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A feasibility study comparing objective and subjective field-based physical exposure measurements during apple harvesting with ladders and mobile platforms

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ABSTRACT

Although mobile orchardplatforms have been developed to improve apple harvesting productivity in the US, the physical exposures of workers usingthe mobile platforms have not been well characterized, partlydue to the lack of assessment tools specific to the tree fruitorchard environment. The purpose of this study was to evaluate the feasibility and utility of different subjective and objective methods for characterizing apple harvesting workers' posture, armrepetition, heart rate, and perceived exertion during platform- and conventional ladder-based harvesting. During a regular full shiftwork (8 hours), the objective physical exposure measures (armelevation, torso inclination, and heart rate) of 6 platform, 6 ground, and 8 ladder workers were measured with tri-axial accelerometersand heart rate monitor; and subjective perceived exertion wascollected using standardized Borg RPE and CR-10 scales, translated into Spanish. The results showed that the arm elevation, torso forward bending, repetitiveness, heart rates, and perceived exertions were lower for the platform-based workers than forthe ladder-based workers. The subjective measures (Borg RPE and Borg CR-10) appeared to be similar and mirror the general trends of the objective heart rate and posture measures.These results indicate the potential benefit of these low-cost subjective measures when direct measurements are too costly,complicated, or not permitted. This study determined that field measurements of objective and subjective physical exposures were feasible for evaluating apple harvesting work. In summary, all themethods used appear to be feasible for field use in orchard-based environments..

KEYWORDS
Borg RPE; Borg CR-10; heart rate; inclinometry; posture

Introduction

The agricultural industry is one of the most hazardous industries in the United States due to the high rate and severity of occupational injuries and illness,[1] particularly in Washington State, where a previous study demonstrated that agricultural workers had greater relative risk of occupational injuries than other workers.[2] Therefore, agriculture is a high-risk working environment that may benefit from health-related research. Agricultural work is a priority area within the National Occupational Research Agenda program, which is promulgated by the National Institute of Occupational Safety and Health. Among all the occupational injuries and illnesses, work-related musculoskeletal disorders (WMSDs) comprise the single largest component of work-related injuries among agricultural workers.[3,4] McCurdy et al.[3] found that sprains and strains were most common among migrant Hispanic farmworkers (31%), and Xiao et al.[4] found that WMSDs in the same population were significantly associated with using awkward work postures and driving heavy equipment. WMSDs develop over time and often result from prolonged exposures to physical risk factors, including forceful exertions, awkward postures, and repetitive work affecting the low back,[4] shoulders,[5,6] and upper limbs.[7]

Previous studies have shown that harvesting apples is associated with many of the WMSD risk factors.[8,9] Fulmer et al.[8] demonstrated that workers engaged in apple harvesting activities could significantly increase shoulder stresses while reaching to pick apples (arms elevated for 62.9%

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of the work time) and back stresses while carrying apple bags or ladders (bags loaded with apples for 78.5% of the work time). Earle-Richardson et al.[9] found that the period of time spent in awkward postures in this population was greater than that in construction workers and nurses, whose WMSD risk is known to be the highest among all the occupations. Furthermore, migrant farmworkers in the United States are vulnerable, because barriers prevent them from accessing public resources such as clinic services, welfare, and worker compensation assistance. These barriers include their illegal work status, lack of health insurance, and lack of job security.[10] Therefore, apple farmworkers are likely to suffer from various work-related illnesses and injuries, many of which may be underreported.

The US tree fruit industry has been facing challenges in price competition from foreign producers, increased labor costs, and a shortage of workers. In response to these challenges, the US tree fruit industry has prioritized automation to increase the efficiency of apple production.[11] As a result, harvest-assisted mobile platforms have been introduced in some orchards in the United States to increase productivity (Figure 1). Mobile platforms may reduce some potentially hazardous activities, such as walking on uneven surfaces, climbing ladders leading to falls, and using awkward postures that may cumulatively contribute to chronic back pain. Previous studies comparing mobile platforms and ladders have shown that the platform reduced the shoulder muscle load among electricians performing overhead work,[12] and reduced energy expenditure in olive tree pruning workers.[13] Despite these benefits of mobile platforms, they may

Figure 1. Left: workers on the mobile platform (back), ground (front). The horizontal line indicates the lower limit of the apple height for platform workers to pick and the upper limit for the ground workers to reach. Right: a worker on a ladder. All workers carried a front apple bag on their shoulder.

introduce different types of risks (e.g., a greater exposure to static activities). However, little research has compared the physical exposures of apple harvesting workers using conventional ladders and those using mobile platforms.

