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EVALUATION OF HUMAN POSTURES DURING WORK IN COFFEE CROPS IN THE SOUTHERN REGION OF MINAS GERAIS

Allan Alves Fernandes[1], Renato Ribeiro de Lima[2], Marcelo Ângelo Cirillo[3], Marco Antônio Gomes Barbosa[4] & Elayne Penha Veiga[5]

1 - PhD student in Statistics and Agricultural Experimentation, UFLA/Lavras-MG, alanfernandes538@yahoo.com.br

2 - PhD in Statistics and Agricultural Experimentation, Professor of UFLA/Lavras-MG, rrlima@des.ufla.br

3 - PhD in Statistics and Agricultural Experimentation, Professor of UFLA/Lavras-MG, macufla@des.ufla.br

4 - PhD in Agricultural Engineering , Professor of UFLA/Lavras-MG, marco.fisioedu@def.ufla.br

5 - PhD in Statistics and Agricultural Experimentation, UFLA/Lavras-MG, elayne@posgrad.ufla.br

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ABSTRACT

Brazil is the largest coffee producer in the world and Minas Gerais is the state responsible for 51.14% of this production, corresponding to 1.55 million tons of beans. In this context, contribution from family farming is significant. The aim of this work was to use a multivariate statistical methodology to provide plausible and interpretable results to diagnose the most influential body postures for each worker in coffee crops. Twelve workers were observed during a period of one hour in different tasks. Greater variability of body posture was shown during herbicide application on sloping ground. Despite body postural variability among workers during the tasks, some body postures, like 131 and 231, stood out. The proposed methodology allowed to identify the most influential body postures for each worker in an ergonomic point of view, and to aware the workers about the importance of adequate body postures during the tasks of coffee harvesting and post harvesting to avoid health damage.

Palavras-chave:
análise multivariada
cafeicultura
combinações posturais
ergonomia

AVALIAÇÃO DAS COMBINAÇÕES POSTURAIS DE TRABALHO EM LAVOURAS DE CAFÉ DO SUL DE MINAS GERAIS UTILIZANDO COMPONENTES PRINCIPAIS

RESUMO

O Brasil é o maior produtor mundial de café e o estado de Minas Gerais é responsável por 51,14% da produção nacional, o que corresponde a cerca de 1,55 milhões de toneladas. Nesse contexto, a agricultura familiar contribui de forma significativa. Diante disso, objetivou-se nesta pesquisa, utilizar uma técnica estatística multivariada, de modo a proporcionar resultados plausíveis de serem interpretados, como um diagnóstico de posturas corporais mais frequentes inerentes a cada trabalhador na prática da atividade cafeeira. Para tanto, foram observados 12 trabalhadores, durante uma hora, em diferentes atividades. A atividade que apresentou maior variabilidade de combinações posturais foi a aplicação de herbicida no morro. Apesar da variabilidade postural entre os trabalhadores durante a prática das atividades, algumas posturas, como a 131 e 231 se destacaram. A metodologia proposta permitiu identificar as posturas mais influentes para cada trabalhador durante as atividades, e do ponto de vista ergonômico, permite ao trabalhador se conscientizar sobre a importância de posturas adequadas na realização das atividades de colheita e pós-colheita do café, evitando danos à saúde.

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INTRODUCTION

Agribusiness plays a major role in Brazilian economy because 33% of gross domestic product and 42% of total exports comes through this activity. The sector employs 17.7 million of workers, which corresponds to 37% of the total number of full-time workers (BRASIL, 2016).

Brazil is the largest coffee producer in the world, responsible for 33% of world production, therefore the importance of coffee to the Brazilian economy is undeniable. Coffee plantations occupy, in total, an area of about 2 million of hectares and can produce 3.05 million of tons of coffee grains; the state of Minas Gerais, in particular, is responsible for 51.14% of this production, which represents 1.55 million of tons (IBGE, 2017).

The persistence of family farming in Brazil has been evidenced by many studies (NIEDERLE; FIALHO; CONTERATO, 2014; SCHNEIDER; CASSOL, 2014), hence the comprehension of ergonomics in this context is very important, since there can be a set of occupational risks with variable severity (BASTOS; BIFANO, 2017).

