# Association between subjective effort surveys and objective directly-measured workloads in Hispanic migrant farmworkers

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Abstract

## 1. Introduction

### 1.1 Objective and subjective measures in ergonomic assessment

Field ergonomic assessment can be done in both objective and subjective manners; in other words, the exposure to occupational ergonomic risk could be evaluated through direct measurement using sensors as well as through participant’s subjective ratings.

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). Due to difficulties in measuring oxygen consumption outside laboratories, numerous studies estimated the MET using other measures 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 the occupational health area, 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 of this technique is that heart rate varies by age, sex, BMI and fitness (Hiilloskorpi et al., 1999). Thus, percent heart rate reserve (% HRR), which adjusts for the maximum heart rate and resting heart rate and which has a proven relationship with the oxygen uptake (Cunha et al., 2011), could instead be used as a predictor of MET. In actual farms, % HRR was used for evaluating an assistive device for digging task (Dewi & Komatsuzaki, 2018).

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) was proven to be an indicator for muscle fatigue (Luttmann et al., 2000). Nowadays, it is feasible to apply EMG techniques in field settings. EMG has already been used for evaluating physical work demand, and comparing new and traditional tools. In actual agricultural fields, EMG was applied to assess on-farm exposures to biomechanical risk factors (Fethke et al., 2020), and to evaluate the efficacy of a rotary milking parlour as compared to herringbone and parallel ones (Douphrate et al., 2017), mobile orchard platform against ladder uses in the tree fruit industry (Thamsuwan & Johnson, 2022) and potential uses of an exoskeleton or a personal assistive suit in some manual farm tasks (Dewi & Komatsuzaki, 2018; Thamsuwan et al., 2020).

With regards to the subjective measures of effort, fatigue and discomfort, several different scales have been developed and validated. 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; 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). 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 has a verbal description for each numeric value, another commonly-used and validated scale called Omni RPE includes pictorial descriptors in a specific context. Omni RPE is, thus, more generalizable (Lea et al., 2022). In addition, the Omni RPE in the pictorial face format was found correlated with heart rate and respiratory rate in both men and women (Huang & Chiou, 2013).

Relationship between subjective and objective measures has 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). In a similar way, correlations were found between the EMG MPF of lumbar muscle and the Borg CR10 results during repetitive and prolong 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) also found the 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.

Despite plenty of laboratory validation of subjective scales, studies on association between objective and subjective ergonomic measures are lacking in the field settings. It is unclear whether subjective ratings validated in the controlled environment could be apply to the ergonomic assessment in the field.

### 1.2 Context of Hispanic migrant farmworkers in North America

Migrant farmworkers… population that are difficult to access…

### 1.3 Objectives of this study

The primary objective of this study was to find the relationships between the objective and subjective evaluation of the exertion at the overall level as well as at local body parts in the context of the Hispanic migrant farmworkers in the United States. Specifically, this study aimed to determine 1.) the correlation between metabolic, i.e. cardiovascular, load and the RPE scales, and 2.) the correlation between muscle fatigue measured through EMG and the local CR10 scales.

## 2. Methods

### 2.1 Participants

Twenty-four Hispanic male seasonal apple pickers participated in the study. The participants’ ages were on average 28.4 years (range 18-47 years). Their experience as farmworkers in the United States were on average 3.4 years (range 1-14 years). The participants were equally divided into three groups to perform different harvesting methods: 1.) picking apples at the lower level of the trees up to their reach distance overhead, denoted as “Ground”, 2.) using a ladder to pick apples from the full trees, denoted as “Ladder”, and 3.) picking apples at the upper level of the trees while standing on the semi-automated mobile orchard platform, denoted as “Platform”. All the participants worked in the same schedule from 7:00 to 15:30 with a break during 9:30-10:00.

The protocols for participant recruitment and data collection were approved by the university’s Human Subject’s Division Institutional Review Board. All the participants provided their informed consent.

### 2.2 Data collection

#### 2.2.1 Heart rate monitors

Participants’ heart rate in beats per minute were collected at 1 Hz throughout a full work day using a heart monitor *(Polar RS100CX; Polar Electro Inc., Lake Success, NY)*.

#### 2.2.2 Electromyography

Local muscle activity signal was collected from both left and right trapezius muscles at 1,000 Hz using single-use disposable pre-gelled electrodes (Blue Sensor N; Ambu; Ballerup, Denmark) connected with pre-amplifiers wires to a battery-powered portable data logger (Biomonitor ME6000; Mega Electronics Ltd.; Kuopio, Finland).

