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Ergonomic Evaluation of Pruning in Simulated Greenhouse conditions

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Greenhouse is a space-efficient structure for farming. The workers stretch their bodies to perform operations away from the body and at different heights. The present study aimed to assess the physiological and postural discomfort because of the varied working heights and horizontal distances and also attempts to suggest suitable interventions to overcome them. The current study investigated the physiological and subjective measures of exertion while working at different heights (elbow height, shoulder height and above shoulder height) and horizontal distances (30, 45, 60, and 75 cm) with two different pruning tools under simulated laboratory conditions. All the physiological parameters and responses against different conditions were recorded from six male participants and analyzed as per experimental requirements. The outcome of the present study demonstrated that physiological cost and subjective measure of exertion varied significantly with the variation in heights and horizontal distances. Heart rate, oxygen consumption, energy expenditure, and perceived exertion were significantly higher "above the shoulder height" than elbow and shoulder height. Similarly, all the measured physiological parameters and Rating of Perceived Exertion (RPE) exhibited a gradual increase with increasing the distance from the worker's body. The study also revealed a differential effect of tools used while performing the pruning work. Further, the multiple regression analysis helped to predict Relative Cardiac Cost from RPE and other evaluated physiological parameters. Overall, findings from the current study concluded that conventional pruning activities need workspace optimization and ergonomic intervention to select pruning tools and achieve the desired productivity with minimum Musculoskeletal Disorders (MSDs).

Keywords: Ergonomics, Greenhouse farming, Physical exertion, Physiology, Working heights

Introduction

Agricultural productivity has increased significantly over the years due to mechanization and automation. Greenhouse agriculture is hi-tech farming, picking up as it is considered a low-cost solution to improve productivity and profitability, especially in countries with harsher climates like India. Worldwide, there is a steady increase in the greenhouse area approximating 5.6 million ha.[1] In India, the area under greenhouse cultivation is about 70 thousand ha.[2,3] Green house agriculture is likely to experience further rapid growth in the coming years due to changing consumer preferences. Greenhouses are suitable for round-the-year cultivation of quality produce. However, the increasing labour cost, harsh environment and musculoskeletal problems of the farmers are associated with greenhouse cultivations and need to be addressed.[4]

Because of the high investment cost, space utilization in greenhouse cultivation is very important. So, the cultivation is in the vertical direction in the form of creepers. Most greenhouse crops require crop training to achieve higher productivity by pruning operations. Pruning occurs in many agriculture applications for two major purposes: to train shoots and branches in the required direction and remove unwanted foliage and branches. The first operation usually must be done with high accuracy, whereas the second can be done less precisely. The vertical spread of crops requires working at different heights. Many tools can be used to do the pruning, ranging from simple hand secateurs and scissors to sophisticated powered tools. Manual pruning shear tools are often preferred by workers due to better hand comfort, freedom of movement and ease of operation. The crops are trained for efficient utilization of space and moved horizontally as well as vertically. The pruning of side branches is also a very important activity. The working height goes up to three meters resulting in workers working above the worker's shoulder height, causing postural stresses.[5–7] It is also reported that the relatively large trunk flexion and

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extension angles, in combination with increased wrist flexion/extension observed in Wine grape Trellis systems, increased the risk of developing MSDs in both the wrist and the back.[8] However, high force demands of the forearm muscles may cause Repetitive Strain Injuries (RSI) of the hand/wrist. Besides hand/arm problems, low back pain often occurs, which may be caused by reaching upwards and forwards.

Pruning tools are typically used with one hand and the palm pressing handle on the line, joining the base of the thumb to the hyposthenia area. In contrast, the lower handle is activated by finger flexion.[9] It is reported that pruning with powered tools enhances the risk of musculoskeletal hand–wrist disorders.[10] Physical load during the pruning task is due to repetitive hand grips and wrist movements[11], combined with static work in the upper arm–shoulder system.[12] Due to their extensive use, it is essential to improve the ergonomic qualities of hand pruning shears. With simple, low-cost moving platforms of fixed height in the greenhouse alleys, the workers have to perform operations by stretching their bodies. The low cost trolleys can move horizontally with chain and gear arrangement but vertical movement is not there which results in adoption of odd postures in performing different operations in the greenhouse (Fig. 1).