Physical exposures, including non-neutral postures and repetitive work, can be assessed by either observational methods (e.g., OWAS,[14] RULA,[15] REBA,[16] and PATH[17]) or direct measurement (e.g., accelerometer-based inclinometers[18–21]and inertial sensors[22–24]). On the one hand, the observational methods have been extensively used in the field given their ease of use; however, they may not be as accurate as the objective direct measurements.[25,26] On the other hand, the direct measurements provide an opportunity to accurately measure the postures and movements in field environments. Teschke et al.[18] used accelerometers to measure trunk postures and developed postural exposure metrics of workers in forestry, manufacturing, warehousing, transportation, and construction. Douphrate et al.[19] successfully used accelerometers to measure shoulder postures, movement velocities, and repetition during the full-time work shift of workers in milking parlors. Slota et al.[22] and Granzow et al.[23] used inertial measurement units to measure upper limb and trunk postures in tree planters. Fethke et al.[24] also used the inertial measurement units to record trunk postures of agricultural machinery operators. Finally, physiological measures, such as the heart rate, have been taken of tree planters.[27] Although objective direct measurements are known to provide better accuracy of the physical exposures and may more accurately identify thresholds for increased risk of cumulative injury that could allow a comparison of postural exposures across work conditions, only a few studies have used the objective measurements to assess physical risk factors resulting from orchard-based activities in field settings.

This study aimed, first, to determine the feasibility of collecting both observational (perceived exertion using Borg RPE and CR-10) and direct measures (heart rate, upper arm, torso posture, and arm repetition) during a full-day shift of professional apple harvesters; and, second, to characterize the physical exposures in three types of apple harvesting: ladder harvesting, mobile platform harvesting, and harvesting apples from the ground.

Methods

Work settings

Two different types of harvesting equipment were used in this study: conventional ladders and mobile orchard platforms (Figure 1). The ladder workers harvested apples from all levels of the tree. In contrast, the mobile platform work required two groups of workers: one group working on the mobile platform to harvest apples from the upper level of the trees, and the other group working on the ground to harvest apples at the lower level.

All three groups of workers picked and placed apples in a shoulder-mounted bag in front of their body (Figure 1). Once the bag was full, the workers put the apples into large storage bins. A typical work day started at sunrise. The workers worked for 4.5–5 hours before taking a 30-minute lunch break. After resuming their work, ladder workers typically worked 3 additional hours, and the platform and ground workers worked for 5–5.5 additional hours.

Participants

Twenty experienced apple harvesters were recruited to participate in this study. Eight workers picked apples using a ladder as a conventional method. Twelve workers picked apples using a new mobile-platform-based harvesting method. Of these 12 mobile-platform-based workers, six worked on the mobile platform and the other six worked on the ground. All participants were Hispanic males, and their self-reported demographics are shown in Table 1. All the study procedures were approved by the University of Washington's Institutional Review board, and all the participants gave their written consent prior to their participation in the study.

Table 1. Subject anthropometry and demographics.

	Mean (SD)			
	Ladder [*n* = 8]	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) [a]	62.7 (3.3) [b]	66.6 (4.4) [b]	0.02
Experience in harvesting apples (year)	10.6 (8.9) [a]	2.7 (1.2) [b]	2.7 (1.5) [b]	0.03

Means with different letters are significantly different.

Physical exposures

To measure upper arm and torso posture, acceleration data were collected at a sampling frequency of 5 Hz from the workers' upper arms and torso over a full workday using a small battery powered tri-axial accelerometers with built-in memory *(G-Links; MicroStrain® Sensing Systems; Williston, VT*). To measure upper arm posture, the accelerometers were attached at the lateral aspects of the participants' left and right arms directly below the deltoid muscle (Figure 2). To measure torso inclination in the sagittal plane, an accelerometer was placed over their sternum (Figure 2). The angle offsets of the accelerometer-based inclinometers, based on how they rested on the body relative to gravity (neutral posture), were marked at the beginning of the data collection while the participants were standing upright with their arms straight down parallel to their body, and the offset angle was subtracted from each device's accelerometer data before the data analysis.

