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Biomechanics analysis in coffee harvesting activity in Colombia

Análisis biomecánico en la actividad de recolección café en Colombia

Sebastián Peláez-Gómez [1,2], Luis Rodríguez-Cheu [3]

[1] Industrial Engineer, Politécnico Grancolombiano, Colombia. Email: spelaez@poligran.edu.co
Orcid: 0000-0002-3399-9135
[2] Pontificia Universidad Javeriana, Colombia. Email: pelaezs@javeriana.edu.co
[3] Escuela Colombiana de Ingeniería Julio Garavito, Colombia. Email: luis.rodriguez@escuelaing.edu.co
Orcid: 0000-0003-3667-1167

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Abstract

During this case study, the risks of posture, strength and repetition associated with the activity of manual coffee harvesting were evaluated. The sample studied was 26 volunteers who participated in the completion of a Nordic questionnaire, 10 of these were evaluated using observational, and postural tools and 8 people participated in the biomechanical evaluation of postural and muscular load using electromyography and inertial. Seven muscles and two body segments of the upper limbs were evaluated. The goal was to assess the working conditions of coffee manual harvesting considering ergonomics. The results of the discomforts were manifested in the Nordic questionnaire where it was evident that throughout a workday harvesting coffee, the discomfort focuses on the back, lower back, hands, and feet. In the muscle load evaluation was identified that the muscles with the highest activity were the Extensor, Flexor Carpi Ulnar and the trapezius. On average, their muscular activity was 20% of their maximum volunteer contraction when performing the statistical analysis. -Tics showed a greater correlation in muscle activation between the Carpi Radial Extender and the trapezius. In the postural evaluation of the body segments from the coffee harvesters evaluated, it was identified that they only maintain between 10% and 20% in neutral ranges, so they are always in risky conditions. In conclusion, it is necessary to carry out interventions in the Colombian coffee sector not only because of these evaluated conditions but also for the conditions in their work environment.

Keywords: mechanic demand; electromyography; manual harvesting; ergonomics.

Resumen

Durante este caso de estudio se evaluaron los riesgos de postura, fuerza y repetición asociados a la actividad de recolección manual de café. La población estudiada fue de 26 personas que participaron voluntariamente para la realización de un cuestionario nórdico, 10 de estos se les evaluó por medio de herramientas posturales observacionales y 8 personas que se ofrecieron para la evaluación de carga postural y muscular evaluadas con electromiografía e inerciales respectivamente. Se evaluaron 7 músculos y 2 segmentos corporales de los miembros superiores. El objetivo fue realizar una evaluación de las condiciones de trabajo de los recolectores de café haciendo uso de herramientas de ergonomía. En los resultados de las incomodidades manifestadas en el cuestionario nórdico por los trabajadores se evidenció que a lo largo de una jornada de trabajo recolectan-do café la incomodidad reportada se centra en las partes del cuerpo en espalda, espalda baja, manos y pies. Respecto a la carga muscular esta fue evaluada y se identificó que los músculos con mayor actividad son el Extensor y Flexor Carpi Ulnar y el trapecio en promedio, para todos los sujetos se acercan a un 20% de la actividad muscular, al realizar el análisis estadístico se evidenció mayor correlación

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en la activación muscular entre el Extensor Carpi Radial y el trapecio. En la evaluación de los segmentos corporales se identificó que mantienen solamente entre el 10% y 20% en rangos neutros, por lo que siempre se encuentran en condiciones de riesgo. Como conclusión es necesario realizar intervenciones en el sector cafetero colombiano no solamente por estas condiciones evaluadas sino por condiciones del entorno de trabajo.

Palabras clave: demanda mecánica; electromiografía; recolección manual; ergonomía.

1. Introduction

Internationally the agriculture sector is one with the highest risk to exposure, according to researchers [1, 2], aspects like the ergonomics risks and the musculoskeletal disorder (MSD) take relevance and importance to improve those risks. Diary the agriculture workers are exposed to musculoskeletal risks in their activities [1, 3]. Likewise, according to the Bureau Labor of Statistics (BLS), in 2014 33,8 cases of 10.000 workers were related to MSD in the agriculture sector one of the highest compared with other economic sectors [4].

For the Colombian republic state, the labor minister reported that in the first place of occupational diseases are the agriculture, hunting, and forestry sector. Also, the disease rate for the sector reported by the minister was 373.28 per 100.000 workers [5].