Despite the huge importance, few previous studies recorded physiological parameters like Heart Rate (HR) during pruning tasks. A pioneering study has identified pruning as a moderate workload activity in terms of heart rate indices.[7] Another study has investigated the effect of apple farming activities, including pruning, on heart rate, oxygen pulse, Net Cardiac Cost (NCC), and Relative Cardiac Cost (RCC) and identified pruning as a moderate intensity workload in terms of physiological costs.[13] But to date, no studies have been conducted to evaluate the physiological parameters or subjective rating of fatigue during pruning activities at different heights and distances in vertical farming, especially in greenhouse farming. Therefore, to bridge the knowledge gap, the present study aimed to assess the physiological and perceived psycho physiological stress during pruning at different horizontal distances and vertical heights.

Fig. 1 — Workers performing operations in the greenhouse

Materials and Methods

Subjects

Six healthy male volunteers, having pruning experience in the agricultural sector, participated in this study. The mean (SD) age, height, weight, and BMI of the participants were 27.17 ± 1.5 years, 169.85 ± 4.9 cm, 66.63 ± 3.6 kg, and 23.14 ± 1.7, respectively. Before commencing the study, a screening of recent and previous history of musculoskeletal disorders of the back and upper extremities was obtained. A consent informing the benefit and risks of the experiments was presented to the participants. Those who showed willingness (n = 6) were allowed to participate in the study.

Experimental Procedure

The experiments were conducted in 2016 at the Farm Machinery lab, IARI, New Delhi, India. Each participant was subjected to ten-minute pruning activity within the laboratory setup, where identical greenhouse creepers were created (Figs 2 & 3). All participants performed pruning using two pruning tools, namely secateurs and scissors. The detailed dimension of the scissor was: Length of scissors: 16.5 cm, Blade length: 8 cm, Size of finger hole: Major axis: 3 cm, Minor axis: 2 cm, Width in closed condition: 6.5 cm, In open condition width: 18 cm. On the other hand, the secateurs had dimensions: Length: 20 cm, Blade length: 4 cm, Width in closed position: 4.5 cm and Handle length: 8.5 cm. The participants were asked to do the pruning at three vertical heights (elbow, shoulder, and above shoulder level). In addition, all volunteers were subjected to the pruning at four different workspace-reach horizontal distances, i.e., 30 cm, 45 cm, 60 cm, and 75 cm, respectively (Fig. 3). During each trial, subjects were asked to prune with one cut/sec for 10 minutes. Physiological parameters and RPE were measured as follows:

Evaluation of physiological parameters: Measurement of the most important cardiopulmonary variable, Heart rate (HR), was done in real-time while performing the task using a Polar heart rate monitor

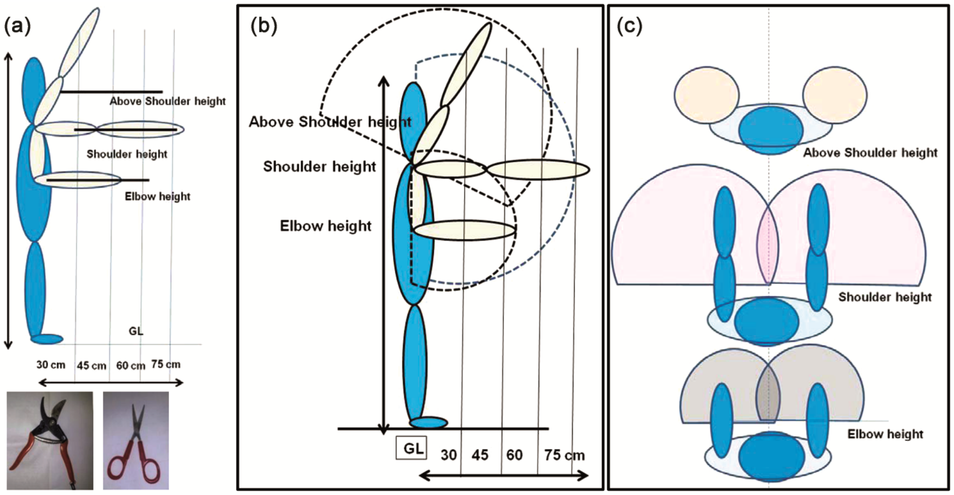

Fig. 2 — (a) Experimental parameters; Workspace at different operation heights (b) vertical plane (c) horizontal plane

