Article

Commonly-used subjective effort scales may not predict directly-measured physical workloads and fatigue in Hispanic farmworkers

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**Abstract:** In North America, Hispanic migrant farmworkers are being exposed to occupational ergonomic risks. Due to cultural differences in the perception and reporting of effort and pain, it was unknown whether standardized subjective ergonomic assessment tools could accurately estimate the directly-measured components of their physical effort. This study investigated whether subjective scales widely used in exercise physiology were associated with direct measures metabolic load and muscle fatigue in this population. Twenty-four migrant apple harvesters participated in this study. Borg RPE in Spanish and Omni RPE with pictures of tree fruit harvesters were used for assessing overall effort at four time points during a full-day 8-hour work shift. Borg CR10 was used for assessing local discomfort at shoulders. To determine whether there were associations between subjective and direct measures of overall exertion measures, we conducted linear regressions of the percentage of heart rate reserve (% HRR) on the Borg RPE and Omni RPE. In terms of local discomfort, the median power frequency (MPF) of trapezius electromyography (EMG) was used for representing muscle fatigue. Then full-day measurements of muscle fatigue were regressed on Borg CR10 changes from the beginning to the end of the work shift. Omni RPE were found correlated with the % HRR. Also, Borg RPE were correlated to the % HRR after the break but not after the work. These scales might be useful for certain situations. For the local discomfort, Borg CR10 were not correlated with the MPF of EMG and, therefore, could not replace direct measurement.

**Keywords:** correlation; Borg; metabolic load; percent of heart rate reserve; muscle fatigue; electromyography

**Relevance to industry:** Hispanic migrant agricultural workers are essential in the North American food supply chain. While they have been exposed to occupational ergonomic risks, subjective research instruments developed for exercise physiology and in other population, such as young healthy white adults, may not be applicable for use in migrant farmworkers. This research examined the correlations between the subjective scales and directly-measured physical measures of effort. The results could be used by practitioners to decide whether to use the less expensive and simpler to use subjective scales and how to interpret the outcomes in relation to the actual workloads. The results of this study informed ergonomics practitioners that subjective effort surveys like Borg scales used in exercises among healthy young men might not be able to accurately quantify effort or fatigue among the Hispanic farmworker population.

1. Introduction

In the past several decades, the majority of farmworkers in the United States and Canada are Hispanic migrants and more than half of the population do not have authorization to work in the United States (Castillo et al., 2021). Despite being essential to the North American economy, language, cultural, immigration status, and educational barriers can negatively affect the migrant farmworkers’ ability to communicate and/or characterize the exposure to physical workplace hazards. Compared to US-born farmworkers, undocumented Hispanic workers had more precarious work, earn less, and are more often paid piece rate than hourly (Reid & Schenker, 2016). This situation has led to more exposure to physical and mental stress (Clouser et al., 2018; Panikkar & Barrett, 2021), ultimately contributing to work-related musculoskeletal injuries (Cooper et al., 2006; McCurdy et al., 2003). Particularly, according to a study of using physician’s examinations in the United States, there were 35% prevalence of work-related musculoskeletal disorders among Latino migrant farmworkers (Mora et al., 2016). Moreover, the Latino migrant farmworkers have been facing language barriers (Hennebry et al., 2016), which impacted their risks in occupational health and safety (Viveros-Guzmán & Gertler, 2015); in the meantime, they were not likely to report their poor working conditions (Landry et al., 2021). Additionally, these known problems have been affected by increasing age and being female (Shah et al., 2009; McCurdy et al., 2003) as well as being compensated in a piece rate, which could incentivize them to work harder and avoid taking frequent or long breaks (Johansson et al., 2010).

Field ergonomic assessment can be conducted by direct measurement with sensors and by questionnaires of subjective self-reported ratings. Various available subjective ergonomic assessment tools such as RULA, REBA, Borg RPE , Borg CR-10 and Standardized Nordic Questionnaires were used to assess ergonomic risk factors among other agricultural workers population (Boriboonsuksri et al., 2022). Notwithstanding, the development and validation of subjective work assessment tools for this population has been lacking.

Despite many laboratory validation studies of subjective scales, studies on associations between direct and subjectively-reported ergonomic measures are lacking in the field settings. It is unclear whether the subjective rating scales validated in the controlled environment could be applied to the ergonomic assessment in the field.