The coffee sector in Colombia represents 10% of the Gross Domestic Product (GDP) in the agricultural sector [6], allowing to select this activity to carry out the research, with an emphasis on the task of coffee harvesting. Regarding the agricultural activities of sowing, cultivation, and harvesting, different investigations have found factors that can be precursors of musculoskeletal disorders.

At the national literature review, few studies were related to agriculture. The researches fields regarding worker conditions have been investigated only in floriculture and coffee. In the floricultural activity, the research made an evaluation where it was carried out taking Nordic questionnaires, evaluation by video, and direct measurements in terms of postures and muscle activity (electromyography (EMG) and electro goniometry (EGM)), design of a prototype cutting tool and its evaluation in real conditions [7, 8, 9, 10]. Otherwise in the coffee activity what was done refers to improvements in crop mechanization and the different tools to help to increase the crop harvesting activity [11].

In the international literature review, the research around the agriculture sector allowed us to identify some factors that generate discomfort or fatigue in body limbs, like the back, hands and feet. These factors where identified like repetitive movements, uncomfortable postures when they were doing the work, hyper-flexion and hyper-extension of the limbs, lifting loads greater than 25 kg among others. They could recognize these factors using different kinds of ergonomic tools like, discomfort questionnaires or Nordic questionnaires, analysis using observational tools and direct measurement [12, 3, 13, 14, 15, 16, 17, 18, 19, 20].

Similar studies were performed in Brazil, for example, De Lima and colleagues analyzed by EMG the lumbar paravertebral musculature and abdominal rectus muscle of rural workers during coffee harvesting with the use of a manual machine. To do that, they compared the performance of different footrest bases. [21]. In addition, Alves and colleagues use a multivariate statistical methodology to provide plausible and interpretable results to diagnose the most influential body postures for each worker in coffee crops evaluated by OWAS [22]. Finally, Barbosa and colleagues assess the physical workload of farm coffee workers from southern Minas Gerais considering variables like heart rate, and postural combinations measured by OWAS [23].

For this case of study, some of the ergonomics tools used by national and international researchers were selected to develop the assessment for the manual coffee harvesting activity. According to the above and the working conditions of the coffee pickers, the following question arises: what is the muscle-skeletal risk for manual coffee harvesters?

2. Material and methods

2.1. Participants

26 volunteers coffee harvesters were involved to participate in the study. The harvesters worked in farms on Marsella, Risaralda, Colombia. The demographic information is shown in the next Table 1 Demographic information.

2.2. Research design

The goal was to assess the working conditions for coffee manual harvesting, considering the discomforts or pain of the workers using a discomfort questionnaire base on the Nordic Questionnaire that was applied to the volunteers [12], [24]. An observational analysis using the Rapid Upper Limb Assessment (RULA) and Ovako

Working Analysis (OWAS) and finally a postural and muscular analysis using electromyography and Inertial Motion Units (IMU's) for 20 minutes to determine the biomechanics of 8 volunteers. Also, an informed consent was shared and read to them, and they voluntarily participated in the measurement. [12, 8].

Table 1. Demographic information

Variable	Men	Female
Average time doing similar activities	21,07	12,18
Maximum time doing similar activities	62	30
Minimum time doing similar activities	0,04	0,08
Right-handed	14	4
Left-handed	7	1
Average age	38,2 (SD, 16,9)	28,9 (SD, 7,7)
Average weight	64,29 (SD, 7,51)	63,63 (SD, 5,83)
Average height	167,06 (SD, 6,39)	158 (SD, 10,27)

Source: authors.

2.3. Body conditions versus the task

The self-report discomfort questionnaire was applied. The questionnaire consists of information extraction associated with the discomfort of harvest task in 16 parts of the body. For each of these, the participant indicated the level of discomfort he felt at that time on a scale of 0 to 10 (Borg Scale). An adaptation of the Nordic Musculoskeletal Questionnaire of section 2 was used, the interview was oriented to determine the discomfort in a specific part of the body. A silhouette of the body was used to help the volunteer identify the specific part of the body with any discomfort, considering the education level of the volunteers. Additionally, a video recording of the activity was used to apply the RULA and OWAS analysis (Figure 1).