Ergonomics is a science responsible to configure, plan and adapt the work to the comfort and efficiency of people, considering the complaints that can arise from unsatisfactory conditions (DUL; WEERDMEESTER, 2004). Therefore, The Ergonomic Work Analysis (EWA) aims to adapt the activity to the worker by improving the tasks to be more practical, secure, and effective, and by minimizing health risks (FERREIRA, 2015).

Among the publications about the ergonomic aspect of labor in coffee crops, Silverstein et al. (2012) used ergonomic approach to improve the labor conditions in a coffee crop in Nicaragua, introducing a financial assistance instead of traditional basic food basket.

Methods are needed to classify the workload in an objective or subjective way, since the farming labor is non-repetitive and non-monotonous activity. In this sense, Abrahão et al. (2012) performed a study to characterize the workload done during the processing of six units of tomato with manual handling of charges in Campinas, São Paulo,. Furthermore, from an ergonomic point of view, Barbosa et al. (2014) highlighted the importance of alerting workers about their body postures during coffee harvesting and post harvesting in order to avoid health damages.

In this way, the aim of this work was to propose, from the observational study carried out, the use of multivariate statistical techniques that consider the original scale of data in line with Gini index and Lorenz curves to provide plausible and interpretable results, such as a diagnostic of most frequent body postures of each worker during coffee activity in coffee crops from southern Minas Gerais.

From an ergonomic point of view, the postural variation during any activity is beneficial because the workers can perform more joint movements and avoid repetitive movements and vicious body postures that can lead to injuries, drop in production and increase of accidents. Thereupon, this kind of study can help detect body postural lesions and can be a tool for researches seeking technological development associated with coffee production, in a way to improve the working condition, minimizing ergonomic risks and increasing the productivity.

MATERIAL AND METHODS

The data used come from an experiment performed by Barbosa (2013). The study was executed in the southeast Minas Gerais, in the city of Santo Antônio do Amparo. Twelve volunteer workers, chosen from seven small family properties of coffee producers, participated in this study and were properly informed about the aims and procedures to be taken; these workers were also allowed to abandon the study at any time, with no early notice of any kind needed. Cultivation, harvesting, post harvesting activities were analyzed and each one of these were composed by subtasks and operational tasks presented as follow:

a) Crop Handling: manual fertilization (empty bag displacement, bag stuffing, full bag displacement and manual fertilization); thinning (thinning); foliar fertilization (empty coastal pulverizer displacement, coastal pulverizer refueling, full coastal pulverizer displacement and application) and herbicide application (empty coastal pulverizer displacement, coastal pulverizer refueling, full coastal pulverizer displacement and application).
b) Harvest: harvest (canvas placement, manual harvest, canvas displacement, sieving, manual cleaning and bagging).
c) Post harvesting: drying on the ground (coffee gathering, canvas cover, canvas uncovering; and spreading) and storage (bagging, transport and bag conditioning).

Each one of the twelve workers was filmed for one hour performing the tasks of crop handling, harvesting and post harvesting, both in flat ground and sloping ground (10% or more slope). Working days in family agriculture can exceed twelve hours and the worker performs many different activities because the properties are small and, therefore, the coffee cultivated is not the only source of income. In this research, a pilot study was developed with three workers being filmed for one hour while executing the tasks and a one hour observation period was determined sufficient since this was the average time spent by workers to accomplish the tasks.

Therefore, the percentages of time for each worker were obtained at each subtask, as well as a predetermined body posture. For drying and storage subtasks, the workers only performed in flat ground.

