Characterizing repetitive upper arm motions in apple harvesting

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1. Introduction

The US tree fruit industry has been facing a labour shortage and international price competition. In attempt to respond to these challenges, a harvest-assisting mobile platform was introduced and expected to replace the use of ladders in large industrialized orchards. With the platform semi-autonomously moving along tree rows, workers can continuously pick apples while standing on the platform, without having to climb up and down ladders. One major concern is whether the platform could lead to increased upper-arm repetition, which is one of the risk factors for shoulder pain.

Although there are some robust methods for characterizing work repetition in laboratory settings (Speilholtz et al. 2001; Ebaugh et al. 2006; Fuller et al. 2009), methods to measure and characterize repetitive motions in field applications are limited. That is, it is difficult to apply capture motion systems that often require various views in field settings where subjects have to move around.

This study aims to develop and evaluate a method using a computational program for characterizing upper-arm repetition from field-collected postural data. Then the method will be used to determine whether there are differences in upper-arm repetition between harvesting apples the conventional ladders and the new technology mobile platforms.

2. Method

2.1 Study Design

2.1.1 Subjects

Upper-arm postures and movement were collected from twenty-four subjects (8 workers using ladders, 8 workers working on platforms and 8 ground workers) while harvesting apples. Subject anthropometric and demographic data are described in Table 1. All study procedures were approved by the Human Subjects Division at the University of Washington.

Table 1. Mean (SD) Worker Anthropometric and Demographic Data

	Ground N = 8	Ladder N = 8	Platform N = 8	p-value
Age (years)	23.9 (1.4)	32.5 (3.0)	28.3 (3.0)	0.09
Weight (kg)	83.9 (4.9)	71.4 (4.5)	74.7 (2.4)	0.11
Height (cm)	177 (3.3)	170 (2.4)	171 (2.4)	0.16
Arm length (cm)	65.6 (1.6)	63.6 (1.0)	66.1 (1.3)	0.36
Upper arm length (cm)	37.1 (1.0)	35.4 (0.4)	35.7 (0.6)	0.26
Forearm length (cm)	35.4 (1.1)	34.7 (0.5)	35.4 (0.9)	0.80

2.1.2 Harvesting Tasks

All the workers were assigned to pick apples at a trellised orchard where all the trees were 7.5 years old. The orchard workers were "1st colour picking" which means they were only picking apples with a desired colour and size. The conventional way of harvesting apples involves ladders where the worker climbs up the ladder with front-mounted bag strapped around the shoulders. Typically the workers will climb the ladder and start harvesting apples from the highest point of the tree and fill their bag with apples as they move their way down the ladder. Once their apple bag is full (20 kg of apples typically) the workers will walk to an apple

bin, bend over and set the apple bag in the bin, open the bottom of their apple bag, and gently disperse the apples into the bin. A new method of picking apples involves the use of mobile platforms. These mobile platforms (*Bandit Xpress; Automated Ag Systems; Moses Lake, WA, USA*) have two platforms which are height adjustable: typically one platform is set to a lower level and the other platform is adjusted to a higher level. Like the other workers, the mobile platform workers wore a front-mounted apple bag, and then when the bag was filled, the apples were deposited into a wood bin in the centre of the platform.

2.2 Instrumental Protocol

2.2.1 Inclinometers

Tri-axial inclinometers *(G-Links; MicroStrain® Sensing Systems; Williston, VT*) were used to continuously collect upper-arm inclinations and movements over a full-day shift of harvesting activity. A computational program was developed using an interactive graphical software program (*LabVIEW 2014; National Instruments; Austin; Texas, USA*) to systematically characterize upper-arm repetition based on the field-collected data. Raw data were filtered using a dual-pass 1-Hz low-pass Butterworth filter.

The upper-arm inclination was calculated in terms of an angle of upper arm relative to gravity in two planes – flexion and abduction – and the vector sum of the two anatomical planes. The inclination angles were denoted as Θ_{FL}, Θ_{AB} and Θ_{VS} for flexion, abduction and vector sum, respectively Using the upper-arm inclination angles, work repetitions were characterized based on changes in upper-arm inclination greater than a movement threshold, denoted as Φ; that is, a repetition cycle was counted when the upper-arm movement between successive minima and maxima exceeded Φ. The values of Φ evaluated in this study ranged from 5° to 45° with in increments of 5°.

2.2.1 Video observations

While collecting the upper-arm postural data, subjects were also videotaped four times for roughly 5-6 minutes, the time it took to fill two consecutive bags. The video recording times started when a subject finished emptying a bag and ended when subject finished emptying the second bag after. The times at the inclinometers video cameras were set based on the same satellite clock.

To synchronize the inclinometer's data and the video recording, the data from torso inclinometer was used. The most obviously detectable movement was when the workers emptied apple bag. Before emptying the bag, the workers generally stood up straight due to the heavy load. Then they slowly bent forward for approximately 90^0, lasting for about 10 seconds. After emptying the bag, they stood straight again adjusting the bag to get ready for the next pick of apples.

The true repetition rate (movement/minute) was determined from the videos using a subset of the subjects and considered the "gold standard". Then, using the computational program, for each value of Φ and each group of workers (ground, platform, ladder) the repetition rates were determined.

2.3 Statistical Analysis

The independent variable was the harvesting method based on the equipment: ladder, platform and ground. The dependent variables of this study were the number of movement cycles per minute characterized from the Θ_{FL}, Θ_{AB} and Θ_{VS}. RANOVA methods were used to compare the repetition rates across the three tasks. The Φ value that best matched the "gold standard" repetition rate was identified using the video observation. The statistical analyses were performed using JMP Statistical Discovery Software (version 11.2; SAS Institute; Cary; South Carolina, USA).