#### 2.2.3 Subjective ratings: Borg RPE, Omni RPE and Borg CR10

Borg RPE and Omni RPE were used as subjective measures of overall effort while Borg CR10 was used as a subjective measure of local discomfort. The Borg RPE and Borg CR10 translated into Spanish were previously validated in the field (O. Thamsuwan et al., 2019). In addition, the Omni RPE with pictures of human wearing an apple bag were included (Figure 1).

The measurement time points of the effort surveys were:

* T0: right before start the work shift
* T1: after working for 150 minutes since the beginning of the work shift
* T2: after taking a break for 30 minutes, immediately after the 150-minute work period
* T3: at the end of 8-hour work shift

### 2.3 Data processing

#### 2.3.1 Metabolic load: percent of heart rate reserve

Raw heart rate data were filtered using a 5-point moving median to eliminate measurement artifacts. The mean heart rate for each period of interest, i.e. corresponding to the effort survey, were extracted.

The metabolic load was calculated in terms of the percent of heart rate reserve 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 before start working, is the heart rate measured while the participant was working, and is the resting heart rate of an individual.

Equation (i)

Equation (ii)

Equation (iii)

%HRR was square-root transformed to meet the assumption of normality and verified by Shapiro-Wilk test. Figure X shows the histograms and Q-Q plots of the data before and after the transformation.

#### 2.3.2 Muscle fatigue: EMG median power frequency

Raw EMG signal were filtered with a 20-450 Hz bandpass filter. By converting a time domain signal into frequency domain, median power frequency 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 to the question (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, was used in the analysis to identify the association between muscle fatigue and the changes over time in the subject-reported local discomfort.

#### 2.3.3 Effort survey

The effort surveys including Borg RPE, Omni RPE and Borg CR10 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.

### 2.4 Statistical analysis

For the overall effort or full body exertion, we calculated a correlation between %HRR and Borg RPE, and a correlation between %HRR and Omni RPE. For the local discomfort or muscle fatigue, we calculated a correlation between muscle fatigue (EMG MPF) and Borg CR10.

Initially, Pearson’s correlations between the subjective and objective measures were calculated. Then we conducted linear regressions 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.

As the dataset was fairly small, that is, 24 participants for overall effort and 20 participants for local discomfort due to EMG data lost, we set the level of statistical significance at 0.90. All the statistical analysis was conducted using R programming language.

## 3. Results

### 3.1 Overall effort: %HRR as metabolic load, Borg RPE and Omni RPE

Based on the Shapiro-Wilk test, initial %HRR was not normally distributed (p = 0.013). After the %HRR was square-root transformed, the data became normally distributed (p = 0.48). Figure 2 shows the histograms and the QQ-plots of data before and after the transformation.

The metabolic load, i.e. %HRR, among each group of workers at each time of measurement is shown in Figure 3. In general, %HRR was between 0.15 and 0.75 after the participants had worked for 90 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). According to Figure 5, the %HRR in the Ladder workers were higher than the %HRR in the Ground and Platform groups at T1 and T3.

The increases in Borg RPE from the beginning of the work shift were greater at the end of the work shift (T3) as compared to the other time (p-value < 0.0001) as shown in Figure 4. However, the increases in Borg RPE over time were not significantly different across the harvesting methods.

The increases 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 5. Moreover, at T3, the increases in Omni RPE from the beginning of the shift were significantly smaller in the Ground workers than in the Ladder and Platform groups (p-value = 0.05).

### 3.2 Association between objective 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 difference was 0.152 with the statistically insignificant p-value of 0.20. Similarly, the correlation coefficient between the %HRR and the Omni RPE difference was 0.169 also with the statistically insignificant p-value of 0.16.

However, when adjusted for the work period and the harvesting method, which had significant effect on the %HRR, the correlation coefficient between the %HRR and the Borg RPE difference became -0.0063 with the p-value of 0.048. In the same way, the correlation coefficient between the %HRR and the Omni RPE difference became -0.0127 with the p-value of 0.027.

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, significant correlations between the %HRR and the Borg RPE difference were found only in the Ground and Ladder groups (p-values = 0.072 and 0.044, respectively), and a significant correlation between the %HRR and the Omni RPE difference was found only in the Ladder group (p-value = 0.078).