The body postural protocol was adapted from OWAS (IIDA, 2005; MESSIAS; OKUNO, 2012; NWE et al., 2012). The OWAS method was developed to identify and evaluate inadequate body postures during the execution of a task and,

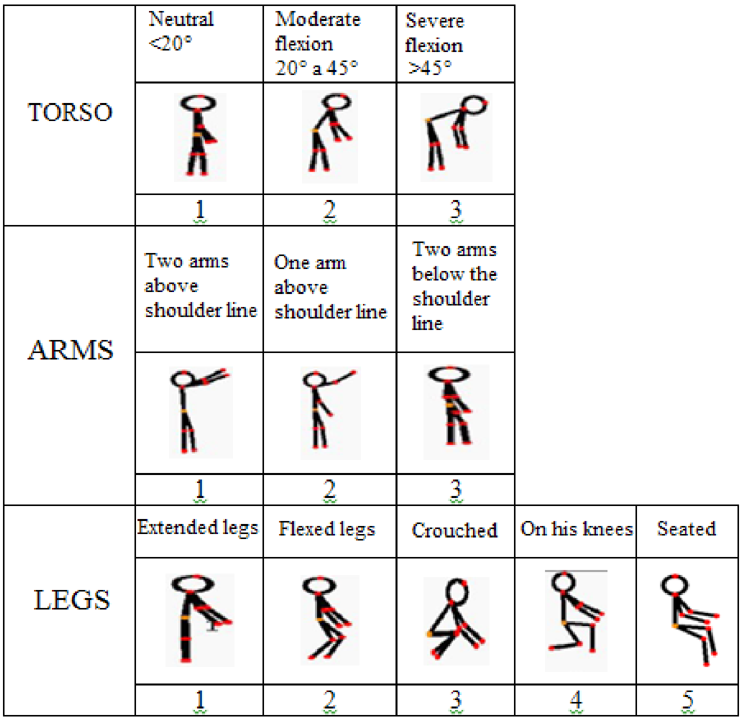

Figure 1. Postural protocol adopted.

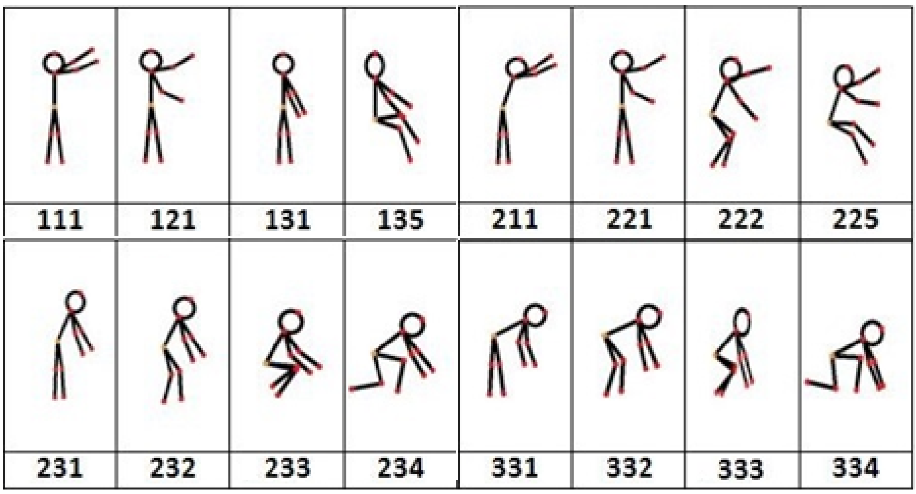

Figure 2. Postural combinations adopted by the workers.

initially, was applied only in construction area. Considering this, another goal of the pilot study was to include the postural characteristics of the workers in coffee crops. Few body postures considered as high ergonomic risk factors, i.e. a severe torsion of the main body, were not observed in a significant way during the tasks.

The Figures 1 and 2 show the protocol adopted and its combinations, respectively.

The data were analyzed with the methodology of principal component analysis through which twelve eigenvalues of variables correlation matrix were obtained and assimilated to the workers. It was possible, then, to obtain the principal components and the scores. Later, the contributions $c_i(j)$ (BÉNASSÉNI, 2005) were calculated to obtain the percentage of contribution that each body posture supplies to the variance of each one of 12 workers. For the *j*-th worker, the contribution $c_i(j)$ of the body posture for its variance can be defined as

$$c_i(j) = \frac{1}{n}\frac{z_{ij}^2}{\lambda_j} \times 100 \qquad (1)$$

where z_{ij} is the score value corresponding to the body posture of the worker, and λ_i corresponds to the eigenvalue.