Fig. 3 — Simulated operation at different operational heights (a) above shoulder (b) shoulder (c) and elbow

(RS300XG1). Two important cardiac parameters, namely NCC and RCC, were evaluated using standard equations as follows.[13]

(1) Net Cardiac Cost (NCC) = Work heart rate- Rest heart rate

(2) Relative Cardiac Cost (RCC) = NCC/ (Max heart rate- Rest heart rate)

After completing all experimental trials, subjects participated in a sub maximal experiment to assess their maximum oxygen consumption using the K4b2 system (COSMED, Italy). A regression equation was developed between HR and oxygen consumption (VO_2) (Fig. 4), and energy expenditure (EE) (kJ/min) was calculated from the calibration chart (Fig. 4; HR-EE). During the in-field real experiment we have calculated only HR and few other parameters. Thereafter, using the HR data we have computed the VO_2 and EE data for each individual. Finally, a multiple regression analysis was conducted to predict the Relative Cardiac Cost (RCC) in terms of HR and Rating of Perceived Exertion (RPE) scaling.

Evaluation of Rating of Perceived Exertion (RPE): A subjective discomfort rating scale (Borg's 6-to-20-point discomfort scale) was administered after each trial for each participant. The subjects were asked to rank (6 through 20) the scale systems in terms of bodily discomfort from least (6) to most (20).

Statistical Analysis

All participants performed pruning tasks using two pruning tools at three vertical working heights and four horizontal working distances. Therefore, each participant performed a repetitive experimental trial in different simulated working conditions. Hence, a repeated measure ANOVA, i.e., within-subject analysis (SPSS version 26.0, IBM, USA), was performed to determine the effect of horizontal working distances, vertical working heights, and tools on all physiological and subjective parameters, both independently and interaction effect of all combinations. Further, a Bonferroni post hoc analysis was conducted to observe the pair wise comparison if any main effect of independent variables and their interaction effect exists. A Pearson correlation analysis was computed to observe the possible relationship among all the evaluated physiological and psycho physiological variables. Next, stepwise multiple linear regression analysis was performed to elucidate whether HR, VO_2, Energy expenditure and RPE are predictors of Relative cardiac cost during such pruning activities. Significance was accepted if the value of alpha remains ≤ 0.05 levels.

Results and Discussion

The present study aimed to observe the main as well as interaction effects of horizontal working distances, vertical working heights, and different pruning tools on selected physiological and subjective variables. The descriptive data (mean ± SD) are presented in Table 1, whereas the significance of the independent and interaction effect of all independent factors on physiological and subjective responses is presented in Table 2.