2.4. Physical workload

An assessment of posture and muscle activity was used. The postural activity required IMU's (MTw Awinda) on the evaluated arm and back joints. Muscle activity was evaluated using seven surface EMG sensors (SX230, BioMetrics Ltd., Uk) that were in the muscle belly of the following muscles and calibrated using the equipment software: Carpi Radial Extender (ECR), Carpu Ulnar Extender (ECU), Flexor Carpi Radial (FCR), Flexor Carpi Ulnar (FCU), Biceps (B), Deltoid (D), Trapezius. The preparation of the skin together with the placement of the sensors and the measurements were made following standardized norms (SENIAM). The EMG signal was filtered with a bandwidth of 20-460 Hz: noise less than 5uV and input impedance greater than 1,000Ω. The registered activity for each volunteer was the first activity in the workday, for 20 minutes to determine the biomechanics of 8 volunteers. Each volunteer was measured once.

Figure 1. RULA and OWAS postures examples. Source: authors.

2.5. Analysis of results

For the analysis of the self-discomfort questionnaire, a percentage was assigned if the proportion of the results exceeded a range. They were assigned a level and color, as shown in the following Table 2 Discomfort level classification.

Table 2. Discomfort level classification

Color assign	Discomfort greater than 3	Level
Green	Less than 10%	Low
Yellow	Between 15% and less than 25%	Medium
Red	Greater than 25%	High

Source: authors.

In addition, the electromyography surface signal was codified in ASCII and it processes using algorithms in the software Matlab R2013a (EE.UU.); the root means signal (RMS) was estimated using a 200 ms moving window and normalized with the maximum voluntary contractions (MVC) registered for each muscle [8]; percentile 10, 50 and 90 (static level, average level, and dynamic level) was estimated in the amplitude probability distribution function (APDF).

For the analysis of postures, the signal processed by the team's datalink software (Biometrics Ltd., Uk) was encoded in ASCII (after the filter), specifically units of measure in degrees. For the angles of interest, the data was processed and analyzed in SPSS 23.0 where the body segments were identified they were outside the neutral ranges.

3. Results

3.1. Physical workload

According to the self-discomfort analysis, in general, the highest body parts with discomfort was hands, wrist, neck, feet, upper back, and low back. The genders analysis showed that in females is higher the discomfort in hands, back, and feet. On the other hand, for males it was the head, shoulder, hands, wrist, upper back, knees, and feet, as it showed in Figure 2 Self-discomfort results.

3.2. Postural behavior of subjects applying observational tools

The analysis of the RULA showed that the group of members with the highest score was in group B. This group corresponds to the neck, trunk, and legs. Group A, which correspond to the arm, forearm, and wrist, always maintained the same score level. The following Table 3 RULA Score is a summary of the 32 analyzed positions.

According to the RULA results, 72% of the postures were in risks 3 and 4, showing that it is necessary to carry out a depth study and correct the posture as soon as possible.

The OWAS result, in Table 4 OWAS score showed that hat the postures in the most affected parts of the body were the back and legs and were the ones that contribute most to the level of risk.

As the same happens in the RULA results, the posture of the arms is constant in the activity.