The contribution $c_i(j)$ is the percentage of component variance explained by the body posture. If the variance concentrates in few body postures with high values of $c_i(j)$, the eigenvalue λ_j, corresponding to the worker, was considered to be very dependent on these body postures, that is, the worker spent most of time in this body posture. Otherwise, if none of the body postures had a significantly high value of $c_i(j)$, therefore λ_j is either insensitive to any other body posture or, in other cases, moderately sensitive to them, which means that the worker spent a short amount of time in this body posture (BÉNASSÉNI, 2005).

As for the contribution, $i = 1,2,\ldots,n, c_{(i)}(j)$ is considered to denote the contributions ($c_i(j)$) in ascending order. Thus, the percentage of variance of λ_j can be defined by explaining k body postures corresponding to k smaller values of $c_i(j)$ through the quation:

$$C_k(j) = \sum_{i=1}^{k} c_{(i)}(j) \qquad for\ k = 1,2,\ldots,n. \qquad (2)$$

The accumulated percentages are used to obtain the Lorenz curves (BÉNASSÉNI, 2013; LORENZ, 1905), which are given by the graph of $C_k(j)$ versus the accumulated percentage of the body postures, given by $p_k = 100 \times k/n$. From these curves, we calculated the Gini index (FARRIS, 2010; GINI, 1912).

The Gini index, given by G_j, measures the Lorenz curve adequacy in relation to the equality line, which is given by a straight line passing through the origin and with 45º of inclination. The G_j index is given by twice the area between the Lorenz curve and the equality straight line and this index is verified as a sensitive indicator varying between 0 and 1.0. In practice, a moderate value indicates the corresponding worker to be insensitive towards any body posture, and, therefore, the work time was distributed between the body postures. A value next to 1.0 indicates that one or more body posture presents big contributions to the worker, thus, he spent most of time in these body postures (BÉNASSÉNI, 2005). The time in which the worker stays in such body posture is noticed to be directly connected to the activity.

We calculated the values of influence function and related them with the contributions $c_i(j)$. The influence function to the eigenvalue λ_j is given by Hampel (2011):

$$I_i(j) = \widetilde{IF}(x, \lambda_j) = z_{ij}^2 - \hat{\lambda}_j \qquad (3)$$

where z_{ij} is the score value to each body posture.

In both (1) and (3), z_{ij}^2 is involved as a main term. There is an interesting relation between these two measures. Generally, high values of $c_i(j)$ correspond to high values of $I_i(j)$ and, accordingly, there is a connection between the values of the Gini index (G_j) and of influence function. A moderate value of G_j indicates that the Lorenz curve is relatively close to the equality line. Therefore, there is no dominant value of $c_i(j)$ and the same can be concluded about $I_i(j)$. On the other hand, high values of G_j tend to indicate that there are few ody postures influencing the high values of $c_i(j)$ and $I_i(j)$ (BÉNASSÉNI, 2005).

The statistical analyses were done with R (R Core Team, 2016).

RESULTS AND DISCUSSION

In Table 1, the subtask of herbicide application presented higher postural variability, followed by drying on the sloping ground, foliar fertilization on flat ground and herbicide application on flat ground. Harvesting, both on flat and sloping ground, presented a lower postural protocol.

The eigenvalues referent to the 12 workers was: $\lambda_1 = 8.642016$, $\lambda_2 = 1.544811$, $\lambda_3 = 0.451927$, $\lambda_4 = 0.218118$, $\lambda_5 = 0.148405$, $\lambda_6 = 0.058407$, $\lambda_7 = 0.044835$, $\lambda_8 = 0.025010$, $\lambda_9 = 0.007252$, $\lambda_{10} = 0.001776$, $\lambda_{11} = 0.000216$ e $\lambda_{12} = 0.000084$. Besides, the proportion of variance explained by the two first components accumulated around 91.42% of all variance, in other words, almost only the first two components explained the postural variability of each worker (Table 2).