On the other hand, when stratified by the work period, i.e. the time point of measurement, Figures 6 and 7 showed the negative correlations between the objective and subjective measures in all time points of measurement. Nevertheless, the correlations between the %HRR and the Borg RPE difference were found statistically significant only at T1 and T3 (both p-values were 0.087). Meanwhile, none of the correlation coefficients between the %HRR and the Omni RPE were statistically significant. Note that the reason might be due to the fact that stratification reduced the sample size and, consequently, there was not enough power to detect a significant correlation in each group.

### 3.3 Local discomfort: EMG MPF as muscle fatigue and Borg CR10

The EMG MDF 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 MDF and Borg CR10. Figure 9 shows the distribution of the while the Shapiro-Wilk test indicated that the data could be normally distributed (p-value = 0.059).

Muscle fatigue, i.e. the EMG MPF, reduced over time as shown by the negative slope ( = -0.0056) in the regression equation (iv) (p-value < 0.0001). This is in accordance to 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).

### 3.4 Association between objective muscle fatigue and subjective local discomfort

Regardless of whether we accounted for the muscle side, work period or harvesting method, there was no correlation between the slope in the equation (iv) and the Borg CR10 difference. 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.

## 4. Discussions

### 4.1 Implications from negative or no correlation

There were negative correlations between the objective and subjective measures of overall effort.

There was no correlation between the objective and subjective measures of local discomfort.

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 this population. Therefore, they should not replace the objective direct-measured ergonomic assessment.

### 4.2 Comparisons to previous studies

While Borg scale could detect a major change in task difficulty, it was found unsuitable to identify minor changes of tasks 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 light load than EMG MPF; 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).

Subjective ratings should be used with objective measurement. In a previous study, Omni RPE alone was not distinguishable across different in walking and running loads in children but the oxygen consumption did (Kung et al., 2020).

### 4.3 Study limitations

### 4.4 Potential applications in other industries

Other industries where work occurs outdoor or in a harsh environment…

In construction, EMG-based muscle fatigue assessment in both time and frequency domains was already proven feasible (Jebelli & Lee, 2019). Moreover, wearable EMG and IMU 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 but no significant patterns was found among the small number of participants (Østensvik et al., 2008).

## 5. Conclusion

Test

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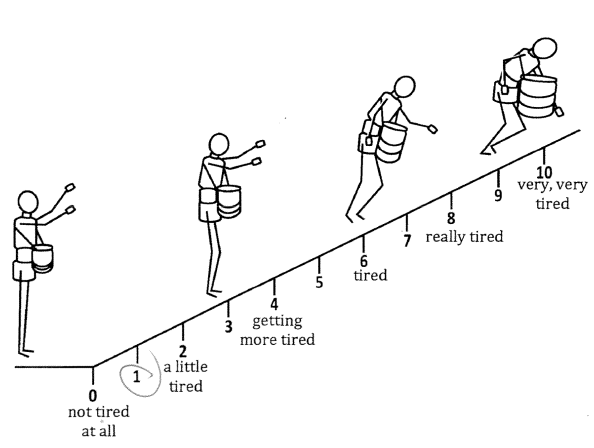


