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Comparison of Exposure to Repetitive Upper Arm Motions and Non-neutral Upper Arm Postures between Apple Harvesting with Ladders and Mobile Platforms

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In attempts to improve productivity in agriculture, a harvest-assisting mobile platform has been developed and is being evaluated for use in Washington State apple orchards; however, its ergonomic effect on work postures and repetitive motions has not yet been characterized. The purposes of this study were: 1) to compare physical exposures between two methods of apple harvesting: a conventional ladder and a newly-developed mobile platform, and 2) to develop systematic methods for characterizing work repetitions, specifically in the upper arms. Using self-contained tri-axial inclinometers with built-in memory, upper arm inclinations were continuously monitored from twenty male workers over a full day of apple harvesting. At the beginning and the end of work shift, Borg CR10 scales were used as self-report measures of perceived fatigue in the shoulder. Postural exposures were characterized as the percent of time the upper arm postures exceeded specified angle ranges. Repetition was evaluated using changes in upper arm angles ranging from 5 to 30 degrees. In terms of prolonged postural exposures, repetitive work exposure and perceived fatigue in the shoulders, the workers using the mobile platform had less physical stress compared to the workers using the ladders. In addition, the upper arm repetition rates were high (over 15 repetitions per minute) for both harvesting methods. A more systematic study of the harvesting methods is needed to characterize differences in repetition rates and productivity between the mobile platforms and ladders. However, the results indicate that the mobile platform could improve workability and may enable more diverse workers to participate in harvesting activities.

INTRODUCTION

The United States tree fruit industry is currently facing challenges due to a shortage of labor as well as an increased international competition. Technological advancement could be a key to the survival and the growth of the industry (WTFREC, 2010). Harvest-assisting mobile platforms have recently been introduced in some large US apple orchards with the objective to increase fruit harvesting productivity. Compared to traditional apple harvesting, which requires climbing up and down ladders, workers on mobile platforms could pick apples while the mobile platform semi-autonomously transports them through the orchard. One major unanswered question is whether mobile platforms will expose workers to greater amounts of static repetitive and non-neutral arm postures which could lead to more cases of shoulder pain in the agricultural workforce.

Risk factors for shoulder pain include repetitive use of the arms, elevated arm postures and heavy workloads (van der Windt et al., 2000; Leclerc et al., 2004). Laboratory studies have shown that repetitive reaching at shoulder level can lead to upper limb fatigue as evidenced through force, EMG and kinematic (range of motion) measures (Fuller et al., 2009). A separate kinematic and EMG laboratory experiment involving a repetitive arm-elevating tasks showed that the fatigue in the shoulder muscles was largest in the mid-range of scapular upward rotation or arm abduction/adduction (60° to 120°) compared to the angles of less than 30° and greater than 150° and in the high-range of scapular external rotation or arm

flexion/extension (90° to 150°) compared to 30° to 60° (Ebaugh et al., 2006). Methods characterizing and measuring arm postures are quite robust; however, methods to characterize and measure the exposures to repetitive movements are less well developed.

The purposes of this study were: 1) to determine and evaluate the upper arm postural impacts of the new mobile platform compared to conventional ladders, and 2) to develop and evaluate computational methods for characterizing repetitive motions in the arms and shoulders from data continuously collected in the field.

METHODS

Study Design

Experimental Protocol. This study compared the use of ladders in a conventional style orchard and the use of a harvest-assisting mobile platform (*Bandit Xpress, Automated Ag Systems, Moses Lake, WA*) in a trellised orchard. As shown in Figure 1, there were workers picking apples while standing on the mobile platform and workers picking apples while walking in front of the mobile platform. Two apple bins were attached to and moved along with the platform - one on the platform level and the other on the ground level.



Figure 1 - Harvest-assisting mobile platform

Subjects. Twenty workers participated in this study. All participants were males of Hispanic origin and native Spanish speakers. Eight workers picked apples from ladders and twelve workers picked apples in conjunction with the operation of the mobile platform. Of these twelve workers, six worked on the platform and the other six worked on the ground in front of the platform. Table 1 presents the anthropometric and demographic information of the twenty workers. Height and weight were measured in the field. All study procedures were approved by the Human Subjects Division of the University of Washington.