Table 1. Variance estimation for each activity

Activities	Variance
Manual fertilization – Sloping ground	321.4609
Manual fertilization – Flat ground	377.3117
Foliar fertilization – Sloping ground	377.4660
Foliar fertilization – Flat ground	457.5505
Herbicide application – Sloping ground	519.0551
Herbicide application – Flat ground	443.1540
Storage	241.0149
Harvesting – Sloping ground	156.8417
Harvesting – Flat ground	175.6207
Thinning – Sloping ground	271.0989
Thinning – Flat ground	213.2739
Drying on the ground	490.3707

Table 2. Standard Deviation, Proportion of Variance and Proportion of Cumulative Variance explained by each principal component to the study of average working time percentage

Principal Components	Standard Deviation	Proportion of Explained Variance	Proportion of Cumulative Variance
CP1	3.05070	0.77560	0.77560
CP2	1.28980	0.13860	0.91420
CP3	0.69760	0.04060	0.95476
CP4	0.48470	0.01960	0.97433
CP5	0.39980	0.01330	0.98765
CP6	0.25080	0.00520	0.99289
CP7	0.21970	0.00400	0.99692
CP8	0.16410	0.00220	0.99916
CP9	0.08840	0.00065	0.99981
CP10	0.04370	0.00016	0.99997
CP11	0.01520	0.00002	0.99999
CP12	0.00950	0.00001	1.00000

The Lorenz curves are presented in Figures 3 and 4, obtained for each one of twelve eigenvalues, corresponding to each worker. The shapes of the curves provide important information about the sensibility the workers individually presented in each body posture. Thus, with a visual inspection, potentially influent body postures could be detected, that is, those postures contributing in a highly significant way to the worker. The graphs are constructed with the values of accumulated contributions, ordered from highest to lowest, hence the value of the most influential body posture is seen by the two last points.

In figures 3 and 4, the Lorenz curves associated to the 1st, 3rd, 6th, 11th, and 12th components correspond the most influential body posture to be associates to, approximately, 50% of the variability performed by the workers to the workers 1, 3, 6, 11 and 12, respectively, in other words, these workers performed about half of the total work time in this body posture. As for the 2nd, 5th, and 10th components, the most influential body posture for each one corresponded to, approximately, 75% of the variability associated to the workers 2, 5 and 10, respectively. In the 4th, 7th, 8th and 9th components, corresponding to workers 4, 7, 8 and 9, respectively, the most influential body posture corresponded to only 38% of the variability associated to these workers, indicating their postural protocol during the activities to be more diversified.