Figure 1. Omni RPE used in this study

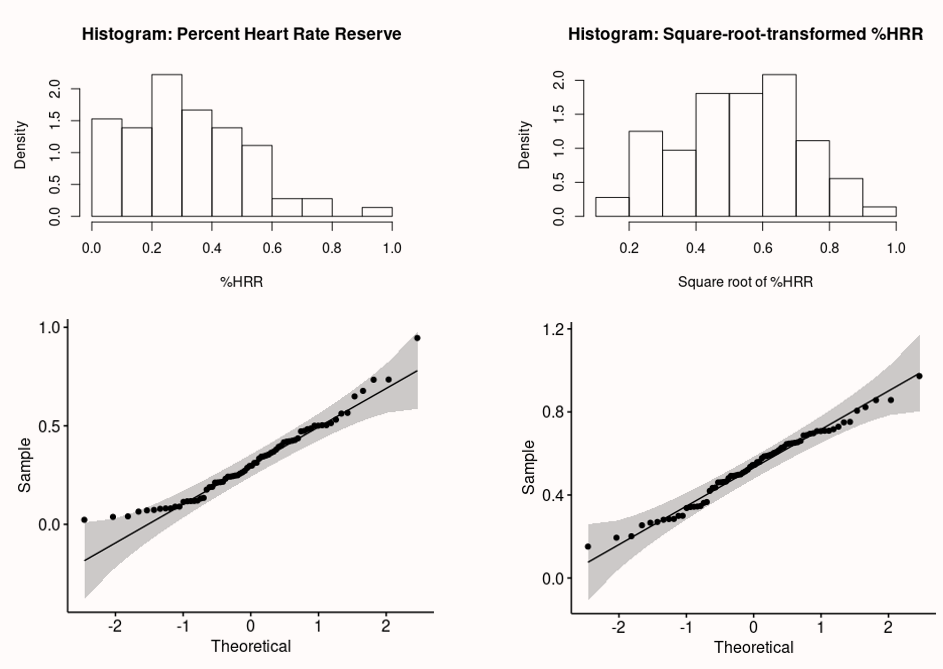


Figure 2. Histograms and Q-Q plots of the %HRR before and after square-root transformed

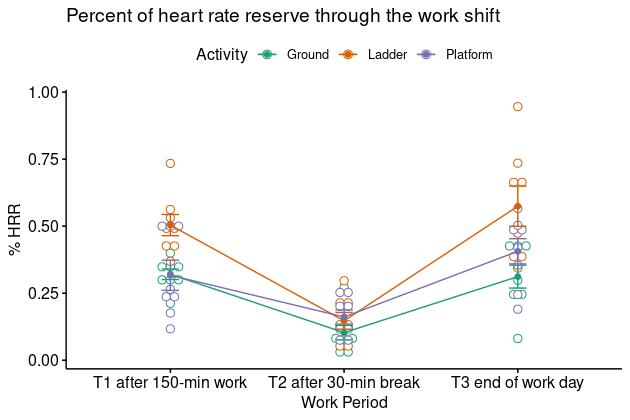


Figure 3. %HRR measured among each group of workers at each work period

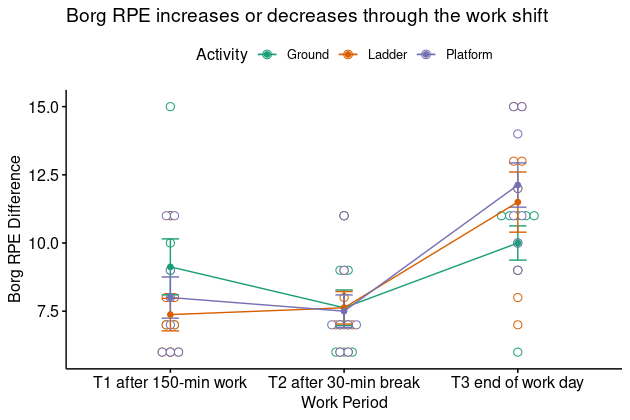


Figure 4. The difference in Borg RPE from the beginning of work reported by each group of workers at each work period

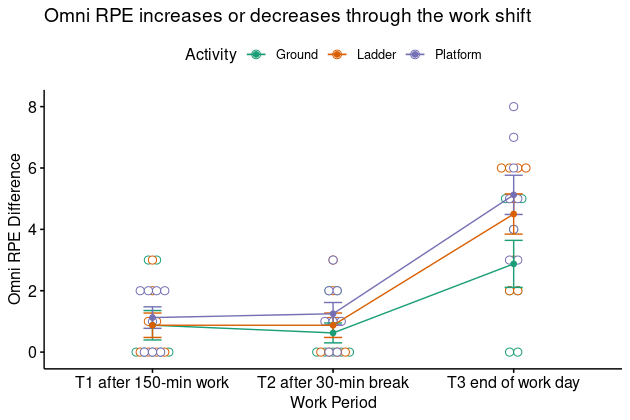


Figure 5. The difference in Omni RPE from the beginning of work reported by each group of workers at each work period

