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Physical workload assessment of coffee farming: biomechanical, physiological e psychophysical aspects

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Abstract

The main objective of this research was the assessment of the physical workload of coffee farm workers from southern Minas Gerais, Brazil. Twelve workers were filmed and their heart rates monitored during one hour in the execution of five different tasks, both on flat terrain and downhill. The assessment of body postures adopted and the actions performed were achieved through the software *Captiv*. We attempted to correlate the results of the assessments and interpret them in the light of the observation of the activities of the workers. The most significant cardiovascular demands occurred in subtasks of foliar fertilization and fertilizer broadcasting, classifying them as moderate work. Harvesting and thinning were the subtasks that appeared to have the greatest variability of postural combinations: the harvest due to the variety of operating actions; the pruning, although only one relevant operational action, due to the very nature of the task. Either cardiovascular indicators or the biomechanical revealed no statistically significant differences between the subtasks undertaken by workers in conditions of flat and sloping terrain.

Keywords: workload, coffee, heart rate, posture

1. Introduction

There are many researches on coffee production regarding technical, agronomic or socio-economic issues; few researches, however, studied the human work on coffee production under an ergonomic perspective, including the assessment of the workload. Being mostly a non-repetitive, non-monotonous type of work, agricultural work needs a group of methods, both objective and subjective, to characterize its workload. In this perspective, Abrahão, Ribeiro e Tereso (2012) aimed the characterization of the physical workload of the organic horticulture, by the determination of the workers frequency of exposure to some activity categories. The approach included an evaluation of physical effort demanded to perform the tasks in the work systems from a systematic sampling of work situations and a synchronized monitoring of the worker's heart rate; a characterization of posture repertoire adopted by workers through an adaptation of the OWAS method; an identification of pain body areas using the Corlett diagram; and a subjective evaluation of perceived effort using the RPE Borg scale. The results of the individual assessments were cross correlated and the observations made of the work done were useful to explain the data. Postural demands were more relevant than cardiovascular demands for the studied tasks, and correlated positively with the expressions of bodily discomfort.
Silverstein, Bao and Russel (2012) adopted a participatory ergonomics approach during two Nicaraguan shade-grown coffee harvesting seasons to reduce the physical load on harvest-

ers with the use of a newly designed bag instead of a basket strapped around the waist. Among basket users, 84.2% reported pain in at least one body area compared to 78.9% of bag users; 74% of participants liked the newly proposed bag much more than the basket.
Heart rate is traditionally used as an indicator of physiological effort, being increasingly used instead of oxygen consumption to estimate the workload of a task (Kromer & Gradjean, 2005). Cardiovascular parameters commonly used include the average heart rate during work − the working heart rate (HRW), the resting heart rate (HRR), the maximum heart rate (HRmax), the limit heart rate (HRL) and the relative heart rate (HRR) (Kirk & Sullman, 2001). HRR at work is an important indicator of physiological strain and should not exceed 40% for an eight hour period to avoid fatigue (Apud, Bostrand, Mobs, Strehlke, 1989). HRW is also used as a strain indicator and determines the following categories of work intensity: light (HRW<90); moderate (90≤HRW<110); heavy (110≤HRW<130), very heavy (130≤HRW<150) and extremely heavy (HRW> 150) (Astrand, Rodahl, Sigmund, 2006).
The effects of the workload on a person can also be estimated through the use of psychophysical methods (body discomfort and body pain surveys) that can be applied to assess the physical effects of the workload (Iida, 2005). Also, to assess the subjective perceived exertion for each task it can be applied the RPE (rate of perceived exertion) Borg scale (Borg, 2000).
Agricultural work is a major subject for Brazil's economy. Agribusiness is responsible for 33% of Brazil's gross domestic product, 42% of total exports and 37% of Brazilians jobs, employing about 17.7 million workers, occupying a prominent position in the Brazilian economy (Brasil, 2008). Coffee production is very important in the context of the Brazilian economy since Brazil is responsible for about a third of the world production, which makes the country the largest producer - a position maintained in the last 150 years. Today, Brazil has a planted area of 2.3 million hectares, with about 5.7 billion coffee trees. The state of Minas Gerais is the largest producer in the country with 45.5% of the Brazilian production (UOL, 2013).
The main objective of this work was the assessment of the physical workload in an agriculture context, applying the proposed method in a case study on coffee farming systems. This kind of study can help to direct research efforts towards the technological development of coffee farming, both to improve human work productivity and to reduce ergonomic hazards.