In the context of Hispanic, both migrant and non-migrant, farmworkers in North America, the primary objective of this study was to determine whether the subjective measures of the exertion of the overall body and at the local body parts could be used to predict the workload and fatigue directly measured with sensors. Specifically, this study aimed to determine 1.) the association between metabolic, i.e. cardiovascular, load and the overall Omni and RPE scales, and 2.) the association between localized muscle fatigue measured through electromyography and the local Borg CR-10 scales.

2. Methods

2.1. Participants

Participants were selected to represent the major characteristics of Hispanic male farmworkers in an industrialized orchard in the Washington State as well as in the United States in general. The research team members include male and female local researchers of Latin American origin, who understand the cultural dynamics within the population. The orchard owners and managers were initially contacted for permission for conducting a research at their site. Then all participants were recruited on the day prior to the first day of data collection. A total of 24 farmworkers participated in this study. The participants were equally divided into three groups, i.e. 8 different farmworkers per group, based on three different harvesting methods: 1.) picking apples at the lower level of the trees up to their reach distance overhead, denoted as “Ground” workers, 2.) using a ladder to pick apples from the full trees, denoted as “Ladder” workers, and 3.) picking apples at the upper level of the trees while standing on the semi-automated mobile orchard platform, denoted as “Platform” workers. All the participants worked in the same schedule from 7:00 to 15:30 with a break during 9:30-10:00.

2.2. Ergonomic exposure parameter selection

2.2.1. Overall exertion

Metabolic equivalent (MET), defined as the oxygen consumption of a person and representing a rate at which a person burns energy, has been widely accepted as a measures for the intensity of a physical exercise or work among adults aged 18 to 65 years (Cristi-Montero, 2016; Haskel et al., 2007). Since it is difficult to measure oxygen consumption outside laboratories, numerous studies estimated the MET using other measures that are feasible in the field such as acceleration (Evans et al., 2022; Nakanishi et al., 2018) and heart rate (Caballero et al., 2019; Keytel et al., 2005; Nakanishi et al., 2018). In occupational health, a heart-rate-based approach was also developed for determining the cost effectiveness of ergonomic interventions including break strategies, i.e. duration and frequency, as well as the provision of air-conditioning (Bedny et al., 2001). In agricultural field settings, heart rates were used for evaluating work conditions in several activities such as cultivating potatoes (Das et al., 2013), rice (Sahu et al., 2013), wheat (Alka et al., 2014) and apples (Thamsuwan et al., 2019). However, one drawback with heart rate-based methods is that heart rate varies by age, sex, BMI and fitness (Hiilloskorpi et al., 1999). For the aforementioned reasons, percent heart rate reserve (% HRR), which adjusts for the maximum heart rate and resting heart rate, and has a strong association with the oxygen uptake (Cunha et al., 2011), has been proposed to be a predictor of MET. % HRR is a measure of the heart’s ability to recover to resting state after physical activities. % HRR was validated as a proxy for physical exertion in comparison to the oxygen uptake in laboratory settings for cardio exercises (cite) as well as during resting and sleeping (cite). On farms, % HRR was used for evaluating an assistive device for digging task (Dewi & Komatsuzaki, 2018).

2.2.2. Local body fatigue

Surface electromyography (EMG) has been used for assessing muscle activity in the field of occupational ergonomics (Hägg et al., 2000; Luttmann et al., 2000). EMG amplitude has a dose-response relationship with a force applied during muscle contraction (Hägg et al., 2000). Also, based on the spectral analysis of an EMG signal, a decrease in EMG mean power frequency (MPF) has been shown to be associated with muscle fatigue (Luttmann et al., 2000). Surface EMG has already been used for evaluating physical work demand, and for comparing new and traditional harvesting tools. In laboratory studies, surface EMG has been used for evaluating the efficacy of emerging technology such as vertical keyboards (van Galen et al., 2007) and the size of different touch screen keyboards (Kim et al., 2014, 2013). Nowadays, it is feasible to apply EMG techniques in field settings for general ergonomic assessments and the follow up of the effectiveness after the implementation of technology. In construction, EMG-based muscle fatigue was used in assessing scaffold building activity (Bangaru et al., 2021). In forestry, surface EMG was also used for measuring muscle activity at trapezius of machine operators (Østensvik et al., 2008). In different agricultural fields, EMG was used to assess on-farm exposures to biomechanical risk factors (Fethke et al., 2020), evaluate the efficacy of a rotary milking parlour as compared to herringbone and parallel milking parlours (Douphrate et al., 2017), compare the differences between farmworkers using ladders and mobile orchard platform in the tree fruit industry (Thamsuwan & Johnson, 2022), and investigate potential uses of an exoskeleton or a personal assistive suit for selected manual farm tasks (Dewi & Komatsuzaki, 2018; Thamsuwan et al., 2020).

