
LUT	Left upper trapezium
MAD	Mean-amplitude deviation
PAS	Personal assist suit
PLAD	Personal lift-assist devices
RMS	Root mean square
RUT	Right upper trapezium

2. Materials and methods

2.1. Research design

This study was conducted at the Center for Field Science Research and Education at Ibaraki University, Japan. All subjects were volunteers, and the study was approved by the human research ethics committees of Ibaraki University. The study follows a case control quasi-experimental design (Harris et al. 2006). The independent variable is the utilization of PAS and gender, and the dependent variables are the specific objective and measured parameters. The standardized Nordic questionnaire (Kuorinka et al. 1987) was used to analyze any subjective musculoskeletal disorder symptoms experienced before the experiment. The effects of the PAS were measured and evaluated by quantifying the heart rate (HR) via the definition of relative workload in heart rate reserved (HRR), electromyogram (EMG) root mean square (RMS) amplitude for muscular demand, and quantified trunk movement obtained from motion mean-amplitude deviation (MAD). The treatment output was measured by a quantitative measure of task achievement. Finally, user acceptance of a PAS was assessed based on a post-task subjective questionnaire.

2.2. Subjects

The subjects consisted of seven males and six females aged 22–75 years old, with a mean age of 41 ± 21.6 years for males and 45 ± 19.2 years for the females. Few subjects were chosen among local volunteers; they represent the older population and have moderate experience in digging. Few subjects were chosen from the students of the Ibaraki University College of Agriculture who represent the young adult population and have moderate experience in digging. Both populations were equally distributed into 2 groups of male and female subjects. The subject characteristics are listed in Table 1. The physiological baseline parameters, including age, resting HR, and age-adjusted HR maximum (HR_{max}), were not significantly different for all subjects. The body-mass index (BMI) of the subjects was normal (WHO, 2004), and none of the subjects had any history of heart or respiratory disease.

2.3. Instrumentation

A multichannel telemetry system (WEB-7000®; Nihon Kohden, Tokyo, Japan) (Fig. 1A) was used to monitor and record the electrocardiogram (ECG), surface electromyogram (sEMG), and acceleration (Dewi et al., 2017) while digging. Six wireless electrodes were used (one ECG, ZB-151H; four EMG, ZB-150H; and one accelerometer, ZB-156H), each electrode was 25 mm wide, 34.5 mm high, and 12 mm deep and weighed 10 g (Fig. 1B). They transmitted to a bio-repeater (ZB-700H; 235 × 92 × 56 mm^3, 380 g) mounted at the waist of the subjects. The bio-receiver received the waveform data from the bio-repeater, which were directly measured, monitored, and recorded using the QP-700H® software (Nihon Kohden, Tokyo, Japan). The subjects performed their tasks in a natural and comfortable manner, and noise due to wire movement was eliminated using a cordless measurement system.

2.3.1. Monitoring using electrocardiogram and surface electromyogram

An ECG electrode attached at the sternum was used to record the electrical activity of the heart as an indirect measure of metabolic demands. To record muscle electrical activity, four sEMG electrodes were attached at specific muscles: the right and left upper trapezium muscles (RUT and LUT) and the lower back muscles at lumbar erector spinae level 3 (L3) (Fig. 1C). The ECG electrode and the sEMG electrodes were fixed to the subjects' bodies using an adhesive tape (EMGH648A; ECGH649, Nihon Kohden, Tokyo, Japan) to obtain stable data. Tissues containing ethanol were used to clean up surface of the skin as skin pretreatment.

2.3.2. Accelerometer

A tri axial accelerometer was used to measure trunk movement and patterns, which had medio-lateral (x), vertical (y), and antero-posterior (z) measurement capability. Accelerometers have previously been used to investigate gait, balance, and movement patterns of the trunk while walking (Menz et al. 2003; Craig et al. 2016). The tri axial accelerometer has been validated during activities containing higher peak acceleration as compared to walking, such as jogging and running (Wundersitz et al. 2015). The results showed that the device can accurately measure jogging and running when filtered at 10 Hz. In preliminary observations of this study, digging has a similar range of peak acceleration for running. The accelerometer was attached to the subjects at the pelvis area and affixed to a surface of the bio-repeater, which was mounted at the level of the sacrum (hip) (Menz et al. 2003; Rowlands and Stiles, 2012; Vähä-Ypyä et al. 2015).

2.3.3. Standardized nordic questionnaire

The standardized Nordic questionnaire (Kourinka et al. 1987) inquiries about nine anatomical regions (neck, shoulder, elbow, wrist, upper and lower back, hips, knees, and feet) where symptoms tend to accumulate and pain may occur. The first section of the questionnaire addresses the participant's general musculoskeletal symptoms within these nine anatomical regions. The second section focuses on the lower back and the neck and shoulders.

Herein, seven subjects were male (53.8%), and six were female (46.1%). About half the subjects (46.1%) reported never having exercised, and one respondent was a former smoker. On the basis of the questionnaire (Table 2), none of the subjects suffered from elbow, wrist,

Table 1
Characteristics of subjects (n = 13).

Variable	Males (n = 7)		Females (n = 6)		p
	Mean	SD	Mean	SD	
Age (years)	41	21.6	45	19.2	0.737
Height (cm)*	170.4	5.9	159.8	7.5	0.020
Body weight (kg)	62.4	9.2	58.0	7.2	0.361
Body mass index (kg/m^2)	21.4	2.3	22.8	3.2	0.390
Resting heart rate (beats/min)	68	10.7	67	7.1	0.834
Age-adjusted HR max (beats/min)	179	21.6	175	19.2	0.737

Body mass index (BMI) = weight (kg)/[height (m)]^2; age-adjusted maximum heart rate (HR max) = 220 − age (years);* Significant at $p < 0.05$ (one-way ANOVA between males and females).