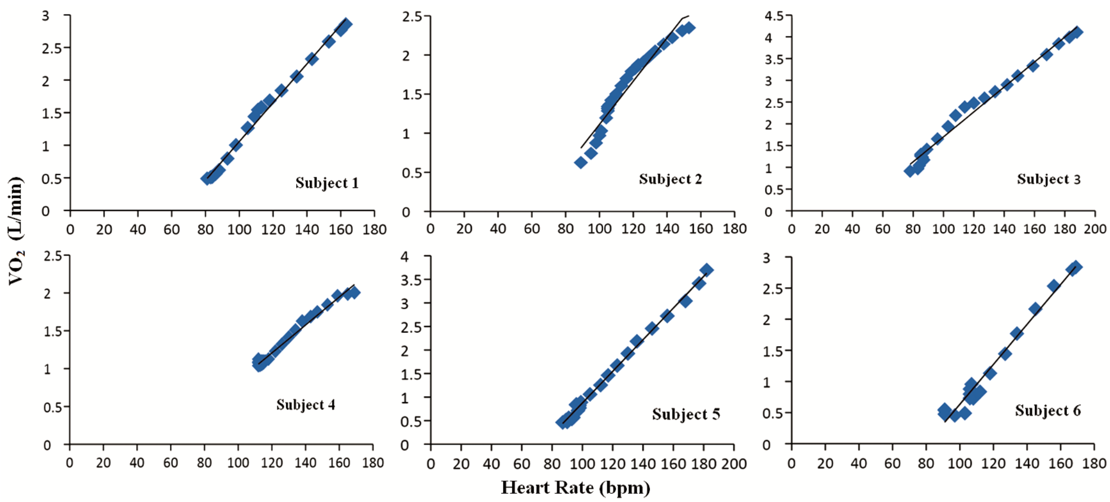

Fig. 4 — Calibration charts of workers

Table 1 — Physiological responses (Mean ± SD) during pruning activity within the laboratory simulation platform

	Working horizontal distances	30 cm		45 cm		60 cm		75 cm	
	Tools Used	Secateurs	Scissor	Secateurs	Scissor	Secateurs	Scissor	Secateurs	Scissor
Physiological Variables	Different working Heights								
HR (bpm)	Elbow	75.8 ± 2.9	82.4 ± 6.0	84.7 ± 3.8	85.9 ± 3.8	92.2 ± 3.9	94.7 ± 4.2	101.6 ± 2.2	104.7 ± 1.4
	Shoulder	81.0 ± 3.1	81.2 ± 2.9	86.7 ± 3.1	88.1 ± 2.1	95.4 ± 5.4	97.6 ± 6.1	105.1 ± 2.5	107.4 ± 4.3
	Above shoulder	82.7 ± 4.4	83.5 ± 4.5	89.3 ± 1.1	92.3 ± 2.8	102.5 ± 2.2	105.2 ± 1.6	108.6 ± 1.5	115.6 ± 3.8
Work Pulse (Delta HR)	Elbow	5.83 ± 2.9	12.37 ± 5.9	13.40 ± 4.0	14.61 ± 4.1	20.85 ± 6.3	23.35 ± 6.9	30.27 ±3.6	33.34 ± 2.5
	Shoulder	9.68 ± 5.3	9.89 ± 5.3	15.33 ± 3.11	16.74 ± 2.5	24.04 ±7.9	26.24 ±8.4	33.74 ± 5.1	36.03 ± 6.4
	Above shoulder	11.39 ± 6.3	12.18 ±6.0	18.01 ± 3.4	20.92 ± 5.2	31.19 ± 3.3	33.82 ± 3.3	37.28 ±4.0	44.26 ± 5.4
VO_2 (L/min)	Elbow	0.03 ± 0.3	0.21 ± 0.5	0.27 ± 0.3	0.30 ± 0.3	0.49 ± 0.5	0.56 ± 0.5	0.74 ± 0.4	0.82 ± 0.4
	Shoulder	0.19 ± 0.4	0.19 ± 0.4	0.32 ± 0.3	0.36 ± 0.4	0.58 ± 0.5	0.64 ± 0.6	0.83 ± 0.5	0.90 ± 0.5
	Above shoulder	0.24 ± 0.4	0.26 ± 0.4	0.41 ± 0.4	0.49 ± 0.5	0.76 ± 0.4	0.84 ± 0.4	0.93 ± 0.5	1.12 ± 0.4
EE (kJ/min)	Elbow	5.8 ± 1.7	9.6 ± 3.5	11.0 ± 2.2	11.7 ± 2.2	15.3 ± 2.3	16.8 ± 2.4	20.8 ± 1.3	22.6 ± 0.8
	Shoulder	8.8 ± 1.8	9.0 ± 1.7	12.1 ± 1.8	12.9 ± 1.2	17.2 ± 3.1	18.5 ± 3.5	22.8 ± 1.4	24.1 ± 2.5
	Above shoulder	9.8 ± 2.6	10.3 ± 2.6	13.7 ± 0.6	15.4 ± 1.6	21.3 ± 1.3	22.9 ± 0.9	24.9 ± 0.8	28.9 ± 2.2
RPE (Borg's scale rating)	Elbow	10.0 ± 0.9	11.2 ± 0.8	11.0 ± 0.9	13.0 ± 1.4	13.0 ± 1.3	13.8 ± 1.2	14.2 ± 0.8	14.7 ± 4.5
	Shoulder	11.2 ± 1.2	12.3 ± 1.0	12.0 ± 0.6	13.8 ± 1.2	13.8 ± 1.2	14.5 ± 0.5	15.2 ± 0.8	16.7 ± 1.0
	Above shoulder	12.8 ± 1.7	13.2 ± 1.5	13.2 ± 1.2	14.5 ± 0.8	13.7 ± 1.4	15.2 ± 1.0	15.8 ± 0.8	16.8 ± 0.8