2.2.3. Subjective measures

On one hand, Borg RPE (Borg, 1970), which is a perceived exertion scale ranging from 6 to 20, has been widely considered as a psychosomatic indicator of physical activity intensity during work. The Borg RPE was developed in the context of cardiovascular treadmill exercise and intended to be highly correlated with heart rate; that is, the RPE score multiplied by 10 generally represents a person’s actual heart rate in beats per minutes.

On the other hand, Borg CR10 (Borg, 1982) which is anchored at the number from 0 to 10, has been used as a local pain scale. The Borg CR10 has applications in ergonomic assessments; for instance, as a predictor of grip forces during hand tools tasks tested in a laboratory setting (McGorry et al., 2010) and as an indicator of risks to injury among janitors (Schwartz et al., 2019) and nurses (Vieira et al., 2006). One disadvantage of the Borg CR10 is a potential error due to the subjective nature; thus, it is needed to calibrate for the maximal level of exertion to achieve high accuracy (Spielholz, 2006).

Borg RPE and CR10 scales have been translated into several languages (Cabral et al., 2020; Haddad et al., 2013; Leung et al., 2004). While the Borg scales have a verbal description for each numeric value, another commonly-used and validated scale, Omni RPE, includes pictorial descriptors in specific to the context along with anchor words. Thus, the Omni RPE is thought to be more generalizable (Lea et al., 2022).

The relationships between subjectively-reported and direct measures have been investigated in laboratory studies. A previous study found a significant linear relationship between the EMG MPF of upper trapezius and the Borg CR10 at shoulder elevation endurance tasks (Hummel et al., 2005). Similarly, correlations were found between the EMG MPF of lumbar muscle and the Borg CR10 results during repetitive and prolonged trunk extension tasks (Dedering et al., 1999; Kankaanpaa et al., 1997). Regarding the muscle activity, i.e. the amplitude of the EMG signal, another study (Kuijt-Evers et al., 2007) observed that there was a relationship between the EMG in the percentage of maximum voluntary contraction and the subjective ratings of discomfort (Groenesteijn et al., 2004) in hand tool uses, only in trapezius but not in other muscles.2.3. Data collection

2.2.1. Heart rate monitors

Participants’ heart rate in beats per minute were sampled every one second throughout a full work day using a heart monitor *(Polar RS100CX; Polar Electro Inc., Lake Success, NY)*.

2.3.2. Electromyography

Local muscle activity signal was collected from both left and right trapezius muscles at 1,000 Hz using single-use disposable 10 mm diameter pre-gelled electrodes (Blue Sensor N; Ambu; Ballerup, Denmark), with a 20 mm inter-electrode spacing. The differential electrode pairs were placed 1-cm distally from the midpoint between the C7 of the spinal column and the acromion, and the ground electrodes were placed on the acromion. The electrodes were connected with pre-amplifiers wires to a battery-powered portable data logger (Biomonitor ME6000; Mega Electronics Ltd.; Kuopio, Finland).

2.3.3. Subjective ratings: Borg RPE, Omni RPE and Borg CR10

Diagram

Description automatically generatedBorg RPE and Omni RPE scales were used as subjective measures of overall effort exerted by the workers, and Borg CR10 scale, asking the participants questions such as “how tired does your right shoulder feel”, was used as a subjective measure of local discomfort, particularly the tiredness (cansado in Spanish) they felt at each specific body part at the moment. Borg RPE scale, ranged from 6 to 20, was accompanied by verbal anchors from “no exertion” at 6 to “maximal exertion” at 20. Borg CR10 was also accompanied by verbal anchors from “not tired” at 0 to “severely tired” at 10. The Spanish version of Borg RPE and Borg CR10 were previously validated in the field (Thamsuwan et al., 2019). In addition, the Omni RPE with pictures of human wearing an apple bag were included (Figure 1). All self-report survey instruments were administered individually to participants by fluent Spanish speaking team members. The participant could view the questions while the team member read them aloud.