Table 1 –Worker Anthropometric and Demographic Data: Mean (SD)

	Ladder [n = 8]	Mobile Platform [n = 6]	Ground [n = 6]	p- value
Age (year)	34.6 (9.0)	29.3 (9.4)	28.3 (7.7)	0.36
Height (cm)	167.1 (2.9)	156.3 (5.1)	176.7 (14)	0.06
Weight (kg)	75.8 (11)	62.7 (3.3)	66.6 (4.4)	0.02

Objective measures. This study measured upper arm postures while workers were performing the harvesting tasks. We characterized the posture in terms of an angle between each upper arm and trunk. We defined work exposure as: 1) the fraction of working time when workers had non-neutral posture, and 2) the number of work cycles during working time, which was normalized to repetition rate.

Measurement equipment. To record upper arm postures over the full work shift, the workers wore tri-axial inclinometers (*G-Links; MicroStrain® Sensing Systems; Williston, VT*) on the upper portions of their left and right arms. The tri-axial inclinometers were battery powered, had 2 MB of built-in memory and recorded continuous posture data at a frequency of 5 Hz. In addition, the workers were videotaped for a short periods of time while picking apples from the ladders and the mobile platforms.

Subjective questionnaires. We assessed perceived fatigue in left and right shoulders at four time points during the work day: before work in the morning, end of the morning work shift just before lunch, the beginning of the afternoon work shift just after lunch, and the end of work day using the Borg CR10 scale (Borg, 1998), which had been translated into Spanish. The translated version had been validated with the workers prior to data collection. Bilingual bicultural field team members administered this survey.

Arm Motions

In general, upper arm postures can be classified into flexion/extension and adduction/abduction (Figure 2). In this study, the posture was characterized simultaneously in both movement planes using the vector sum of the two postural planes. The concentric cones of the arm postures (angles) created by the vector sum of the two postural planes were measured about the shoulder.

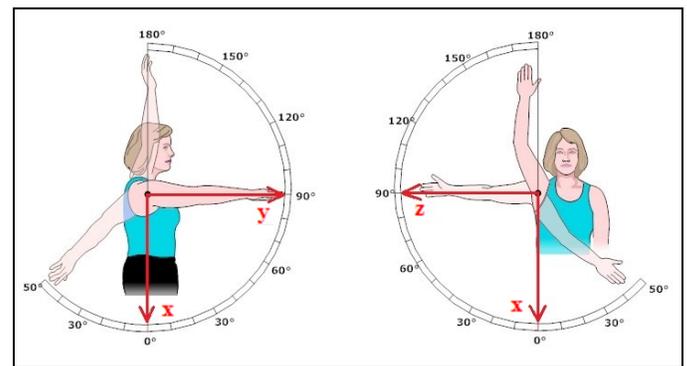


Figure 2 - Arm range of motions and corresponding angles: (left) flexion/extension in lateral view, (right) abduction/adduction in anterior view

Data Processing

The data collected from the tri-axial inclinometers were processed and analyzed using an interactive graphical software program (*LabVIEW 2012; National Instruments; Austin, Texas, USA*). To reduce noise, raw data were filtered using a dual-pass 1-Hz low-pass Butterworth filter. Left and right upper arm angles were calculated using equation (1) where x, y and z are displacements in longitudinal, sagittal and frontal axes, respectively (Figure 2).

$$\theta = \tan^{-1}[\sqrt{y^2 + z^2}/x] \tag{1}$$

Four time segments of upper arm angle data were extracted from each subject. These included two from their morning work shift and two from their afternoon work shift. There were two segments of work each half-day because there was one 15-minute break within each shift. Therefore, each segment contained approximately two hours of data.

Non-neutral postures. In this study, work postures were characterized in terms of the percentage of time when the upper arm angles (θ) exceeded 10°, 20°, 30°, 40°, 50°, 60°,

70°, 80° and 90°. When upper arm angles exceed 90° the arms are working above shoulder level.