Table 3. RULA Score

Posture	Group A (1-9)	Group B (1-9)	RULA Score (1-7)	Risk level (1-4)
2	3	8	7	4
3	5	6	7	4
1	4	6	6	3
1	3	7	6	3
1	4	6	6	3
1	4	6	6	3
1	4	6	6	3
2	4	8	6	3
2	4	6	6	3
2	4	6	6	3
2	4	6	6	3
2	4	6	6	3
2	4	6	6	3
2	4	6	6	3
2	4	9	6	3
3	4	8	6	3
3	4	6	6	3
3	4	9	6	3
3	4	6	6	3
3	4	6	6	3
3	4	7	6	3
5	4	5	5	3
6	4	7	6	3
1	4	4	4	2
1	4	4	4	2
1	4	4	4	2
1	4	4	4	2
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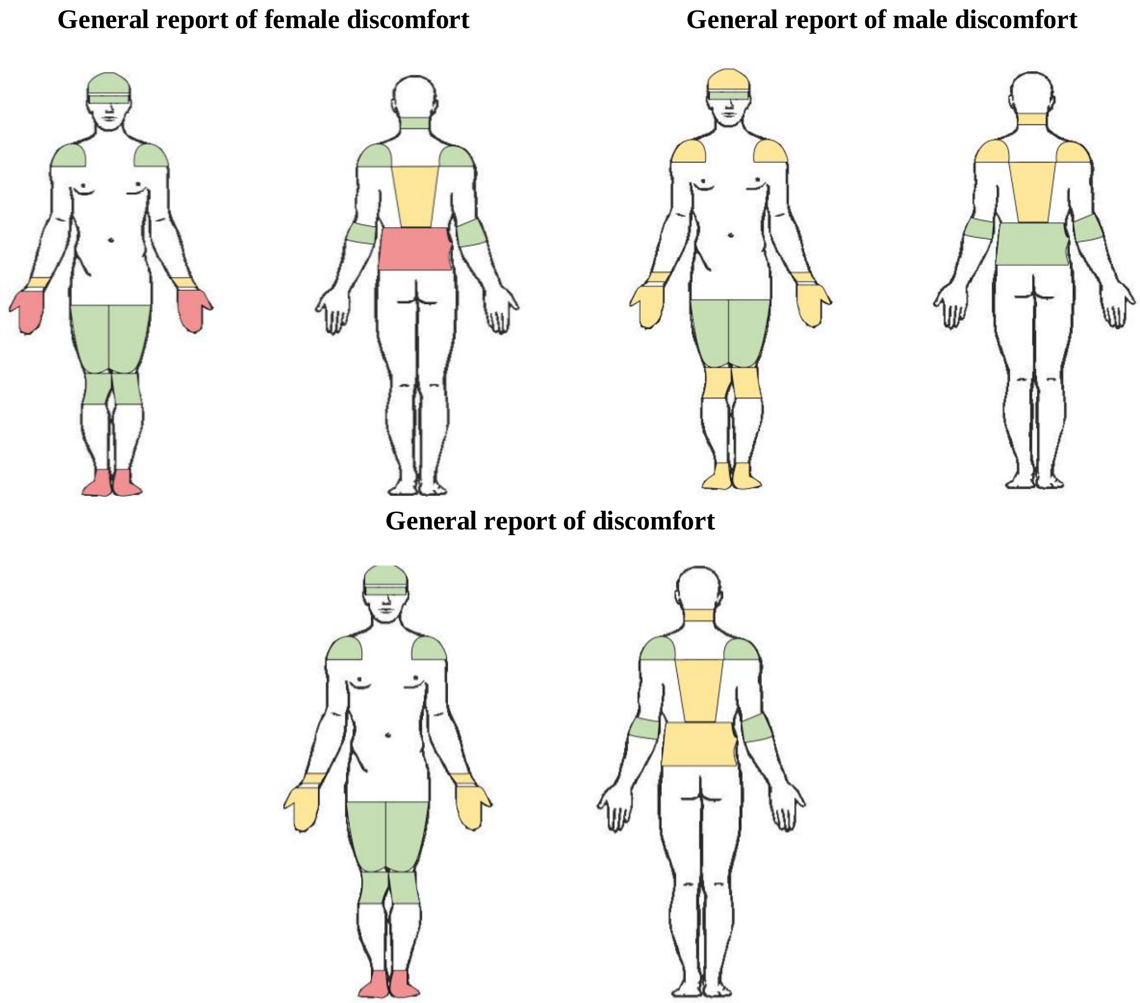
3	4	4	4	2
3	3	3	3	2
4	4	3	3	2



Color assigned	Percentage of the population reporting discomfort greater than or equal to 4
Green	0 % -10 %
Yellow	10 % - 25 %
Red	more than 25%

Figure 2. Self-discomfort results. Source: authors.

According to Table 4 OWAS score, 65% of the posture were in risk level 2 and 3, that means that the postures associated with risk level 3 have harmful effects on the musculoskeletal system and that therefore corrective actions are required as soon as possible. Regarding risk level 2 postures, there is an existing possibility of causing damage to the musculoskeletal system and the changes may be gradual and corrective soon.

3.3. Postural direct assessment results

The results of the two segments (Back, and arm) were presented below. To obtain the neutral postural angles, the angles proposed by the RULA and the REBA for these body segments were taken as a base.

As a result of the lateral deviations, it was evidenced that the coffee pickers remain around 82% of the time outside the neutral range. As shown in Figure 3 Back lateral deviation and Table 5 Percentage of the time in back lateral deviation postures presented.

Regarding the flexion and extension of the back, as a result, it was obtained that they perform a back extension 28% of the time, while in 38% of the time they remain flexed outside of a neutral range, as shown in Table 6 Percentage of the time in back flexion and extension postures and Figure 4 back flexion and extension angles ranges.