**Figure 1.** Omni RPE used in this study.

The measurement time points of the effort surveys were:

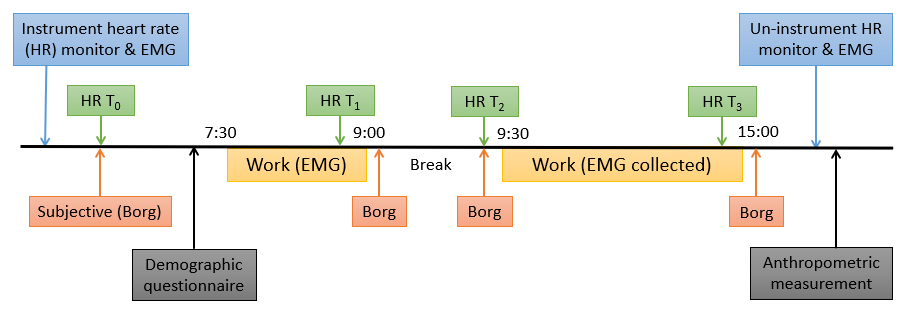
T0: before starting the work shift (15-minute heart rate measurement)

T1: after working for 150 minutes since the beginning of the work shift (10-minute heart rate measurement)

T2: after taking a break for 30 minutes, immediately after the 150-minute work period (10-minute heart rate measurement)

T3: at the end of 8-hour work shift (10-minute heart rate measurement)

These measurement time points are illustrated in a diagram as shown in Figure 2.



**Figure 2.** Study design showing the measurement time points for each measure.

2.4. Data processing

2.4.1. Metabolic load: percent of heart rate reserve

Raw heart rate data were filtered using a 5-point moving median to eliminate measurement artifacts. Then the mean of filtered heart rate for each period of interest, i.e. corresponding to the effort survey, were extracted. The time periods of interest for heart rates (T0, T1, T2 and T3) are also presented in the Figure 2. Note that T0 and T2 were the exact match between the time of subjective measurement. Meanwhile, T1 and T3 for the heart rate measures were during work period just right before the break rather than the heart rate while the participants were not working and answering the questionnaires.

The metabolic load was calculated in terms of the percent of heart rate reserve (% HRR) during the work period based on the equations (i), (ii) and (iii) where is the maximal heart rate of an individual, is the heart rate measured while the participant was sitting for 10 minutes before start working, is the heart rate measured while the participant was working, and is the resting heart rate of an individual.

Equation (i) (cite)

Equation (ii)

Equation (iii)

% HRR was square-root transformed to meet the assumption of normality and verified by Shapiro-Wilk test.

2.4.2. Muscle fatigue: EMG median power frequency

Raw EMG signal were filtered with a 20-450 Hz bandpass filter. Then errors and artifacts in EMG data were diagnosed using principal component analysis of several parameters including the percentiles of EMG amplitudes, and mean and median power frequencies, and then removed as described in the previous study (Thamsuwan & Johnson, 2022). By converting a time domain signal into a frequency domain, median power frequency (MPF) of the EMG was calculated for every 10 minutes. Then we conducted a linear regression of MPF on time for each trapezius side and each individual subject based on the equation (iv).

Equation (iv)

The slope of the time factor () from the equation (iv), which represented an increase or decrease in MPF over the work period, and excluding the break, as indicated in the diagram in the Figure 2, was used in the analysis to identify the association between muscle fatigue and the changes over time in the subject-reported local discomfort.

2.4.3. Subjective ratings: Borg RPE, Omni RPE and Borg CR10

Unlike the previous study recommending the calibration to the maximum value of the scale (Spielholz, 2006), the effort surveys including Borg RPE, Omni RPE and Borg CR10 scales at the specific time point were analyzed in terms of the increase or decrease as compared to the values at the beginning of the work shift (T0) to make the data interpretable.

2.5. Statistical analysis

The relationship between direct and self-reported measures were investigated for both overall and local levels. For the overall effort or full body exertion, correlations between % HRR and Borg RPE, and correlations between % HRR and Omni RPE were calculated. For the local discomfort or muscle fatigue, correlations between muscle fatigue (EMG MPF) and Borg CR10 were calculated.

Initially, Pearson’s correlations between the subjective and direct measures were calculated. Then linear regressions were conducted to adjust for known confounders; that is, the harvesting method and the time of measurement for the overall exertion, and the harvesting method and the side of trapezius (dominant and non-dominant) for the local discomfort. Additionally, between the two subjective measures of overall effort, i.e. Borg RPE and Omni RPE, Spearman’s correlations were used as the non-parametric tests for their relationship.

Moreover, these measures were evaluated for the effect by harvesting method and work period. The effects on the % HRR were tested using ANOVA and the effects on the Borg RPE, Omni RPE and Borg CR10 were tested using the Kruskal-Wallis tests.