Repetitions. To count the number of arm repetitions, local minima and maxima within the arm movements had to be detected. One of the goals of this study was to determine how much of an arm angle excursion (denoted by Φ) would be appropriate for counting and characterizing repetitive arm movements.

Apple picking is achieved through two movements: 1) a major movement of reaching for an apple, and 2) and a smaller sub-movement of removing the apple and stem from the tree. In many cases when analyzing the upper arm postural data for repetitions, there were two local maxima and minima corresponding to these two movements associated with apple picking. Thus, in signal processing, if the angle difference between any pairs of sub-movements within the major movement was less than Φ , only the larger movement was used to register the repetitive movement. This procedure was done to prevent counting sub-movements as independent repetitions. After that, repetitions were characterized and counted using successive minima and maxima which had various Φ -degree angle differences. The values of Φ chosen were 5°, 10°, 15°, 20°, 25° and 30° so that small and moderate upper arm movements could be assessed. Also, a time-motion study of the picking task was conducted through the videos and compared to the results from the computational data analysis. Finally, the number of repetitions within work periods with different Φ -degree angle differences was normalized to a rate with units of repetitions per minute.

Statistical Analysis

The effects of the three types of harvesting on upper arm repetitions for each Φ -degree difference, postures and subjective ratings were analyzed using ANOVA methods with type I error of 0.05. JMP Statistical Discovery Software (version 9.0; SAS Institute; Cary; South Carolina, USA) was used to perform the statistical analysis.

RESULTS

Non-neutral postures

The angle data were not significantly different across the four time segments; therefore, the data throughout the day were pooled together for the analysis of the effect of the harvesting method.

As shown in Figure 3, compared to harvesting on ladders, working on the mobile platform and working from the ground reduced the exposure to non-neutral upper arm postures, i.e. the vector sum angles (Θ) exceeding 30°, 60° and 90°.

Repetitions

The Φ angle difference of 10° was found to best approximate the repetition rates identified from the videos. Similarly to the analysis of the posture data, the repetition

rates of the four time segments throughout the work day were considered as a random effect in the analysis instead of fixed effect. Repetition rates in left and right upper arms were not significantly different for the Φ of 5°, 10° and 15° (p-values = 0.59, 0.62 and 0.16, respectively) but the repetitions in left arm were significantly higher at the angles of $\Phi = 20^\circ, 25^\circ$ and 30° (p-values = 0.02, 0.002 and 0.0004, respectively). When these differences were insignificant, the side of body was treated as a random effect.

As shown in Figure 4, the smaller the Φ , the greater the repetitions rates. The repetition rates were significantly greater in the workers using ladders compared to those who picked apples from the platform and those who walked on the ground along with the platform. These differences were regardless of the angle differences (Φ) used for characterizing the repetition (p-values < 0.001 for all cases – various angles and both when left and right shoulders were characterized separately and together; p-value = 0.0095 when considered $\Phi = 10^\circ$ and treated left-right arm as a random effect).

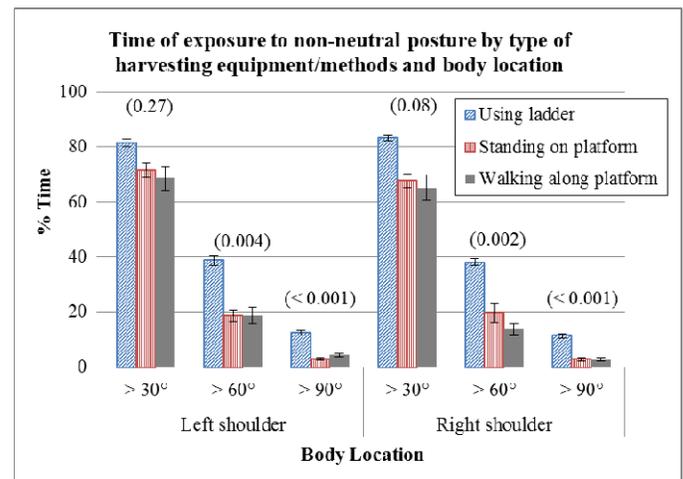


Figure 3 – Exposure to non-neutral upper arm postures by type of harvesting method and body location