HR = Heart rate, *VO_2 = Oxygen consumption*, *EE = Energy expenditure* and *RPE = Rating of perceived exertion*

Table 2 — Statistical significance for all dependent variables on independent variables and their combinations

Independent variables and their combinations	df	F value				Significance level				Partial Eta Square			
		HR	VO_2	EE	RPE	HR	VO_2	EE	RPE	HR	VO_2	EE	RPE
Distance	(3, 15)	172.3	90.11	172.21	36.42	0.001	0.001	0.001	0.001	0.972	0.947	0.972	0.879
Height	(2, 10)	34.99	26.56	35.00	19.06	0.001	0.001	0.001	0.001	0.875	0.842	0.875	0.792
Tools	(1, 5)	113.97	49.25	113.70	74.71	0.001	0.001	0.001	0.001	0.958	0.908	0.958	0.937
Distance × height	(6, 30)	1.653	1.351	1.65	0.53	NS	NS	NS	NS	0.248	0.213	0.249	0.096
Distance × tools	(3, 15)	1.772	1.523	1.77	0.65	NS	NS	NS	NS	0.262	0.234	0.196	0.115
Height × tools	(2, 10)	4.402	3.466	4.37	0.24	0.05	NS	0.05	NS	0.468	0.409	0.467	0.047
Distance × height × tools	(6, 30)	3.891	3.358	3.89	0.62	0.01	0.05	0.01	NS	0.438	0.402	0.438	0.111

Table 3 — Regression analysis model summary, ANOVA, and coefficients of dependent variable RCC (Relative Cardiac Cost)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.993[a]	0.986	0.986	1.09065

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11626.638	2	5813.319	4887.156	0.000[c]
	Residual	167.721	141	1.190		
	Total	11794.359	143			

Residuals

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-56.853	0.778		-73.046	0.000
	HR	0.801	0.011	0.976	69.769	0.000
	RPE	0.103	0.059	0.024	1.737	0.085

a. Predictors: (Constant), RPE, HR
b. Dependent Variable: RCC
c. Significance level: $p < 0.001$

The subjects performed the repetitive task of pruning activity in a simulated laboratory setup with three independent variables (horizontal distances, vertical heights and tools). A repeated measure ANOVA is best fitted for analyzing the variances of dependent variables (HR, VO_2, EE and RPE) effect. It was observed that HR, VO_2, EE and RPE showed overall significance for all independent variables and their combinations (Table 2). Also, Table 1 shows how dependent variables like heart rate (HR), oxygen consumption (VO_2), energy expenditure (EE) and Rating of Perceived Exertion (RPE) changed with vertical height as well as horizontal distances.

Individually almost all the working distances, heights, and tools exhibited significant alterations of physiological and subjective variables. Further, HR and EE had a significant height × tool interaction effect. In contrast, all physiological variables, including HR, VO_2, and EE, had a significant distance × height × tools interaction effect. However, the subjective response did not reveal any interaction of the independent variables. Partial eta squared data revealed that working at different horizontal distances had a higher impact, compared to different heights and tool use, on the observed population in terms of all physiological and subjective variables. While the least physiological and psycho physiological responses were observed with vertical working height. Pair wise comparison after Bonferroni correction revealed that physiological variables (HR, VO_2, and EE) and subjective discomfort rating (Borg's scale) gradually increased with increasing horizontal working distances, vertical working heights and changing the types of pruning tools. Correlation and multiple regression analyses were conducted to examine the relationship between RCC and various other potential predictors, including HR and RPE. The multiple regression model with these two predictors led to $R^2 = 0.986$, $F(2, 141) = 4887.156$, $p < 0.001$, described in Table 3. A graphical representation (Fig. 5) of multiple regressions revealed the RCC mapping according to the strain of HR and RPE.