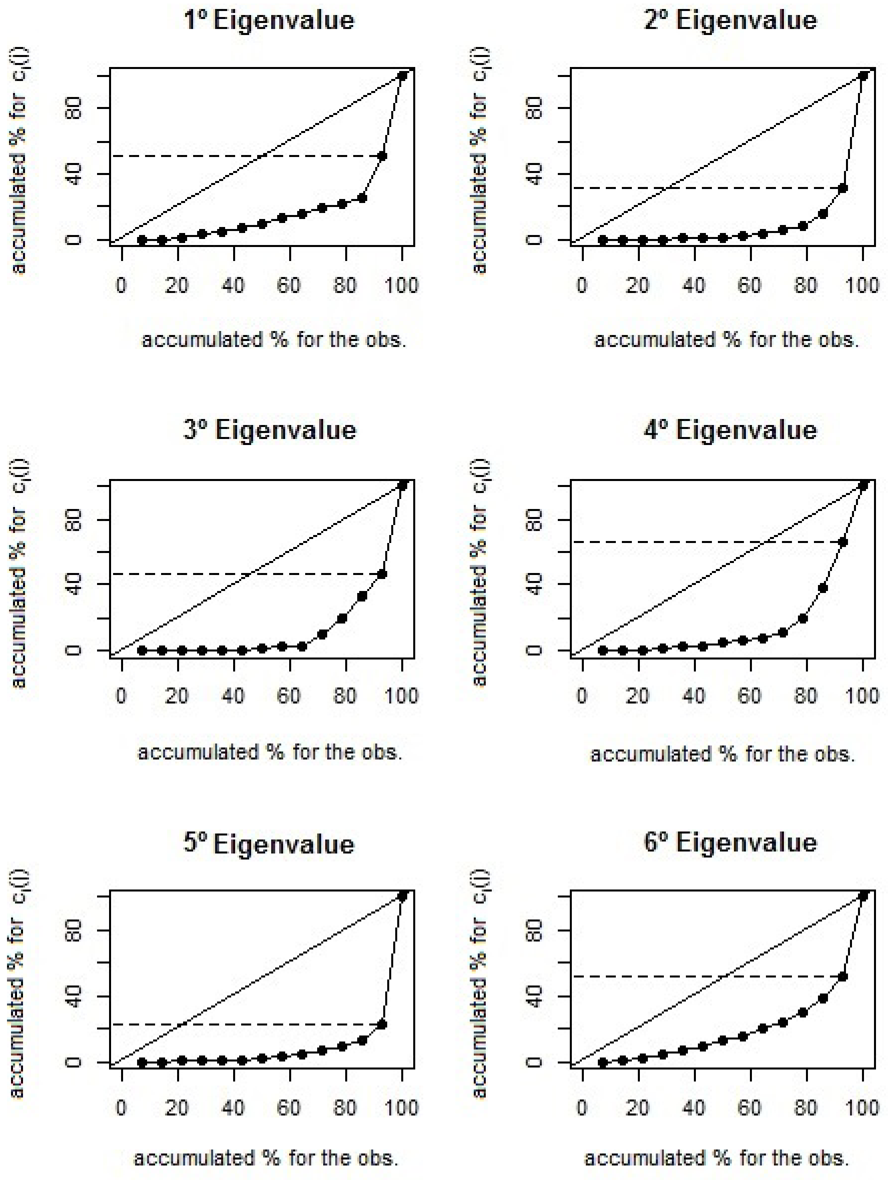

Figure 3. Lorenz curves for components from 1 to 6.