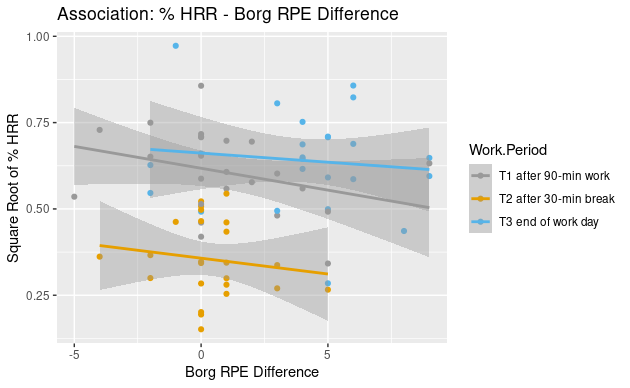


Figure 6. The association between %HRR and Borg RPE difference from the beginning of work shift

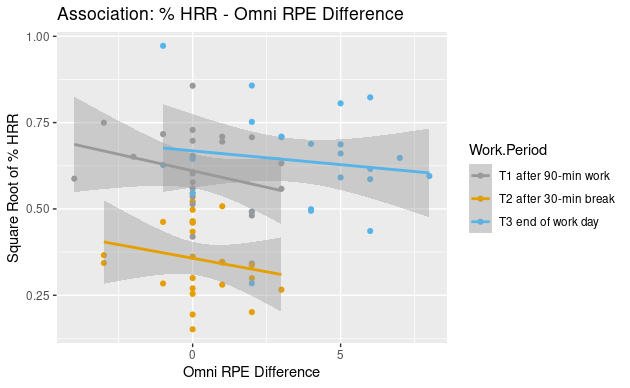


Figure 7. The association between %HRR and Omni RPE difference from the beginning of work shift

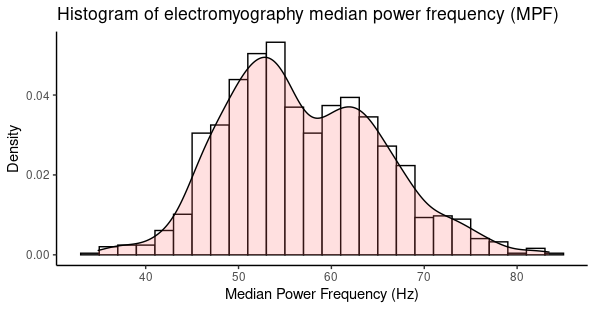


Figure 8. The histogram showing bi-modal distribution of EMG median power frequency

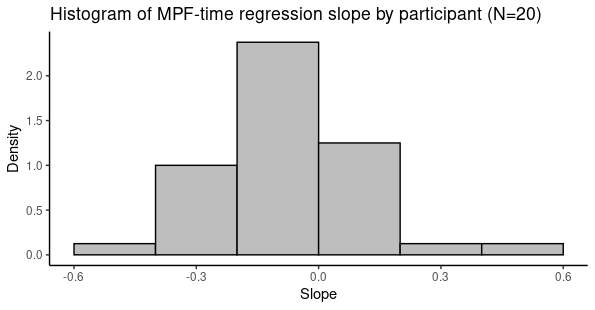


Figure 9. The histogram of the EMG median power frequency regression slope ()

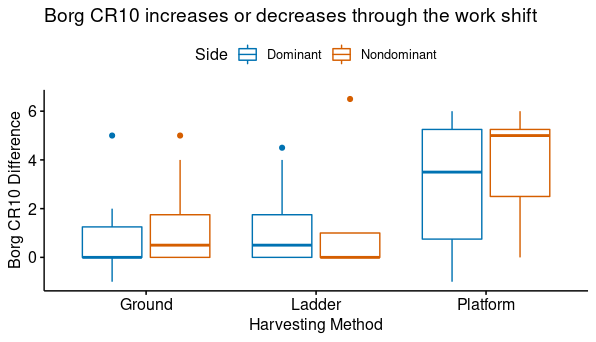


Figure 10. Borg CR10 difference between the beginning and the end of work shift by harvesting method and muscle side

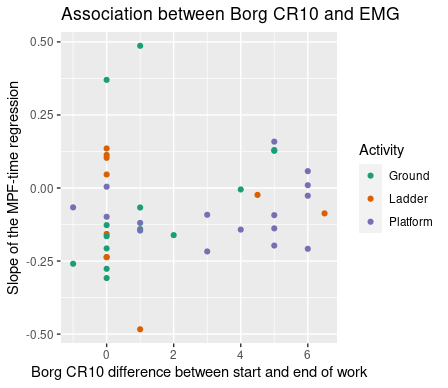


Figure 11. The scatter plot of Borg CR10 difference on x-axis and the on y-axis