Table 4. OWAS score

Posture	Back	Arms	Legs	Load	Risk
3	2	1	5	1	3
3	2	3	3	1	3
3	2	3	3	1	3
1	2	1	2	1	2
2	2	1	2	1	2
2	2	1	2	1	2
3	4	1	2	1	2
1	1	1	4	1	2
4	1	1	5	1	2
5	2	1	2	1	2
6	2	2	3	1	2
1	2	1	6	1	2
2	2	1	2	1	2
1	2	1	2	1	2
2	2	1	3	1	2
1	2	1	2	1	2
2	2	1	3	1	2
3	4	1	3	1	2
2	2	1	3	1	2
2	2	1	3	1	2
2	1	1	3	1	1
1	1	1	2	1	1
1	1	1	3	1	1
2	1	1	2	1	1
3	1	3	2	1	1
3	1	3	2	1	1
3	1	1	3	1	1
1	1	2	3	1	1
2	1	1	3	1	1
1	1	3	3	1	1
1	1	3	3	1	1

Table 5. Percentage of the time in back lateral deviation postures

Back	
Desv. Neutral	16%
Left Dev. Greater than 40°	41%
Right Dev. Greater than 40°	42%

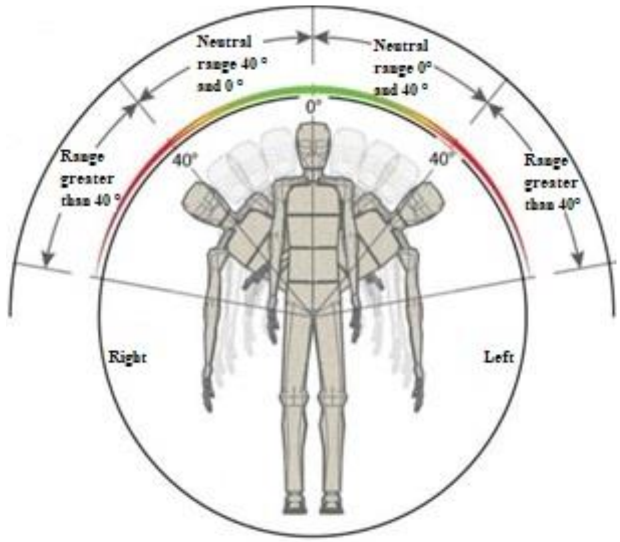


Figure 3. Back lateral deviation. Source: authors.

Table 6. Percentage of the time in back flexion and extension postures

Back	
0° - Flexion 20°	33%
Flexion greater than 20° to 60°	36%
Flexion greater than 60°	2%
Extension	28%

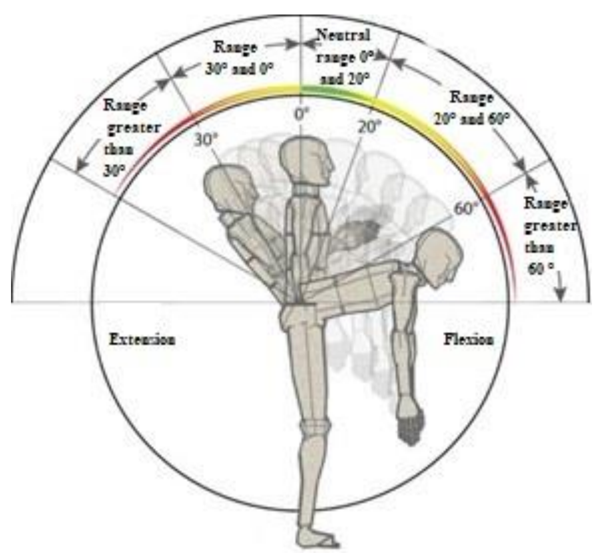


Figure 4. Back flexion and extension angles ranges. Source: authors.

The previous result could cause damage to the intervertebral discs, and that can lead to muscle problems such as low back pain and back pain.

For the postural analysis of the arm, it was obtained that most of the time they remain in a normal posture. It should be noted that the neutral angle is quite permissive, but it is necessary to review it in conjunction with its adduction and abduction, a result that will be presented in Table 7 and Figure 5.