2. Materials and methods

The proposed study is experimental under field conditions with quantitative and qualitative elements. The descriptors of the physical workload are the group of dependent variables, including those of physiological (heart rate, cardiovascular load), biomechanical (postural combinations) and psychophysical nature (indication of physical discomfort and perceived exertion). The independent variables are composed by tasks, subtasks and the topography of the farms.
Twelve workers from twelve small family coffee farms from Santo Antonio do Amparo, southern Minas Gerais, agreed to participate in this study. Each subject was voluntary and received adequate information about the research. They had the right to withdraw from participation at any time, without penalty of any kind and without providing reasons. Each of them was filmed performing one hour work of the subtasks, both in flat terrain and in areas with more than 10% slope (with the exception of the subtasks from the post-harvest group, that were performed only in flat terrain). The heart rate (HR) was measured continuously for each subject, synchronized with the video recording. A Polar RS800CX G3 heart rate monitor was used with a sampling rate of 2 seconds.
Table 1 shows personal and biometric data of the workers.

Table 1: Personal and biometric data of the workers.

Worker	Gender	Age (years)	Seniority (years)	Weight (kg)	Height (cm)	HR_R (bpm)	HR_{max} (bpm)
1	M	59	22	64	165	66	161
2	M	30	8	93	179	52	190
3	M	60	11	70	171	63	160
4	M	30	10	60	163	59	190
5	M	40	20	94	187	64	180
6	M	34	9	63	165	56	186
7	M	31	20	61	172	66	189
8	F	25	6	66	160	53	195
9	M	35	20	100	190	65	185
10	M	39	19	84	182	67	181
11	M	29	20	74	180	53	192
12	M	68	39	54	169	71	153

The tasks from the coffee farming systems considered in this study are crop handling and harvest. They had the following subtasks and respective operations:
a) **Crop Handling** − manual fertilization (empty bag displacement, bag stuffing, full bag displacement and manual fertilization); foliar fertilization (empty costal pulverizer displacement, costal pulverizer refuelling, full costal pulverizer displacement and application); thinning (thinning); herbicide application (empty costal pulverizer displacement, costal pulverizer refuelling, full costal pulverizer displacement and application).
b) **Harvest** – harvest (canvas placement, manual harvest, canvas displacement, sieving, manual cleaning and bagging).
To assess the perceived exertion for each subtask, each subject had to indicate their perception on a Borg scale, ranging from 1 (very light) to 7 (extremely intense). It was also used a body part discomfort scale to assess the levels of body discomfort of the workers at the end of the workday. The heart rate indicators adopted in this work were calculated as follows, according to (Astrand, Rodahl, Sigmund, 2006) and (Apud, Bostrand, Mobs, Strehlke, 1989).

$$HR_{max} = 220 - age \quad (1)$$

$$HR_L = 0{,}40(HR_{max} - HR_R) - HR_R \quad (2)$$

$$HRR = \frac{(HR_W - HR_R)}{(HR_{max} - HR_R)} \times 100 \quad (3)$$

The postural protocol was adapted from OWAS [9] to include the characteristics postures of coffee farm labor (Figure 1).

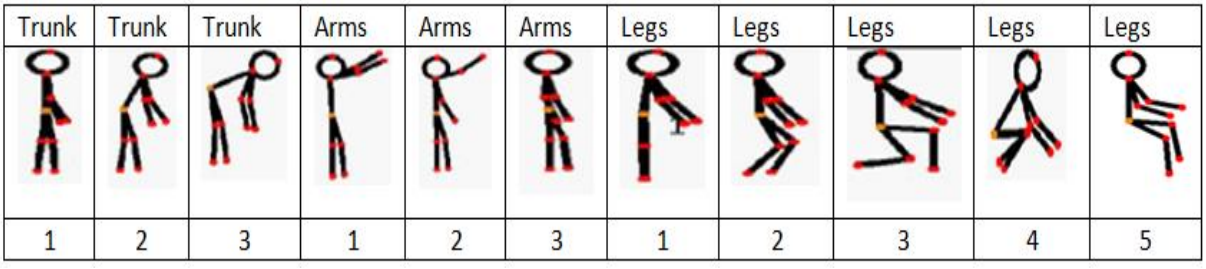

Figure 1: Postural protocol adopted

The experiment was conducted in a randomized block design, where each worker was considered a block in a 5x2 factorial design. The factors were slope and the subtasks. It was performed an analysis of variance and the Tukey test was applied to compare means.