Raw data were filtered using a dual-pass 1-Hz low-pass Butterworth filter and converted to angular data using a custom-built analysis software program (*LabVIEW 2014; National Instruments; Austin; Texas, USA*). The three directions of movement were fore-aft (x-axis), lateral (y-axis), and vertical (z-axis). The upper arm elevation angle ($\theta_{UpperArm}$) was the cone angle between the upper arm and the direction of gravity (z), as shown in Figure 3, and calculated using equation (1). The forward bending of the torso relative to the gravitational line in the sagittal plane (θ_{Torso}) was calculated using equation (2).

Figure 2. A participant wearing tri-axial accelerometer-based inclinometers.

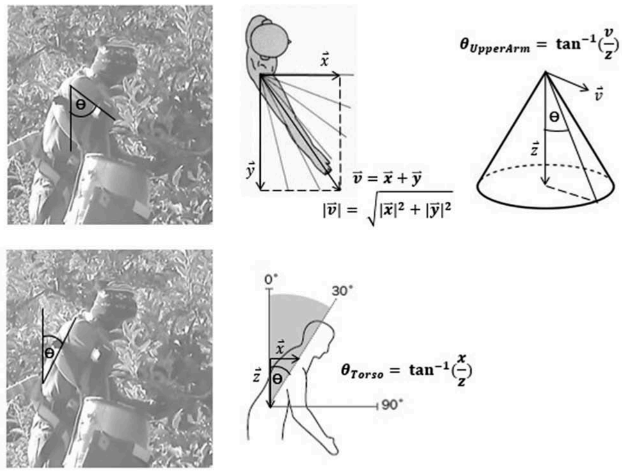

Figure 3. Top: Upper arm inclination angle calculation. The x and y are the accelerations in forward and lateral directions, respectively, which are perpendicular. The v represents the vector sum of the x and the y accelerations. The upper arm inclination angle is the arctangent of the v/z. Bottom: Trunk inclination angle calculation. The x and z are the accelerations in forward and vertical directions, respectively. The trunk inclination angle is the arctangent of the x/z.

$$\theta_{UpperArm} = \tan^{-1}\left(\frac{\sqrt{x^2+y^2}}{z}\right) \quad (1)$$

$$\theta_{Torso} = \tan^{-1}\left(\frac{x}{z}\right) \quad (2)$$

Upper arm angle data were calculated over the whole day excluding the 30-minute lunch period. Exposures to non-neutral postures were characterized in terms of the percentage of time (% work time) when the elevation angles of the upper arm ($\theta_{UpperArm}$) were greater than 30°,60°, and 90° and when the torso inclinations (θ_{Torso}) were greater than 15°, 30°, and 45°.

To count the number of upper arm repetitions, local minima and maxima within the upper arm elevation angle ($\theta_{UpperArm}$) were used. Based on previous work,[28] a repetition cycle was counted if a difference between successive minima and maxima was greater than 10°. Then, to account for different work duration between harvesting methods, the repetitiveness was expressed as the number of movement cycles per minute.

Heart rate

The heart rate of the participants in beats per minute (bpm) was continuously collected at a frequency of 1 Hz throughout a full work day using a heart monitor *(Polar RS100CX; Polar Electro Inc., Lake Success, NY)*. Raw heart rate data were filtered using a 5-point moving median to eliminate measurement artifacts (e.g., extreme values). Then, descriptive summary statistics (mean and SD) for each 1-minute interval were calculated over the participant's whole shift. The time periods of interest for the heart rate were at the beginning of the workday, before and after the lunch break, and at the end of the workday. At the beginning of the day (Beg AM Shift), the heart rate was measured for 10 minutes while participants were sitting still. This rate was defined as the sitting heart rate. For the first 15 minutes directly after the end of the morning work shift (End AM Shift), the heart rate was measured while participants were taking their lunch break; that is, they were sitting, standing, or walking around but not carrying loads. Just after the lunch break, for the first 15 minutes of the participants' afternoon work shift (Beg PM Shift), the heart rate was measured while participants were carrying loads, picking apples, climbing a ladder, standing on a platform, or walking. At the end of the day (End PM Shift), the heart rate was measured for 15 minutes. During this time, participants were sitting or standing while waiting for the researchers to remove the instrumentation. In other words, the participants were no longer performing strenuous work.