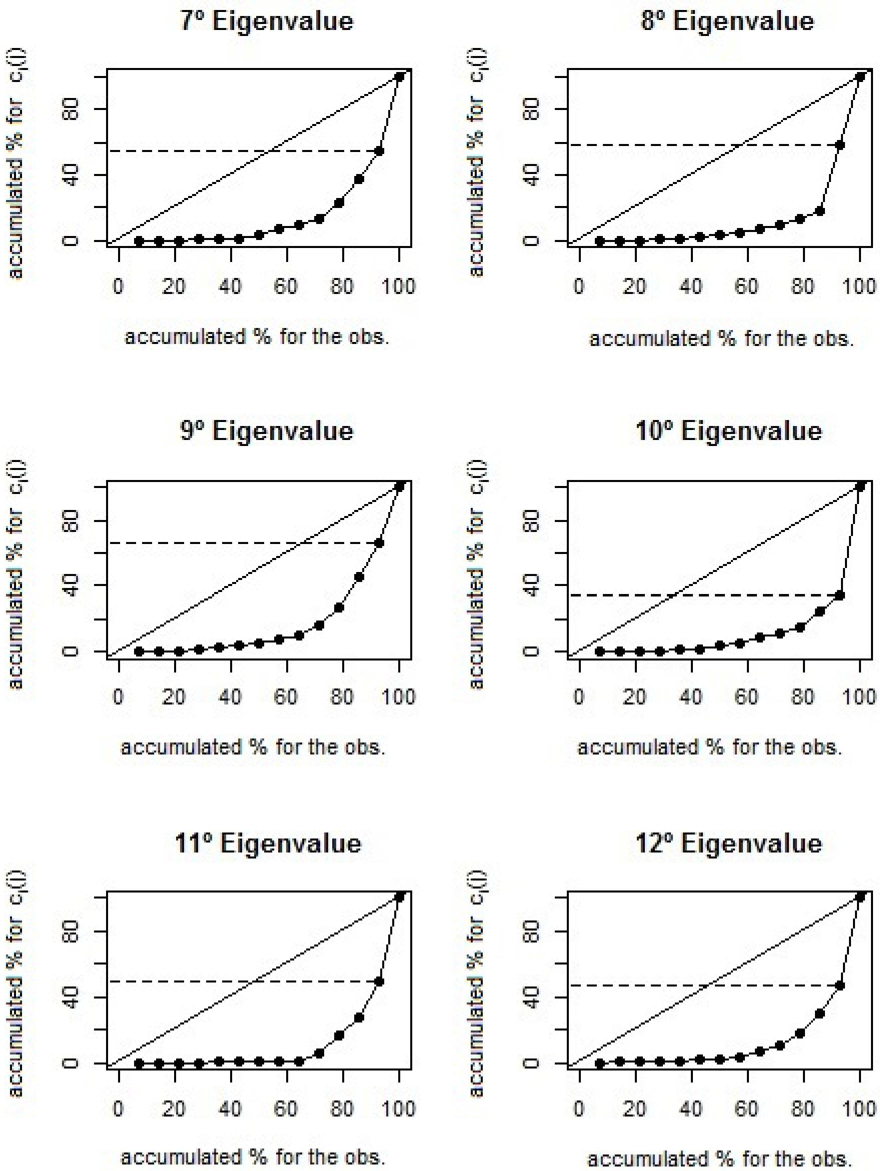

Figure 4. Lorenz curves to components from 7 to 12.

The values of Gini index are: $G_1 = 0.6797$, $G_2 = 0.8276$, $G_3 = 0.7596$, $G_4 = 0.6992$, $G_5 = 0.8393$, $G_6 = 0.6211$, $G_7 = 0.7073$, $G_8 = 0.7589$, $G_9 = 0.6637$, $G_{10} = 0.7757$, $G_{11} = 0.7856$ e $G_{12} = 0.7569$. Most of the values are next to 1.0, which indicates – through visual inspection – one or more body posture to present big contributions to these eigenvalues, that is, most of the workers spent more time in a certain body posture. Thus, the identification of which body postures are prominent is shown to be necessary, and the contributions $c_i(j)$ and de values of influence function $I_i(j)$, presented in Tables 3 and 4, respectively, should be used.

Body postures with the highest values of contribution also presented the highest values of influence on function. Besides, observations with lower contributions present lower values of influence on function, generally negatives. This confirms the observed results in the Lorenz curves and the Gini index.

It is important to say that the results show that those body postures with higher values to contribution and function influence, for certain eigenvalues, are not the same presented by others,

Table 3. Contributions values of each body posture in an average working time

P	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}
	c_i (1)	c_i (2)	c_i (3)	c_i (4)	c_i (5)	c_i (6)	c_i (7)	c_i (8)	c_i (9)	c_i (10)	c_i (11)	c_i (12)
111	1.50	2.08	0.72	17.92	1.47	1.54	0.12	0.001	33.83	10.24	0.04	0.32
121	0.26	14.75	6.46	34.45	0.66	5.68	0.74	0.02	20.45	1.63	0.02	0.20
131	25.04	0.81	53.46	1.10	1.21	3.91	2.92	0.80	0.97	0.64	0.001	0.93
211	2.35	0.30	10.36	0.35	0.43	1.97	15.05	41.71	10.91	2.19	0.05	3.41
222	3.32	0.21	0.05	0.04	0.25	2.34	0.06	2.08	19.02	3.49	11.44	17.30
225	3.34	0.08	0.07	1.60	3.06	3.46	8.57	0.65	5.26	0.34	50.92	7.95
231	49.00	8.27	13.28	7.85	0.08	8.60	2.46	1.73	0.54	0.31	0.07	0.004
232	2.58	68.94	13.23	0.79	2.20	3.36	0.05	0.02	1.29	0.001	0.03	0.17
233	3.56	0.12	0.17	0.02	0.04	2.50	0.34	1.15	1.32	9.23	5.13	52.71
234	2.83	0.05	0.44	3.57	9.61	13.95	17.52	4.75	3.47	3.18	21.43	12.05
331	3.03	0.26	0.16	0.93	0.03	0.01	0.30	0.60	2.01	65.41	10.55	3.61
332	0.01	0.96	0.001	1.55	77.86	4.43	3.13	4.28	0.06	0.03	0.01	0.27
333	1.44	2.64	0.64	28.10	2.80	47.61	3.77	2.22	0.04	2.89	0.05	0.60
334	1.74	0.53	0.97	1.73	0.30	0.65	44.97	39.98	0.83	0.44	0.25	0.46