3. Results and discussion

The mean heart rate results and the standard deviation for the twelve workers performing all subtasks in both topographic conditions are summarized on Table 2.

Table 2: Heart rate results for workers performing all subtasks.

Worker	$HR_W \pm SD$	HRR ± SD
1	88,9 ± 5,1	24,11 ± 5,4
2	90,0 ± 5,8	27,54 ± 4,2
3	95,5 ± 3,9	31,05 ± 4,1
4	105,8 ± 5,1	38,99 ± 3,7
5	79,9 ± 2,0	14,63 ± 2,2
6	98,9 ± 3,3	33,99 ± 2,4
7	96,8 ± 2,9	32,42 ± 3,1
8	96,2 ± 6,1	32,03 ± 4,4
9	81,6 ± 4,5	16,42 ± 4,8
10	88,4 ± 5,7	26,38 ± 4,1
11	101,2 ± 4,2	37,05 ± 4,4
12	85,9 ± 4,4	24,57 ± 3,2

Table 2 shows that 58,3% of the workers exhibited HRW between 90 and 110 bpm, configuring moderate work intensity, while 41,7% had HRW less than 90 bpm, configuring light work intensity. All of the HRR results are under 40% and in safe limits according to the literature.
ANOVA results showed that the slope factor was not statistically significant with respect to heart rate results. On the other hand, the subtask factor was statistically significant for ($p<0,05$).
Table 3 shows mean heart rate values for all the workers performing the subtasks. Means followed by same letter do not differ at the 5% level of significance by the Tukey test. Foliar and manual fertilization exhibited significantly greater values of HRW and HRR than the other subtasks. The results configure a moderate work intensity for foliar and manual fertilization and light work intensity for herbicide application, thinning and harvest.

Table 3: Heart rate results for workers performing specific subtasks

Subtasks	$HR_W \pm SD$	HRR ± SD
Foliar fertilization	99,88 ± 2,9 a	34,73 ± 2,8 a
Manual fertilization	99,46 ± 4,1 a	34,88 ± 3,4 a
Herbicide application	88,54 ± 2,3 b	24,96 ± 2,1 b
Thining	85,96 ± 2,7 b	22,40 ± 2,3 b
Harvest	88,29 ± 2,8 b	24,34 ± 2,5 b

The mean postural combinations adopted by the workers in percentage of the working time on flat terrain are expressed on Figure 2 for the five subtasks analyzed. Four categories were the most frequent, occurring in more than 80% of the sampling time: (131) – standing erect, arms down, extended legs; (231) - moderate trunk flexion (<45º), arms down, extended legs; (232) - moderate trunk flexion (<45º), arms down, flexed legs and (332) - severe trunk flexion (>45º), arms down, flexed legs. The postural combinations 111 (standing erect, arms up, extended legs) and 121 (standing erect, one arm up, extended legs) occurred more than 15% during foliar fertilization and thinning. Harvest was the subtask that showed the greater variety of postural combinations.