The level of statistical significance was set at 0.95; that is, we have a 95% confidence to reject the null hypothesis or 5% probability of making an error of rejecting the null hypothesis while it was true. All the statistical analysis was conducted using R programming language. Particularly, the ‘lm’ function was used to run a linear regression to find correlation coefficients of the relationship between parameters and the ‘anova’ function was used for extracting the significant levels of the effect. Additionally, for the nonparametric tests to show the effect of harvesting method and measurement time point on the subjective measures, the ‘dunn.test’ package was used for post hoc pairwise comparisons using rank sums. All the graphics were made using the ‘ggplot2’ package.

3. Results

3.1. Sociodemographic characteristics of the respondents

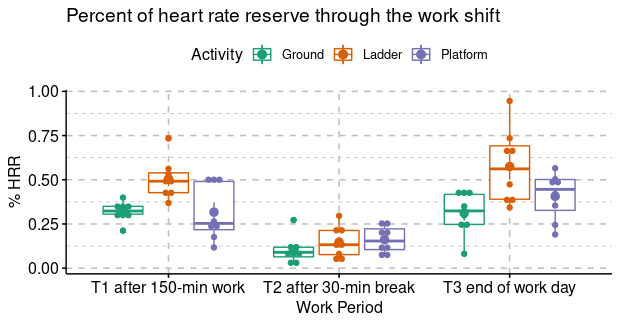
Twenty-four Hispanic male apple pickers participated in the study. Despite our effort to include both genders in the participant recruitment, we could not find female volunteers to participate in the study since most workers were men. The participants’ ages were on average 28.4 years (range 18-47 years). Their experience as farmworkers harvesting tree fruits in the United States were on average 3.4 years (range 1-14 years).

3.2. Overall effort: % HRR as metabolic load, Borg RPE and Omni RPE

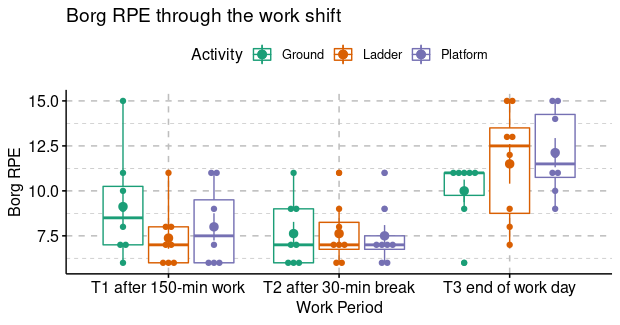
Chart, histogram

Description automatically generatedThe calculated % HRR was not normally distributed according to the p-value of 0.013 in the Shapiro-Wilk test for normality. After the % HRR was square-root transformed, the data became normally distributed, i.e., p-value of 0.48 in the normality test. Figure 3 shows the histograms and the QQ-plots of data before and after the transformation.

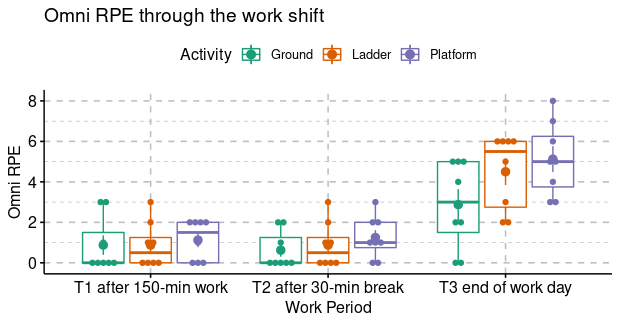
**Figure 3.** Histograms and Q-Q plots of the %HRR before and after square-root transformed.

The metabolic load, i.e. % HRR, among each group of workers at each time of measurement is shown in Figure 4. In general, % HRR values were between 0.15 and 0.75 after the participants had worked for 150 minutes (T1). Then the % HRR significantly dropped after a 30-minute break (T2) and increased again at the end of the work shift (T3) (p-value < 0.0001). Overall, the % HRRs among the Ladder group were higher than the % HRR among the Ground and Platform workers (Tukey HSD p-value = 0.0001 for the comparison between the Ladder and Ground workers, and 0.009 for the comparison between the Ladder and Platform workers).