Table 4. Values of Influence function to each body posture

P	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}
	I_i (1)	I_i (2)	I_i (3)	I_i (4)	I_i (5)	I_i (5)	I_i (7)	I_i (8)	I_i (9)	I_i (10)	I_i (11)	I_i (12)
111	-6.82	-1.10	-0.41	0.33	-0.12	-0.05	-0.04	-0.03	0.03	0.01	-0.002	-0.001
121	-8.33	1.65	-0.04	0.83	-0.14	-0.01	-0.04	-0.03	0.01	-0.01	-0.002	-0.001
131	21.65	-1.37	2.93	-0.18	-0.12	-0.03	-0.03	-0.02	-0.01	-0.01	-0.002	-0.001
211	-5.80	-1.48	0.20	-0.21	-0.14	-0.04	0.05	0.12	0.01	-0.01	-0.002	-0.001
222	-4.62	-1.50	-0.45	-0.22	-0.14	-0.04	-0.04	-0.02	0.01	-0.01	0.001	0.001
225	-4.60	-1.53	-0.45	-0.17	-0.09	-0.03	0.01	-0.02	-0.01	-0.01	0.001	0.0001
231	50.65	0.24	0.39	0.02	-0.15	0.01	-0.03	-0.02	-0.01	-0.01	-0.002	-0.001
232	-5.53	13.37	0.39	-0.19	-0.10	-0.03	-0.05	-0.03	-0.01	-0.01	-0.002	-0.001
233	-4.33	-1.52	-0.44	-0.22	-0.15	-0.04	-0.04	-0.02	-0.01	0.01	-0.001	0.001
234	-5.22	-1.53	-0.42	-0.11	0.05	0.06	0.07	-0.01	-0.00	-0.01	0.004	0.001
331	-4.98	-1.49	-0.44	-0.19	-0.15	-0.06	-0.04	-0.02	-0.01	0.02	0.001	-0.001
332	-8.63	-1.34	-0.45	-0.17	1.47	-0.02	-0.03	-0.01	-0.01	-0.01	-0.002	-0.001
333	-6.90	-0.97	-0.41	0.64	-0.09	0.33	-0.02	-0.02	-0.01	-0.01	-0.002	-0.001
334	-6.54	-1.43	-0.39	-0.17	-0.14	-0.05	0.24	0.12	-0.01	-0.01	-0.002	-0.001

that is, certain body postures can be very influential to one worker and, on the other hand, may not be to other. This shows variability among workers, and, therefore, the body postures vary among workers.

Despite of the variation of body postures among workers during the tasks in agricultural practices, some body postures stood out: body postures 121, 131 and 231 to workers 1, 2, 3, 4 e 9 and body posture number 234 to workers 6 and 7. The body postures 233 and 211 were less executed.

In general, the results showed that harvesting, both in sloping and flat ground, should be executed with more attention, due to the low postural variability, because the repetitive movements and vicious body postures can lead to injuries and increased muscle fatigue, causing a drop in production and increasing the risk of accidents.

Most of the workers remained more than half of the observed time in the same body posture, which is a behavior with ergonomic risk for them for the practiced tasks. On the other hand, more aggressive body postures, as those which present severe flexion of the main body, were less observed during the tasks. Similar results were observed by Barbosa et al. (2014) and Tereso et al. (2015).

The obtained results allow, from the individual evaluation of each worker, to relate the postures to areas of discomfort, thus indicating an individualized, ergonomically optimal working condition.

CONCLUSION

- The proposed statistical methodology to analyze behavioral data was plausible because of the possibility to identify the most influential body postures during the activities executed by each worker. This methodology also allowed useful ergonomic inferences to be made for studies done in coffee crops and to bring awareness towards the workers about the importance of adequate body postures during activities of harvesting and post harvesting of coffee, avoiding health damage.

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