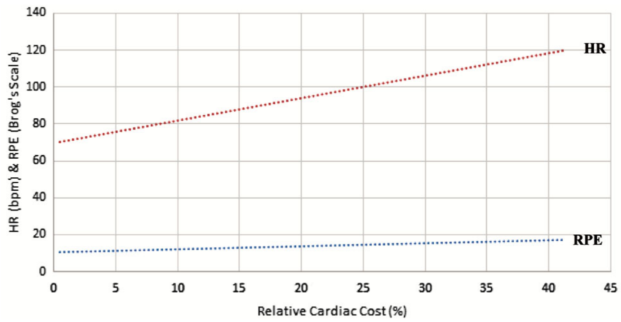

Fig. 5 — Graphical representation of multiple regressions among RCC, HR and RPE

The pruning above shoulder height has significantly increased the HR, VO_2, EE, NCC, RCC, and RPE than working at elbow and shoulder height. Thus, pruning above shoulder height should be avoided in long-term exposure in the green. Appropriate technological interventions, like hydraulic platforms, should be used to adjust the working height. It has also taken into account that pruning with scissors increased HR, VO_2, EE and RPE compared to the secateurs tool. Also, the combination of height and tool used, or the distance and height significantly affected HR, VO_2 and EE at $p < 0.05$.

Several researchers have studied the pruning of vines and reported that overall strain could be rated as tolerable for cutting vines using different shears because the working heart rate remained below the upper limit for strain. The heart rate ranged between 75 bpm to 120 bpm in the present study and was considered within the tolerable limit, thus corroborating our findings with the previous study. But in terms of energy expenditure, we could find that with increasing horizontal distances, the VO_2 and EE increased almost two-fold while the distance increased from 45 cm to 60 cm. It could be because of static work; there is always energy expenditure to maintain the muscular tone for standing/standing-bending tasks. As the body moves away from the workspace, the external force required for pruning was more. Repetitive tasks and forceful cuts had to be made to perform tasks on-farm; shoulder flexion remained in a constant working mode, resulting in an awkward posture.[6] Working in the vineyard, almost half of the population reported musculoskeletal strains.[14,6] Our findings also showed that the RPE score increases with an increase in horizontal distance and vertical work height. Thus, the study suggests avoiding prolonged working with more distance and vertical positions. The physical environment of the workplace (temperature, humidity and tool quality) was not considered. The present study has some limitations in terms of its environment and the size of the population investigated. However, this study provides novel information related to the physiological strain of pruning. The energy expenditure analysis showed that the workers' concomitant physiological strain remained high at the above shoulder level with a medium distance during pruning**.** These results suggest that pruning activity is associated with a high risk of developing musculoskeletal disorders in the lower back. The adoption of frequent and continuous forward bending postures can be considered as 'extreme'. These analyzes suggest a link between the RPE ratings and the energy expenditure associated with this task.

Conclusions

Overall, the study identified the effect of pruning activity, done from different horizontal and vertical distances, on important physiological parameters and perceived relative stress in a simulated lab environment. The experimental outcomes revealed a gradual increase in physiological and psycho physiological stress with increasing the distance from the worker's body. Physiologically the work stress can be categorized as slightly moderate to moderately heavy. These findings also infer that ergonomic interventions are highly required for greenhouse workers to significantly modify workspace and reduce postural and physiological stresses for different heights and distances.

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Conflict of interest: None

List of Abbreviations

RPE	:	Rating of perceived exertion
MSD	:	Musculoskeletal disorders
RSI	:	Repetitive strain injuries
HR	:	Heart rate
NCC	:	Net cardiac cost
RCC	:	Relative cardiac cost
EE	:	Energy expenditure
ANOVA	:	Analysis of variance

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