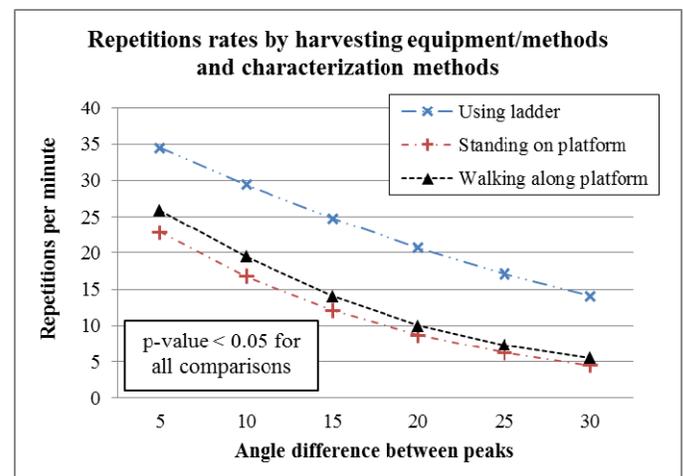


Figure 4 – Repetition rate by type of harvesting method and upper arm angle difference

Subjective Measures

Using ANOVA and considering both harvesting method and work period as fixed effects but separating the analysis of left and right shoulder perceived fatigued, the Borg CR10 scores were significantly different across the harvesting methods for left shoulder (p-value = 0.04) but not significantly different for right shoulder (p-value = 0.25). Comparing across the for time segments, there was no significant effect on the Borg CR10 (p-value = 0.27 and 0.49 for left and right shoulder). However, the descriptive statistics presented some differences in the Borg CR10 over time. In this paper, only the score at the beginning and the end of the work day are shown (Figure 5).

In Figure 5, the Borg CR10 scores of perceived fatigue in the shoulders at the beginning of the work day were not significantly different by the type of harvesting method. However, at the end of the work day, perceived fatigue ratings in the shoulders were significantly higher in the workers who used ladders.

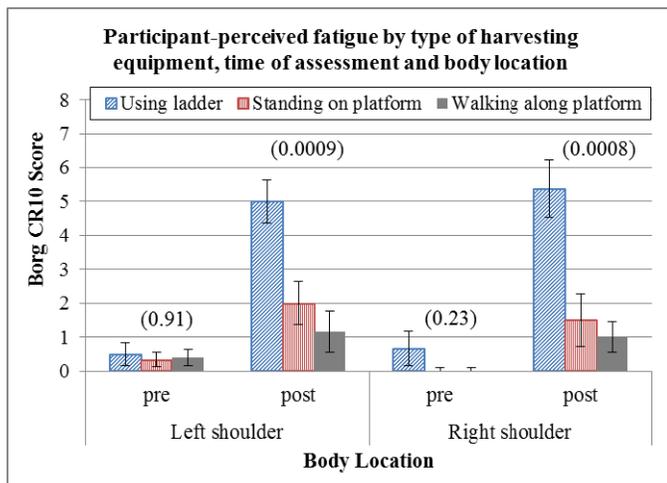


Figure 5 - Participant-perceived fatigue by type of harvesting method, time of assessment and body location

DISCUSSION

Equipment Comparisons

The objective and subjective results clearly showed that the use of mobile platforms and harvesting from the ground reduced the physical exposures in upper extremities. Apple harvesting from the mobile platform and ground significantly reduced the exposure to non-neutral postures where the upper arms were above 60° as well as the exposure to overhead work (arm angles above 90°), which is considered a risk factor for musculoskeletal pain. In addition, harvesting from the mobile platform and ground also reduced repetition rates.