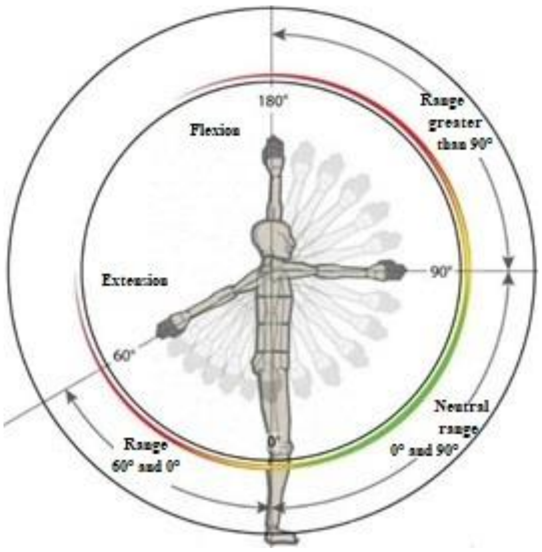


Figure 5. Arm flexion and extension angles ranges. Source: authors.

Table 7. Percentage of the time in arm flexion and extension postures

Arm	
Neutral	83%
Extension greater than 0° and Flexion greater than 90°	16%

Finally, in Figure 6 and Table 8, because of abductions and adductions, it was found that more than 60% of the time people remain in abductions, as evidenced by the table and illustration presented for this joint movement. Staying in these ranges, added with the extension flexion of the arm, could generate shoulder joint problems due to wear over a long period of time and that could cause problems in the rotator cuff.

Table 8. Percentage of the time in arm abduction and adduction postures

Arm	
Neutral range 10° Adduction and 90° Abduction	15%
Adduction 10° to 60°	30%
Adduction greater than 60°	2%
Abductions greater than 90°	52%

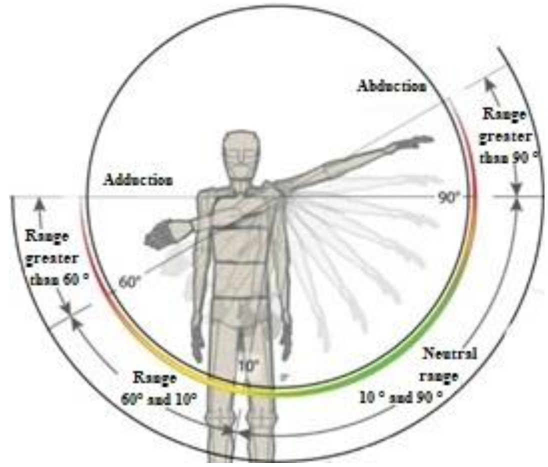


Figure 6. Arm abduction and adduction angles ranges. Source: authors.

3.4. Upper limb muscular activity results

For the analysis of results, signal processing was performed: rectification and smoothing by applying RMS (root mean square) with a 200 ms window. The values were normalized concerning the MVC of each muscle. Subsequently, an analysis of the APDF normalized EMG signals were used and the 10th, 50th (see Figure 7), and 90th percentiles were calculated as it is shown in Table 9.

During the Electromyography data processing, it was necessary to remove the generated “outliers”, considered as noise since these are higher values than those recorded by the team and compared with the maximum voluntary contraction. Considering the above, the following results were obtained (see Table 9).

According to the results previously presented in Table 9 EMG descriptive results, it is evident that some of the muscles with greater activity are the Extensor and Flexor Carpi Ulnar. On average, for all subjects, they approach 20% of muscle activity. Considering that the coffee harvest is carried out in season during the 8 hours, its exposure can be considered at risk for these muscles.

On the other hand, it was evidenced that the trapezius due to its postural condition is found with a great muscular activity where the average of the analyzed subjects reached 20%, a condition that reflects a great impact on this muscle.

Table 9. EMG descriptive results

Descriptive results							
	ER	EU	FR	FU	Biceps	Deltoids	Trapezius
Mean	14,4%	19,4%	13,0%	19,0%	9,9%	11,9%	20,6%
Variance	1,1%	1,7%	1,5%	1,7%	0,8%	1,2%	2,3%
Standard Deviation	10,4%	13,2%	12,3%	12,9%	9,1%	10,9%	15,1%
Minimum	0,1%	0,2%	0,1%	0,2%	0,1%	0,2%	0,2%
Maximum	60,0%	100,0%	144,6%	60,0%	128,6%	60,0%	60,0%
P 10	3,4%	5,1%	2,1%	4,5%	1,4%	2,0%	3,4%
P 50	12,1%	16,7%	10,0%	16,2%	7,3%	8,3%	17,4%
P 90	28,7%	36,8%	26,8%	37,9%	22,0%	26,8%	43,6%