**Figure 4.** % HRR measured among each group of workers at each work period (n = 8 for each group).

As shown in Figure 5, relative to the Borg RPE ratings collected at the beginning of the work break (T0), there were no difference between the ratings collected at the beginning of the first break (T1) and after 30 minutes of rest (T2). The Borg RPE ratings collected at end of the work shift (T3) were significantly greater than those measured at the beginning of the first break (T1) and those measured after the 30-minute rest (T2) (Dunn’s test p-values = 0.0007 and 0.0001). Nevertheless, the Borg RPE was not significantly different across the harvesting methods (Dunn’s test p-value = 0.09).

**Figure 5.** Borg RPE, a measure of overall exertion reported by each group of workers at each work period (n = 8 for each group).

The difference in Omni RPE from the beginning of the work shift were also greater at the end of the work shift (T3) as compared to the other time (p-value < 0.0001) as shown in Figure 6. Comparing across workers’ groups, the Omni RPE was significantly higher among the Ground workers as compared to the Platform and Ladder workers (Dunn’s test p-values = 0.04 and 0.02).

**Figure 6.** Omni RPE, a measure of overall exertion, reported by each group of workers at each work period (n = 8 for each group).

Finally, Borg RPE and Omni RPE were found positively correlated with the Spearman’s correlation of 0.618.

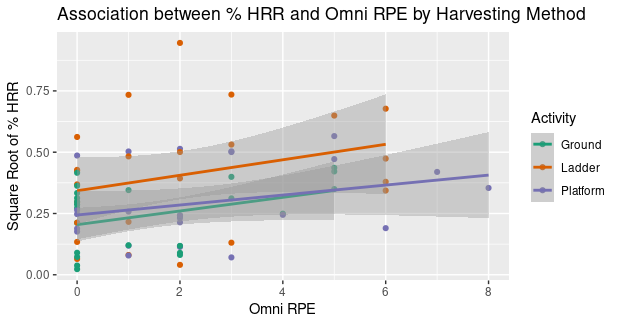
3.3. Association between metabolic load and subjective overall effort

Without adjusting for neither work period (T1, T2 and T3) nor harvesting method (Ground, Ladder and Platform), the correlation coefficient between the % HRR and the Borg RPE was insignificant (p-value = 0.23). In contrast, the correlation coefficient between the % HRR and the Omni RPE was positive (p-value = 0.006).

In addition, when adjusted for the work period and the harvesting method, which had significant effect on the % HRR, the regression coefficient between the % HRR and the Borg RPE became negative, with the p-value of 0.054. In the same way, the regression coefficient between the % HRR and the Omni RPE also became negative, with the p-value < 0.0001.

With the confounding effect, the analyses were further stratified by the harvesting method and by the work period. On one hand, when the analysis was stratified by the harvesting method and the effect of the work period was adjusted, correlations between the % HRR and the Borg RPE were no longer significant, meanwhile statistically significant or almost significant correlations between the % HRR and the Omni RPE were found in all the worker groups (p-value = 0.014, 0.015 and 0.086 for Ground, Ladder and Platform groups, respectively) as shown in Figure 7. On the other hand, when stratified by the work period, i.e. the time point of measurement, the correlations between the % HRR and the Borg RPE difference were found statistically significant only at T2 (p-value = 0.0041) as shown in Figure 8. Meanwhile, none of the correlation coefficients between the % HRR and the Omni RPE were statistically significant.

Chart, scatter chart

Description automatically generated**Figure 6.** The statistically significant association between % HRR and Omni RPE in all groups when stratifying by harvesting method and combining all time points.

**Figure 7.** The statistically significant association between % HRR and Borg RPE after a 30-minute break, combining all harvesting methods.

3.4. Local discomfort: EMG MPF as muscle fatigue and Borg CR10

The EMG MPF in 10-minute windows of all participants had a bi-modal distribution (Figure 8) due to the difference between dominant and non-dominant muscle sides and the difference across harvesting methods as well as across the time of the day. These differences were adjusted using linear regression. After removing, i.e. adjusting for, the effects of muscle side () and the effects of the participants () who were different across the harvesting methods, the slope of the time variable () was used for analysis to find correlation between EMG MPF and Borg CR10. Figure 9 shows the distribution of the while the Shapiro-Wilk test indicated that the parameter could be considered as normally distributed (p-value = 0.059).