Subjective measures

To measure perceived whole body exertion, a Borg RPE scale[29] in Spanish was administered by bicultural native Spanish-speaking researchers at four time points corresponding to the time of the heart rate measurement: Beg AM Shift, End AM Shift, Beg PM Shift, and End PM Shift. The verbal anchors for the Borg RPE were provided as follows:

- 6 is "no exertion" ("ningún esfuerzo")
- 7 is "very, very light" ("muy, muy liviano")
- 9 is "very light" work, like working slowly at your own pace for a while (Es trabajo "muy liviano". Es como caminar lentamente a su propio paso por un rato.)

- 11 is "fairly light" ("más o menos liviano")
- 13 is "somewhat hard" work, but still feels okay to continue (En la escala es trabajo "más o menos duro", pero todavía se siente bien para continuar.)
- 15 is "hard" ("duro")
- 17 is "very hard" work. You can keep working but you must push yourself. You will feel very tired. (En la escala es trabajo "muy duro". Usted puede seguir trabajando, pero debe esforzarse usted mismo para seguir trabajando. Se sentirá muy cansado.)
- 19 is "very, very hard". For most people, this is the hardest work of exercise they have ever experienced. (En la escala corresponde a trabajando "muy, muy duro". Para la mayoría de la gente este es el trabajo o -ejercicio más fuerte del que tienen experiencia.)
- 20 is "maximal exertion" ("esfuerzo máximo")

Localized perceived exertion in the shoulders and low back was collected using Borg CR10[30] scales in Spanish, administered at the same time when Borg RPE measurements were collected: Beg AM Shift, End AM Shift, Beg PM Shift, and End PM Shift. The verbal anchors were provided as follows:

- 0 is "not tired" ("no cansado")
- 1 is "slightly tired" ("un poco cansado")
- 3 is "moderately tired" ("moderadamente cansado")
- 5 is "tired" ("cansado")
- 7 is "very tired" ("muy cansado")
- 10 is "severely tired" ("severamente cansado")

Borg RPE is a measure of how much effort a person feels and was designed to correlate with the cardiovascular load.[31] Borg CR-10 is an indicator of a muscular load in localized body regions.[32] Therefore, this study compared Borg RPE to heart rates, and Borg CR-10 at the shoulders and low back to the upper arm and torso inclination postures.

Statistical analysis

A descriptive statistical summary was initially conducted in JMP Statistical Discovery Software (version 11.2; SAS Institute; Cary; South Carolina, USA). Normality tests (Shapiro-Wilk tests) indicated that all the parameters were normally distributed except the upper arm postures (% of work time when $\theta_{UpperArm} > 30°$, 60°, and 90°). The variances were tested for homogeneity across the levels of the factors, using Bartlett's test. A single-factor ANOVA was used to determine whether there were any differences in the postures of the torso (in % of work time when $\theta_{Torso} > 15°$, 30°, and 45°) and the repetition rates of upper arm movement (in movements/minute) across the apple harvesters working with ladders, on platforms, and on the ground. A non-parametric Kruskal–Willis test was used for determining whether the harvesting methods affected the upper arm posture (in % of work time when $\theta_{UpperArm} > 30°$, 60°, and 90°). A repeated-measures two-way ANOVA with the participant as a random effect was used to determine whether heart rates (in bpm), Borg RPE, and Borg CR10 were affected by harvesting methods or the time point of measurement (Beg AM Shift, End AM Shift, Beg PM Shift, and End PM Shift). The model included two fixed effects (harvesting method and time point of measurement) and a random effect (participant). The statistical significance was noted at $\alpha = 0.05$.

Results

The following results demonstrate the feasibility and capability of the objective methods, the accelerometers, and heart rate monitors to collect full-shift physical exposures during orchard-based work. The following results also show that associations exist between the more involved objective measures (postures, repetitions, and heart rate) and simpler subjective measures (Borg RPE and Borg CR-10).