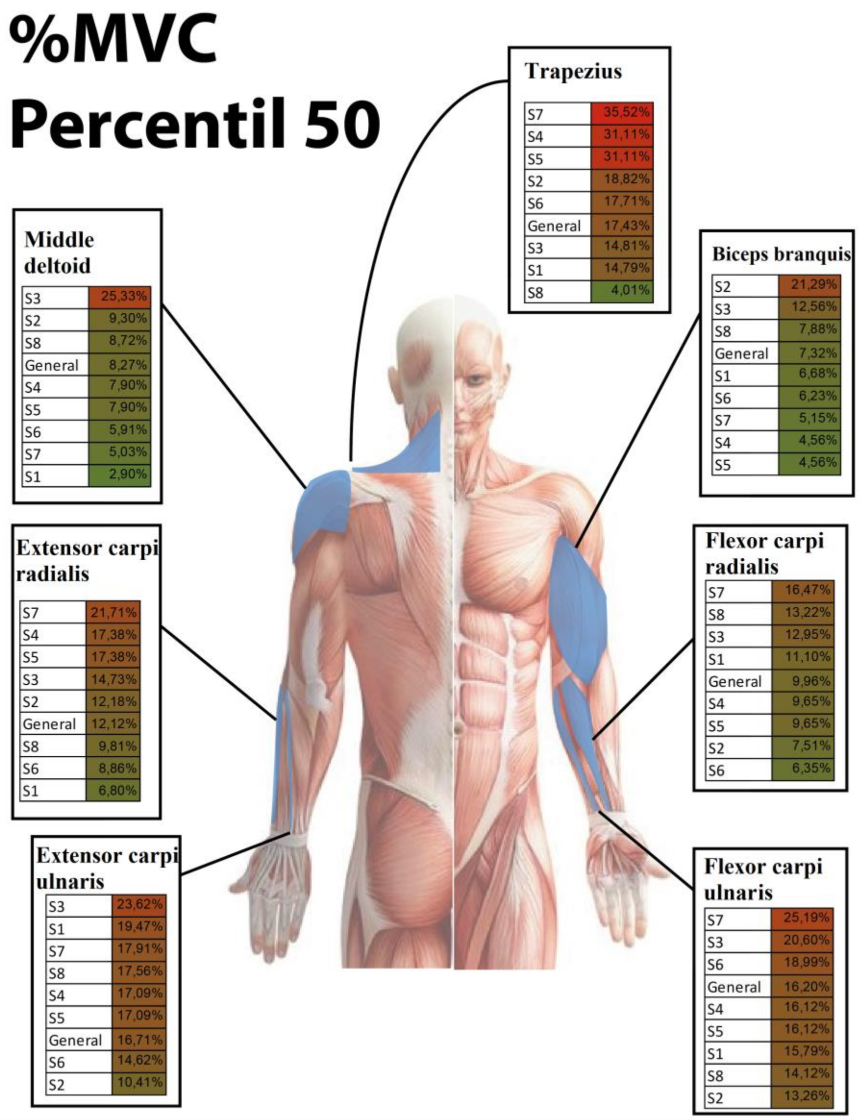


Figure 7. MVC percentage per subject. Source: authors.

3.5. Principals Components Analysis between muscles

An additional analysis of the information was made using principal components analysis. The result is as follows:

The data were processed to calculate the own values, where it is evident that 87.76% of the data is explained with two components, but it should be noted that the first component is more important than the others, as it is shown in Figure 8 PCA distribution.

```
> #valores propios
> inertia.dudi(acp)
Inertia information:
Call: inertia.dudi(x = acp)

Decomposition of total inert
     inertia     cum   cum(%)
Ax1 5.40268    5.403   77.18
Ax2 0.74051    6.143   87.76
Ax3 0.42232    6.566   93.79
Ax4 0.25071    6.816   97.37
Ax5 0.09613    6.912   98.75
Ax6 0.05558    6.968   99.54
Ax7 0.03205    7.000  100.00
```

In the review of the own vectors, it was evident two factors of the group the muscles. In the first group, trapezius and forearm muscles were grouped and in the other group were the biceps and the deltoids like was showed in Table 10.