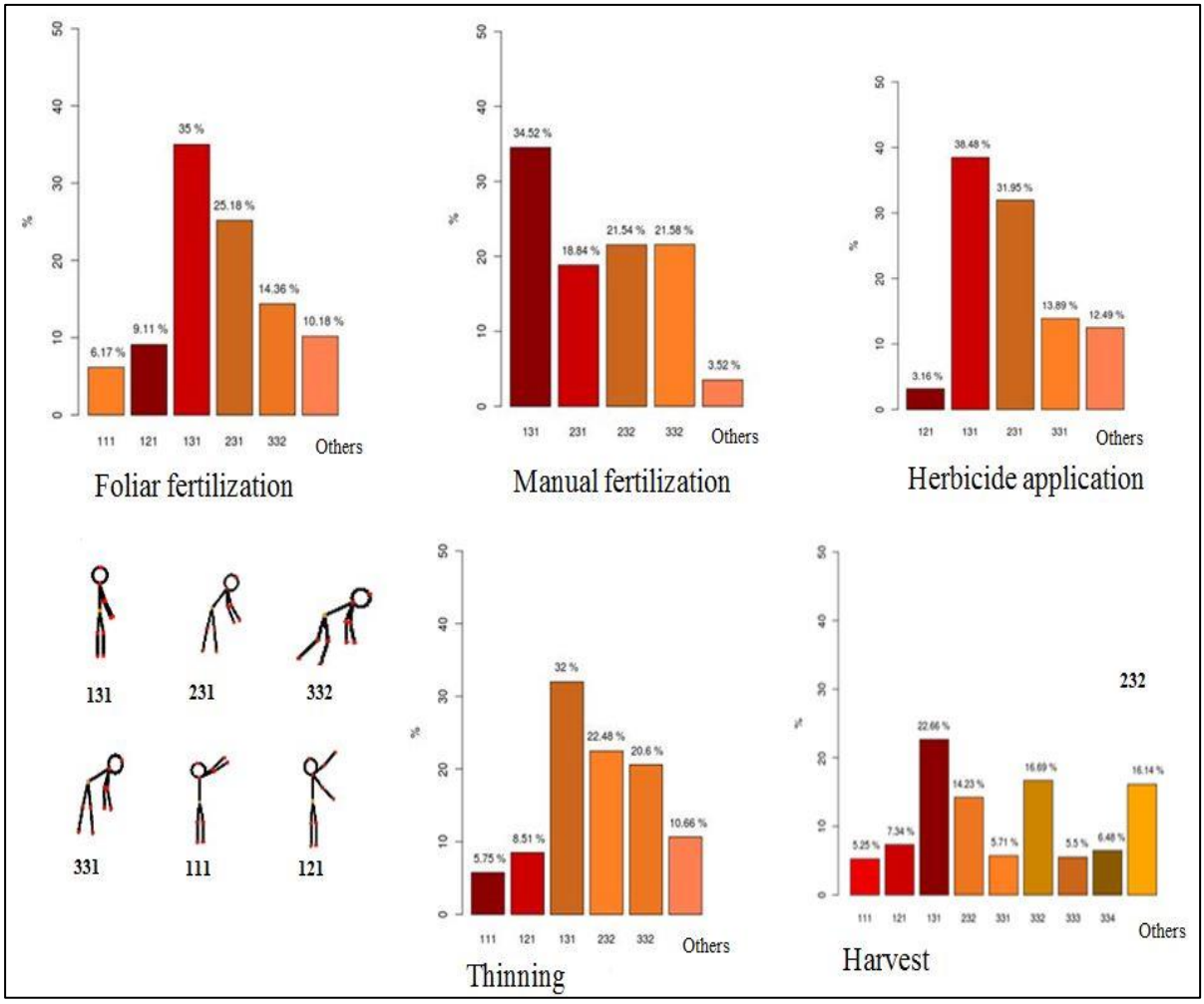

Figure 2: Postural combinations for each subtask

The mean results of the application to all the workers of the modified Borg scale for the rate of perceived exertion (RPE) for each subtask considering the scores 5 (intense), 6 (very intense) and 7 (extremely intense) were: manual fertilization – 38%; thinning – 5%; foliar fertilization – 60%; herbicide application – 25%; and harvest – 18%.
The results of the body discomfort survey showed that the main body areas pointed by the workers with some degree of discomfort were the shoulders and the back; approximately one quarter of the workers pointed that the degree of discomfort for the shoulders and the back ranged from uncomfortable to extremely uncomfortable.

4. Conclusions

The cardiovascular effort was not particularly severe for the subtasks analyzed. On the other hand, the biomechanical demands expressed by some difficult postures were considerable. Manual fertilization, thinning and harvest exhibited moderate and severe trunk flexion and leg flexion during more than 25% of the work time.
Foliar and manual fertilization were pointed by the workers as the most demanding subtasks according to the BORG RPE scale. The results of the body areas discomfort analyses indicated the back and shoulders as the most uncomfortable body areas. For the foliar fertilization and herbicide application, the postural demands and the use of the manual pulverizer contributed for the complaints.
It is expected that the results of this study can benefit coffee farm workers by the characterization of their workload, helping to direct efforts towards the development of new technologies designed to minimize the workload and raise the work productivity.

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