3. Results

Using the computational program, the smaller the Φ resulted in the greater the repetitions rates calculated. Regardless of Φ used for analysis, repetition rates were significantly greater in the workers using ladders than those who picked apples from the platform and those who worked in the ground level (p-values < 0.001 for all Φ).

Repetition rates based on the Θ_{FL} in the left and right upper arms were not significantly different for the Φ of 5°, 10° and 25°-45°; however, the differences approached significance and were significant for the Φ of 15° and 20° (p-values = 0.066 and 0.026, respectively). Repetition rates based on the Θ_{AB} in the left and

right upper arms were significantly different for all values of Φ (p-values < 0.01). Repetition rates based on the Θ_{VS} in the left and right upper arms were not significantly different for the Φ of 5° and 30°-45° but the differences were significant for the Φ of 10°-25° (p-values = 0.01. 0.001, 0.0007 and 0.003, respectively). Since many of the differences were significant, the left and right upper arms were evaluated separately.

Comparing the repetition rates counted from the video and from the computational program, the value of Φ = 15° was found to best approximate the video-based repetition rate (14.0 repetitions/minute). Repetitions computed from the program using Φ = 15° are shown in Figure 1. Repetition rates were generally highest in the ladder workers; significantly higher when compared to the platform and ground workers in left upper arm flexion and vector sum methods. There was no difference between the repetition rates between platform and ground workers.

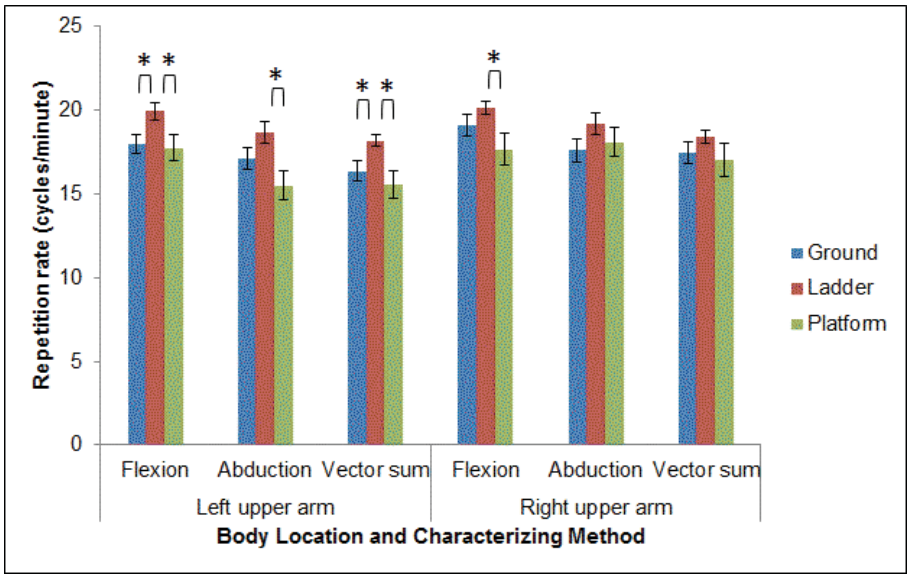

Figure 1. Repetition rates calculated from the computational program when using Φ = 15°.

4. Discussion

The repetition assessment method developed in this study differs from other studies that used the number of movements passing an anatomically-based cut-point (Speilholtz et al. 2001). Most previous studies have been conducted in a well-control laboratory settings, in which subjects performed designated, constrained tasks rather than their daily activities. However, the repetitions evaluated in this study were from actual field work, which involves a great deal of postural variation due to the nature of the apple picking task (i.e. apples on trees were at various heights and upper-arm postures do not return to the same set angle every cycle). Assessing repetition through changes in posture was more applicable.

The results were compared to previous work where overall productivity was counted. The previous report in the Washington State claimed that the average apple removal rate of a worker performing a first-pick on a mobile platform was 45 apples per minute (WTRFC 2014). In other words, approximately 22.5 apples were picked by each hand. This is much higher than our results. This could be due to the fact that the harvesting task observed in this study requires stem-clipping and that slowed down the repetition rate.

Although this study was well-controlled for a fair comparison among work methods in certain settings, there is also a limitation in terms of generalizability. The study was conducted in a trellised orchard, which is a developing into one of the standard orchard types in Washington State but not in other parts of the world. The apple trees were grown as tree walls making easier to pick apples in this study than from big trees in regular orchards. It should also be noted that apple variety (requiring stem-clipping or not), picking technique (strip pick, 1st colour pick and 2nd colour pick) and the density of apples on the trees could influence work repetition.

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References

Ebaugh, D.D., McClure, P.W. & Karduna, A.R., 2006. “Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics.” *Journal of Electromyography and Kinesiology*, 16: 224–235.

Fuller, J.R. et al., 2009. “Posture-movement changes following repetitive motion-induced shoulder muscle fatigue.” *Journal of electromyography and kinesiology□: official journal of the International Society of Electrophysiological Kinesiology*, 19(6):1043–52.

Spielholz, P. et al., 2001. :Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors.” *Ergonomics*, 44: 588–613.

WTRFC. 2014. Design and development of apple harvesting techniques, Final Project Report. Washington Tree Fruit Research Commission (WTFRC). [Accessed 3 Sep 2014]