Chart, histogram

Description automatically generated

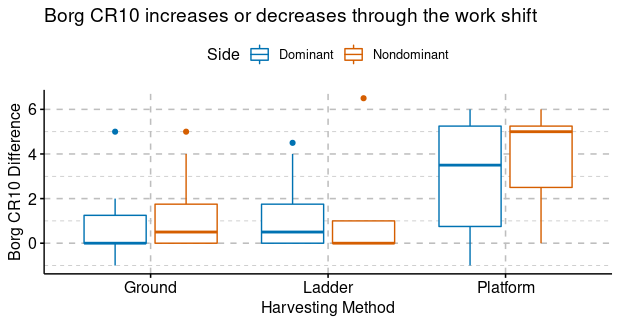
**Figure 8.** The histogram showing bi-modal distribution of EMG median power frequency.

Chart, histogram

Description automatically generated

Figure 9. The histogram of the EMG median power frequency regression slope (b\_Time)

Muscle fatigue, i.e. the EMG MPF, decreased over time as shown by the negative slope ( = -0.0056) in the regression equation (iv) (p-value < 0.0001). This is in accordance with the results of muscle activity from the previous study (Thamsuwan & Johnson, 2022).

The Borg CR10 difference between the beginning and the end of work shift by each harvesting method is shown in Figure 10. The increases in Borg CR10 from the beginning to the end of the work shift was higher in the Platform group than in the Ground and Ladder groups. According to the Kruskal-Wallis tests for nonparametric data, the harvesting method had a statistically significant effect on the Borg CR10 increase over time (p-value = 0.013) but the side of trapezius did not (p-value = 0.51).

**Figure 10.** Borg CR10 difference between the beginning and the end of work shift by harvesting method and muscle side.

3.5. Association between muscle fatigue and subjective local discomfort

Chart, line chart

Description automatically generatedRegardless of whether we accounted for the muscle side, work period or harvesting method, there was no correlation between the slope in the equation (iv), i.e., the increase or decrease of EMG mean power frequency over time, and the Borg CR10 difference between the beginning and the end of the work shift. That is, there was no relationship between the EMG mean power frequency representing muscle fatigue and the Borg CR10 increases or decreases over the work period. Figure 11 shows the scatter plot between the on the y-axis and the Borg CR10 difference between the start and the end of work shift on the x-axis.

**Figure 11.** The scatter plot of Borg CR10 difference on x-axis and the on y-axis. All the correlations were nearly zeros and the confidence intervals were large.

4. Discussions

4.1. Interpretations and implications from negative or no correlation

This study found significant correlations between the direct and subjective measures of overall effort when the analysis adjusted for the harvesting method and the time of measurement; however, the directions of corrections were contradictory for Borg RPE and Omni RPE. The negative correlations between Borg RPE and % HRR suggested that the Borg RPE may not be useful as subjective measures for this population whereas the positive correlations between Omni RPE and % HRR suggested that the Omni RPE could predict the outcomes of % HRR.

When stratifying by harvesting method, the significance level was still strong only when using Omni RPE but not for Borg RPE. This phenomenon was evident across all the worker groups. This finding on stronger correlations suggested that the Omni RPE with the pictures of apple harvesters may be more useful than the Borg RPE with only verbal anchors on the scale from 6 to 20, which might not be comprehensible for farmworkers.

When stratifying by the time in the work shift, the statistically significant relationship between Borg RPE and % HRR was found at T2, i.e. after the lunch break, but not at T1 and T3, i.e. after morning and afternoon work sessions. That is, when the effort was relatively light, the subjective Borg RPE responses could be meaningful. Otherwise, for the heavy workload, the use of Borg RPE could not discern the effort levels. In other words, Borg RPE was not interpretable in this population and might not be used to assess a recovery from the rest in place of the direct measurement. Additionally, when stratifying by the time in the work shift, the relationship between Omni RPE and % HRR became statistically insignificant. This finding contradicts with the stratification by harvesting methods. As a result, the Omni RPE with the pictures of apple harvesters carrying an apple bag in different phases of tiredness (Figure 1) may still not be robust and should be improved.

There was no significant correlation between the direct and subjective measures of local discomfort. In other words, Borg CR10 scales at local body parts, particularly the shoulders, were not representative for the muscle fatigue as directly measured and characterized by EMG. Thus, the use of Borg CR-10 to assess local body fatigue is not recommended for this population.

Despite being translated and adapted to the culture, the subjective effort surveys, namely Omni RPE, Borg RPE and Borg CR10, may not be suitable for ergonomic assessment among Hispanic fruit pickers, especially in this case when the physical workload were extreme. Therefore, they could not fully replace the directly-measured outcomes like metabolic load or muscle fatigue.