Physical exposures

The average upper arm and torso postural exposures measured in the morning and afternoon work sessions were not different ($p = 0.80$, 0.22, and 0.87 for the average left arm, right arm, and torso inclination angles, respectively). Therefore, the posture data in the morning and afternoon were pooled together for summarizing the postures of the three harvesting methods. In addition to the participants, the period of measurement was a random-effect factor in the mixed-effects model. As shown in Figure 4, the platform-based group (groups working on the platform and ground) spent less time with $\theta_{UpperArm}$ > 90° compared to the ladder group (p = 0.02) for both the left and right upper arms. For the ladder workers, roughly 80% of the time was spent with $\theta_{UpperArm}$ > 30°, 40% of the time working with $\theta_{UpperArm}$ > 60°, and about 15% of the time with $\theta_{UpperArm}$ > 90°. For the platform and ground workers, their work time spent with $\theta_{UpperArm}$ > 30° was about 75%, their time spent with $\theta_{UpperArm}$ > 60° was less than 20%, and their time spent with $\theta_{UpperArm}$ > 90° was less than 5%. However, there were no significant differences in the percentage of work time spent in torso flexion between the three harvesting methods. Roughly 75% of the time was spent with θ_{Torso} > 15°, around 25% of the time with θ_{Torso} > 30°, and less than 10% of the time with θ_{Torso} > 45°.

The repetition rates in the left and right upper arms were not different (p = 0.62); this was true for all three harvesting methods. However, the repetition rates were significantly greater in the participants who picked apples from the ladders (p = 0.01) compared to those who picked apples from the ground and those who worked on the mobile platform (Table 2). The mean (SE) repetition rates averaged over both arms were 29.3 (0.42) per minute for the ladder workers (roughly one repetition every 2 seconds), 16.8 (0.48) for the platform workers (one every 4 seconds), and 19.5 (0.48) for the ground workers (roughly one repetition every 3 seconds).

Table 2. Repetition rates in movement cycles per minute across groups.

	Mean (SE)			
	Ladder [n = 8]	Platform [n = 6]	Ground [n = 6]	p-value
Repetition rates at left upper arm	28.3 (0.67) [a]	16.9 (0.62) [b]	20.6 (0.55) [b]	< 0.01
Repetition rates at right upper arm	30.3 (0.51) [a]	16.6 (0.74) [b]	18.4 (0.78) [b]	0.01

Means with different letters are significantly different.

Heart rate

Corresponding to their greater postural and repetition exposures, workers in the ladder group showed greater increases in their heart rate during the morning (from 93 to 127 bpm, 37.6%, p = 0.01) and afternoon shifts (from 100 to 126 bpm, 25.4%, p < 0.01), whereas the platform group experienced no minimal (p > 0.64) heart rate changes (Figure 5). The average heart rate across the whole shift showed that the ladder group (111.7 ± 11.0 bpm) had higher heart rates (p < 0.01) than the platform (92.9 ± 14.1 bpm) and ground workers (90.8 ± 10.9 bpm). For those in the ladder group, the heart rates decreased during the 30-min lunch break and approached baseline levels (Figure 5).

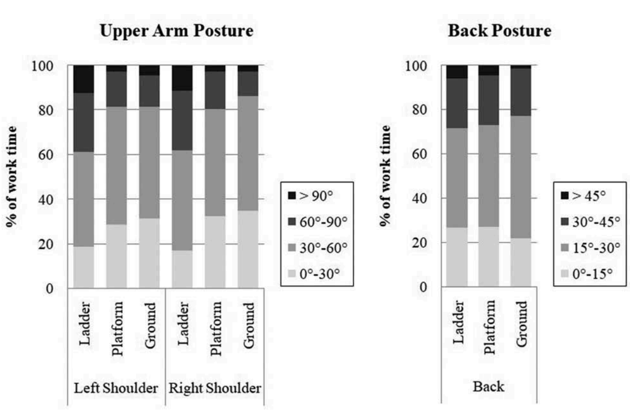

Figure 4. Mean percentages of time in the various postural categories across groups (n = 8 ladder; n = 6 platform; n = 6 ground).