Still, it is currently unknown whether the mobile platform would improve or reduce productivity. Further work is needed as we found measuring productivity to be challenging. On a platform or on the ground three to four people harvest as a team whereas one works individually with ladders. Part of

the repetition difference can be due to an individual versus team approach to harvesting. In addition, the duty cycle of harvesting on the platform is much greater as the workers are always working in the tree canopy and not climbing up and down ladders or in and out of the tree canopy.

As the majority of the results indicate that mobile platform could improve workability, i.e. working with the mobile platform had less strenuous and lower postural exposures to the upper arms, small, female and older workers may be able to participate in the harvesting tasks. This would help relieve the current labor shortage experienced in many agricultural regions, which is becoming an increasingly critical concern.

Characterizing Repetitions

This study explored defining repetitions using several thresholds for changes (Φ) in upper arm angles. This method differs from the method used by Spielholz et al. (2001), which defined repetitions using the number of movements passing a postural cut-point. In that study repetitions were measured based on wrist movements crossing and returning back to a neutral orientation (0°). The Spielholz study was conducted in a more control setting, in which subjects performed designated tasks rather than their daily activities. In contrast, our study characterized upper arm postures and repetition during actual work. There was 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 there were differences among participant stature. Thus, starting postures were rarely neutral and from the same fixed posture. Therefore, in this study, assessing repetition through changes in posture was a more applicable approach.

Using a 10° change in upper arm posture, the repetition rates calculated from the postural data closely approximated the repetition rates identified in the videos. Comparing the calculated repetition rates to the actual repetition rates from the video is one way to validate the computational method, but there could be a question whether the repetitions visually counted from the video were accurate or reliable enough to be used as a standard for comparison. During the video analysis, repetition rates were counted based on the subjective judgment of the researcher. In this study, the participants were only videotaped in short and various length intervals of time (0.5-3.5 minutes).

Overall, the method for computationally characterizing repetition was fairly close to the repetition rate estimates based on the video observation. This method to computationally calculate repetitions even took into consideration the fact that apple picking has two distinct steps (reaching to the tree and removing the apple and stem from the branch). The method could potentially be applied to other studies of repetitive motion. Furthermore, the use of a difference in angle rather than an absolute cut-point could facilitate determining repetition rates in future field studies in which guiding subjects to change their work posture back to neutral while they are on duty is impractical.

Limitations

Subject Selection. The anthropometry of the subjects in this study was somewhat different across the three groups. Workers who use ladder can be anyone that is trained; thus, the average height of this group presented in this study was close to the average height of men in Mexico (165 cm). However, in harvesting activity with the mobile platform, tall workers are generally selected to be those who walk along with the mobile platform to pick apples but short workers are selected to stand on the platform to pick apples. During the subject recruitment, the researchers were not able to control for height since even the shortest one of those walking on the ground was taller than the tallest one standing on the platform in the same harvesting team. The results of this study may not allow inferences for individual performing this harvesting work, but they may be generalized to the current working population in the tree fruit industry. Regarding the subject weight, the ladder workers were significantly heavier than the platform workers (Table 1). This could be due to the fact that working with ladder requires training and we recruited the subjects that had some experience. They were presumably stronger and older than the platform workers and, therefore, likely to be heavier.

Orchard Architecture. During the study, the numbers of apples harvested in the trellised orchards with the mobile platforms were fewer than those in the conventional orchards using ladders. This could have produced bias, especially the repetitions and the time of postural exposures. The different orchard characteristics along with the type of fruits produced were the factors we could not control in this study but will seek to control in future studies. For example, we would like to choose the orchards with the same type of apples.

Future Work

Through the observation during the field study, other interesting body parts which should be studied in the future are back and knees. Workers using ladders were seen to have a lot more bent back and flexed knee postures. Workers walking along with the mobile platform were also prone to these postures when they had to pick apples near the ground. It would be interesting to study whether back and knee discomforts are issues and whether there are differences in the subjective perception of fatigue and the objective assessment of the postures between mobile platform and ladder harvesting. That would also be translated into a way to improve workability particularly with regards to aging workers.

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