4.2. Comparisons to previous studies and directions for future work

This study indicated the unsuitability of subjective scales for ergonomic assessment in fruit harvesting tasks undertaken by the Hispanic migrant workers, as compared to the uses of cardiac measures and the muscle fatigue of trapezius. However, the findings from this study that the subjective scales were more sensitive to light workload (T2) is opposite to a previous work; that is, while Borg scale could detect a major change in task difficulty, it was found unsuitable to identify minor changes of task difficulty and discomfort, in contrast to the capability of EMG at biceps brachii and triceps brachii (Shafti et al., 2016). On a contrary, Borg CR10 was found to be more sensitive to a light load than EMG MPF did; that is, in a laboratory study using the EMG MPF of trapezius and Borg CR10 during arm abduction, there was a strong negative correlation between the MPF and the CR10 scores at heavy load while the MPF did not change at low load (Öberg et al., 1994). Above all, even though this study found increases over time in both EMG MPF and Borg CR10, we did not address whether the direct measure of muscle fatigue like EMG or the subjective discomfort responses like Borg scales could provide a better ergonomic assessment.

Newly developed subjective rating scales like Omni RPE may be used for certain contexts. This subjective measurement could be used as a complement of their corresponding direct measurement rather than as standalone tools. Even though a previous study found that the Omni RPE in a pictorial face format was correlated with heart rate and respiratory rate in both men and women (Huang & Chiou, 2013), Omni RPE alone was not distinguishable across different walking and running loads in children whereas the oxygen consumption did (Kung et al., 2020). Alternatively, we propose a combination of farmworkers carrying apple bag and faces representing emotions in the Omni RPE

4.3. Study limitations

A number of systematic biases in this study should be mentioned. Firstly, the presence of researchers in the field might have altered the way the participants worked; thus, the directly-measured outcomes on muscle fatigue or metabolic load may be affected. Secondly, the administration of the Borg and Omni questionnaires could have interrupted the workers’ lunch break. It is possible that some workers could have answered the questions quickly rather than attentively.

Moreover, there was a limitation associated with the heart rate measurement. In the ideal situation, a resting heart rate should be measured in a recumbent position, but this was not possible in the orchard setting. However, in this study, heart rates were measured during a quiet sitting position prior to the work shift, and then the measured values were subtracted by 10 as per the equation (ii) similarly to the previous work (Thamsuwan et al., 2019); in other words, the resting heart rate was obtained by approximation rather than exact measurement.

Furthermore, there were challenges in EMG measurement in the field due to the perspiration of workers and the physical contact between electrodes and the apple bag strap or the ladder. Anomalies in EMG data were detected and removed with a new algorithm to retain the muscle activity signal (Thamsuwan & Johnson, 2022) but there were still some data loss. Future studies should instead find a way to detect the anomalies in real time during the data collection, which could prevent data loss more effectively as compared to logging the data to examine later at the end of the work shift like in this study.

Above all, these limitations could be anticipated prior to the study. On one hand, part of the systematic bias during the data collection were not able to fully eliminated due to the nature of the fieldwork. That is, firstly, researchers were present and indirectly influencing how the farmworkers behave and, secondly, the quiet sitting period for the resting heart rate measurement was difficult to be ensured. On the other hand, the data loss due to EMG connection was mitigated by the development of the algorithms to remove errors and retain only meaningful signals.

5. Conclusion

This study examined whether there was a relationship between subjective and direct measures of overall cardiovascular load and local muscle fatigue among Hispanic migrant farmworkers harvesting apples in North America. Borg RPE and Borg CR10 were translated into Spanish, and Omni RPE with pictures were created for this specific population. The Borg RPE and Omni RPE results were compared to metabolic load derived from heart rate data, which represented overall physical exertion. This study found some strong negative correlations between the direct and subjective measures: % HRR and Borg RPE after the workers took a short break but not after they performed hard work; and % HRR and Omni RPE when stratifying by harvesting methods. The Borg CR10, which was expected to indicate local discomfort, was compared to the muscle fatigue as characterized by EMG at trapezius. Unlike the results of the correlations between the RPE’s and the cardiovascular load, there was no significant correlation between the Borg CR10 and the EMG. All things considered, for the Hispanic farmworkers population, direct measures of ergonomic exposures could not be replaced by subjective measures according to this study. If only the subjective measures are possible in the field assessment, the results will have to be interpreted with cautions. If necessary, Omni RPE, i.e., the scales accompanied with pictures, would be a better option than Borg RPE or Borg CR-10 which only have verbal anchors and were developed during different activities performed by different population.

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