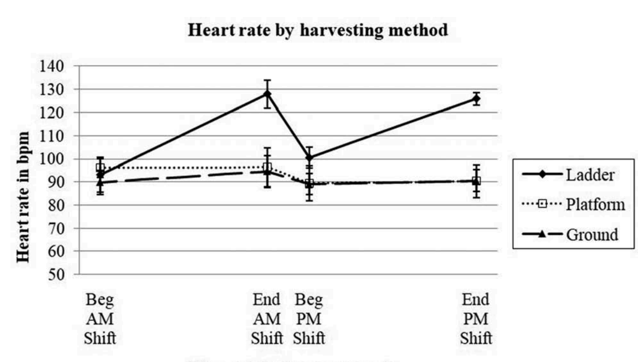

Figure 5. Heart rate across groups with respect to the time point of measurement (n = 8 ladder; n = 6 platform; n = 6 ground).

Subjective measures

Perceived whole-body exertion (Borg RPE) increased as the workday progressed over time for the ladder and platform groups, whereas the increase with time was not present in the ground group (Figure 6). Similar to the objective measures of heart rate, there was a greater increase in the Borg RPE ratings overtime in the ladder group; however, the increases did not reach statistical significance ($p = 0.19$). Despite no statistical significance, there were apparent trends showing differences in whole-body exertion (Borg RPE) across the three working groups when averaged over the full shift ($p = 0.06$). The average Borg RPE score showed that the ladder group had higher whole-body exertion ratings (10.4 ± 2.0) than the platform group (8.5 ± 2.4) and the ground (7.5 ± 1.7).

As shown in Figure 7, the ladder group experienced increases in localized perceived exertions (Borg CR-10) in the shoulder and back compared to the participants that worked on the platform and ground. Additionally, the time-dependent changes in localized perceived exertion differed across the three groups. Since there were no differences between the left and right shoulders in all three groups, the left, and right shoulder results were pooled together. When averaged across all four time periods, the ladder group had higher Borg CR-10 scores in both the shoulders ($p < 0.01$) and back ($p = 0.01$) compared to the mobile platform and ground groups.

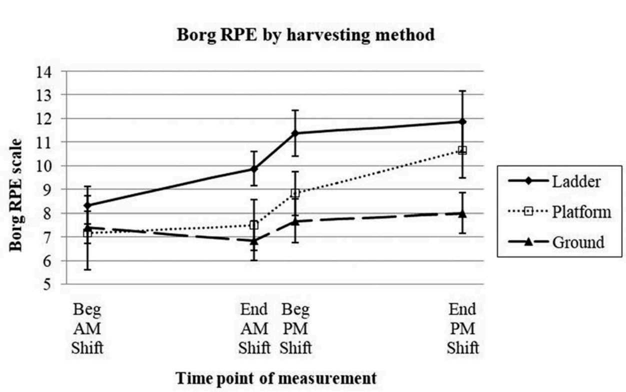

Figure 6. Borg RPE across groups with respect to the time point of measurement ($n = 8$ ladder; $n = 6$ platform; $n = 6$ ground).

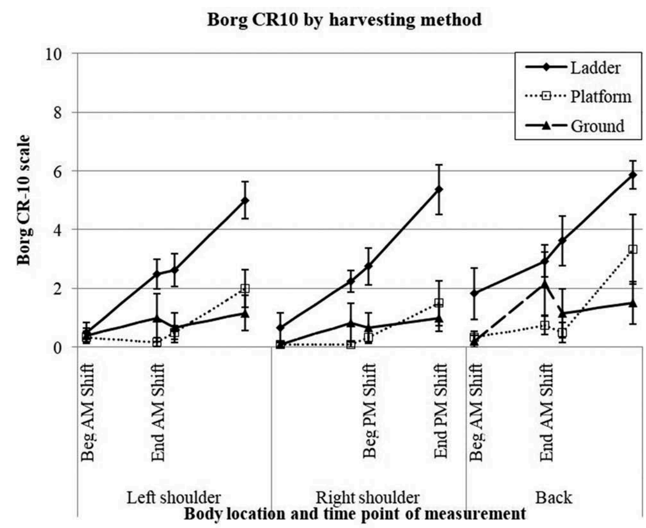

Figure 7. Borg CR-10 ratings by body regions across groups with respect to the time point of measurement ($n = 8$ ladder; $n = 6$ platform; $n = 6$ ground).