In the circular graph, a greater correlation was evident between the trapezius, ECR, ECU, FCU, and FCR muscles, as the component with the major quantity of muscles.

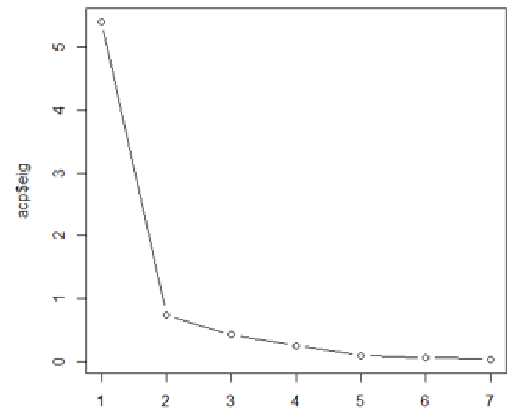


Figure 8. PCA distribution. Source: authors.

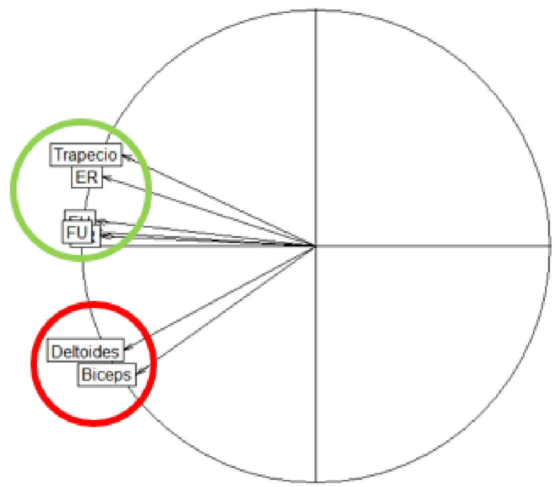


Figure 9. PCA distribution graph.

4. Conclusions

In this study, a methodology based on biomechanical analysis was used to determine what were the working conditions in the Colombian coffee sector; specifically, in manual coffee harvesting; and have a starting point for future research.

Table 10. PCA distribution vectors

	Distribution vectors						
	Cs1	Cs2	Cs3	Cs4	Cs5	Cs6	Cs7
ER	-0,39	0,34	0,27	-0,09	0,65	0,40	-0,27
EU	-0,40	0,12	-0,36	-0,30	-0,02	-0,06	-0,48
FR	-0,39	0,05	-0,52	0,28	0,29	-0,06	0,63
FU	-0,41	0,69	-0,28	0,12	-0,60	0,58	-0,21
Biceps	-0,33	-0,63	0,26	0,57	0,09	-0,15	-0,25
Deltoids	-0,35	-0,51	0,19	-0,68	-0,05	0,10	0,32
Trapezius	0,36	0,45	0,58	0,13	-0,36	-0,31	0,30

Likewise, in this study, it was possible to approach the identification of risk factors in the manual harvesting of coffee from the perspective of the worker and making measurements of the muscular activity and the angular segments studied. The probability of the risk in the Extensor muscle Carpi Ulnar increase and reduce the use of this muscle to reduce the latent risk.

The third level measurement in terms of muscle activation in the Flexor carpi ulnaris and extensor carpi ulnaris and the reflex trapezius is a great activation of the muscle superior to 15% of the muscular activation. The above can generate possible problems of musculoskeletal disorders MSD, especially in the forearm muscles and in the neck zone muscles.

The percentage of time in exposure to back extension and flexion in non-neutral angles greater than 60% of the time can cause problems in the lumbar vertebrae, whereby they can be produced lumbago´s or herniated discs.

Finally, in the case of the arm, when performing abduction movements over long or repetitive times could generate problems with the shoulder joint, leading to a possible rotator cuff problem.

For future research, it is recommended to analyze the lower limbs including the back using surface electromyography and including more inertial sensors to determine the impact of loading the coffee collecting bucket on the manual harvesting activity of coffee. For futures studies, it is necessary to evaluate different topographic conditions of coffee harvesting because different parts of the body will be affected. Some limitations were, that access to different kinds of coffee crops is difficult it is necessary to come up to the different coffee association to get the farmer information and the workers in the coffee usually are temporary workers it makes difficult to get the same volunteer during of the data recollection.

Acknowledgment

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