Discussion

Feasibility, ability to collect objective and subjective data for a full day with limited loss of data

The study shows the capability and feasibility of using accelerometer-based inclinometers and heart rate monitors to collect full-shift physical exposures in orchard workers, along with the feasibility of comparing the more involved objective measures (postures, repetitions, and heart rate) and the simpler subjective measures (Borg RPE and Borg CR-10). In addition, differences in the objective and subjective physical exposures were measured across the three methods of apple harvesting, with the work on ladders having the greatest physical exposures and being perceived as the most strenuous.

Comparison to previous studies in similar work environments

The results show that mobile platforms have the potential to reduce the physical exposures in the upper arms of workers relative to those of workers on ladders. Harvesting apples from the mobile platform and the ground reduced the exposure to overhead work and torso flexion in more extreme angles, both of which are considered risk factors for musculoskeletal pain. The results are comparable to a previous study in New York State,[33] where workers postures were visually observed while the workers were harvesting apples with ladders. The New York researchers found that for 39.4% of work time both arms were below 60°, for 30% of work time one arm was above 60°, and for 29.3% of work time, both arms were above 60°. Our study found that for, on average, 60% of the time the ladder workers' arms were below 60°. As for torso posture, the ladder workers in our study spent 6% of work time bending >45°, slightly higher than the 3.5% of work time found in the study in New York.[33]

Harvesting apples from the mobile platform and ground had lower repetition rates compared to solely working on the ladder. However, the difference in repetition rates may have partly been due to differences in work tasks. For example, ladder workers could set their own work pace and were paid in piece rate, whereas the participants working on the mobile platform and ground were constrained to the speed of the mobile platform and were paid hourly. In the platform and ground crews, people worked as a team, whereas the ladder crews could work as individuals. A part of the repetition difference may also be attributed to the individual versus the team approach. This study counted a repetition cycle when the consecutive minima and maxima of upper arm angles were more than 10° apart from each other. This method differs from those used in a previous study,[34] which defined repetitions using the number of movements passing a postural cut-point (e.g., a joint neutral position). The new method overcame the challenge in postural variation due to the nature of the apple picking task, where postures rarely originate from the same fixed or neutral posture.

The average heart rate of participants picking apples using ladders in this study (111.7 ± 11.0 bpm) was higher than the results of a previous study in Italy[35] (93.7 ± 11.5 bpm), but the Borg RPE at the end of the workday (11.9 ± 1.3) was slightly lower than in the previous study (13.3 ± 1.5). However, the previous study was based on 2–4 hours of harvesting apples among older workers (40 ± 10 years). Although the younger age of the workers in this study might have contributed to lower heart-rate increases during the work, the longer duration of the work could have contributed to greater increases in heart rate.

Comparison between objective and subjective measures of physical exposures

Heart rate was used as an objective measure of exertion and compared with the Borg RPE scale, which roughly corresponds to the heart rate if the Borg RPE response is multiplied by 10.[31] As seen in Figures 5 and 6, the trends of heart rate and Borg RPE with respect to time were different, but there were some similarities between the two different measures when averaged and compared across the full shift. However, there were differences in temporal behavior between the two measures during the lunch break. The objectively measured heart rate increased with work and then dropped down during the lunch break, whereas Borg RPE increased over the course of the day, especially for the ladder group. This result appears to indicate that the Borg RPE measurements were less sensitive to short-term fluctuations in workload and may be more a cumulative measure of work. Nevertheless, given the relatively good correspondence between the heart rate and the Spanish Borg RPE scores when averaged over the full shift, it appears the participants understood the translation of the verbal anchors into Spanish and that the Spanish translation of the verbal anchors was appropriate and reasonable approximations of the English verbal anchors.

Additionally, our objective measures of upper arm and torso postures were comparable to the localized exertions measured using the Borg CR-10 scale. The Borg CR-10 scores indicated increasing trends of perceived exertion across the morning and afternoon shifts. In particular, the increase was more substantial in the ladder workers compared to that in the other two groups. Consequently, the results of subjective scores indicated that the ladder work was perceived as more strenuous than the platform and groundwork. The ladder group had the highest repetition rates and postural extremes, which appeared to be mirrored by the highest levels of perceived exertion, whereas the platform and ground workers had lower postural exposures, repetition rates, and correspondingly lower levels of perceived exertion. Like the Borg RPE measurements, the Borg CR-10 ratings seem to be a more cumulative measure of physical exertion, whereas our objective measurements were not cumulative but characterized the average postures. Perhaps, in future studies comparing subjective and objective measures and developing measures of the cumulative postural load may be beneficial. Since these Borg CR-10 scales translated into Spanish were used for the first time, the results from the general trends show promise, but further evaluation of our Borg CR-10 scales may be merited.

Merits to industry

The majority of the results indicate that the use of mobile platform may improve workability, as working with the platform led to more neutral postures, lower heart rates, and was perceived as less strenuous. The improved workability of the mobile orchard platform may open harvesting jobs to female workers, older workers, or people who may not or no longer be able to harvest with ladders. This would help create employment for people who may need it and relieve the current labor shortage experienced in many agricultural regions in the US. Another benefit is that mobile orchard platforms could reduce injuries associated with climbing and falling off ladders.[36] All these factors have the potential to improve occupational health and wellbeing in apple harvesters. The other benefit of this study was the relative simplicity and minimal invasiveness of the self-contained accelerometers used. These devices demonstrated their simplicity and utility in collecting all day postural data. Finally, our low cost, simple subjective methods showed some merit for estimating physical exposures as they mirrored the general trends of the physical exposure differences between the two groups. In summary, all the methods used in this study appear feasible for field use but differ in cost, utility, and complexity.

Limitations

As shown in Table 1, the anthropometry and working experience differed across the three groups. This was an uncontrollable factor and depended on the orchard managers' preferences. Participants who worked on the ladders were more experienced workers and were of average height (165 cm) for Mexican men. The orchard managers preferred to select taller workers to work on the ground and shorter workers to work on the mobile platform. This difference in participants' height between workers on the platform and the ground might have caused their rates of arm movement to be different; that is, workers with shorter arms may have had to reach beyond their limits more frequently and thus spent more time in each picking cycle. In addition, the greater body mass index of the ladder workers compared to that of the platform and ground workers could have influenced the greater increase in their heart rate during the work period; thus, their heart rates might not be truly comparable. The demographical differences between the groups may have introduced some biases, as described. However, since grouping workers by experience and height is not an uncommon practice in agricultural settings, the study results should be representative to the current Hispanic workers employed in the US tree fruit industry.

In addition, the posture estimation technique using only accelerometers during dynamic activities may be prone to small errors. Inertial measurement units that include tri-axial gyroscopes and some gyroscope fusion algorithms have been found to provide better accuracy.[37–39]

Finally, this study did not collect data on the workers' overall productivity, i.e., how many apples they picked during their work shift nor the percentage of time the ladder workers spent on the ground or on the ladder. The information on worker productivity in the different types of orchards where the work occurred in this study, i.e., traditional orchards with taller freestanding trees and trellised orchards with smaller tree rows, would be valuable not only for interpreting the work repetition results but also for providing recommendations if the mobile platforms could bring economic benefits to the industry. A previous study comparing the productivity between mobile platforms and ladders found that the ladder crew was more productive than the platform-based workers in pear harvesting.[40] This result could be attributed to the differing pay rates of ladder workers who received a piece rate and platform workers who were paid hourly. Future work is needed for fair comparisons between harvesting methods under the same pay scheme and picking instructions.

Conclusion

The results demonstrated that the subjective and objective methods employed in this study were feasible for use in orchard-based agricultural settings. The methods may be applied to compare objective measures of body posture, repetition, heart rate, and subjective measures of perceived whole-body and localized exertion in other agricultural settings. Harvesting using the mobile platform led to less exposure to non-neutral postures, fewer repetitive motions in the upper arms, and lower whole body and localized perceived exertion compared to the conventional ladder-based harvesting method. In addition, since the platform work reduced physical exposures and was perceived as less strenuous, it may open up harvesting work to other workers who cannot or do not want to work on ladders.

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Disclosure statement

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