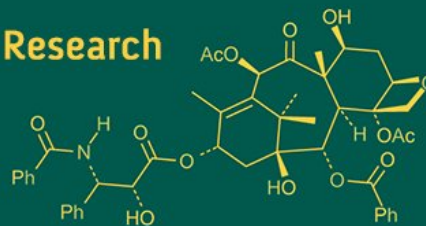


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Ergonomic evaluation of female farm workers performing agricultural spraying operations

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Abstract

Agricultural spraying operations expose women workers to considerable physiological workload, awkward working postures and musculoskeletal discomfort, necessitating reliable ergonomic assessment methods. The present study comparatively evaluated the effectiveness of Body Part Discomfort Score (BPDS), Working Heart Rate (WHR) and Rapid Upper Limb Assessment (RULA) for assessing ergonomic stress during agricultural spraying operations. Seven experienced women workers performed spraying using three electric knapsack sprayers (12, 16, and 20 L) at three crop heights under field conditions. WHR, RULA and BPDS were recorded for each treatment combination and analyzed using two-way repeated-measures ANOVA, Tukey's test, Pearson correlation, and relative sensitivity analysis. Significant effects of sprayer type, crop height and their interaction were observed for all three ergonomic indicators ($p < 0.05$). BPDS exhibited the highest sensitivity, recording a 161.10% increase across treatments, compared with 32.74% for WHR and 38.69% for RULA. Similarly, BPDS showed the largest F-values for sprayer (271.763) and height (145.815), indicating greater responsiveness to changes in operational conditions than WHR and RULA. Pearson correlation analysis revealed a strong positive relationship between BPDS and WHR ($r = 0.885$), while moderate correlations were observed between BPDS and RULA ($r = 0.444$) and between WHR and RULA ($r = 0.494$). Overall, although all three indicators effectively differentiated ergonomic stress during spraying operations, BPDS demonstrated superior sensitivity in detecting discomfort-related changes, suggesting its suitability as a comprehensive ergonomic assessment tool for women engaged in agricultural spraying.

Keywords: Body part discomfort score, RULA score, working heart rate, women agricultural workers, knapsack sprayer, occupational ergonomics

1. Introduction

Spraying pesticides in agriculture is essential for protecting crop from insects and pest (infestation) (Oerke *et al.*, 2004) [13]. It is labor-intensive and exhaustive due to the repetitive movements involved (Fathallah, 2010) [6]. Recent studies showed men migration from rural area to urban for financial security. Therefore, women participation in agriculture increased. Women constitute a substantial proportion of the agricultural workforce and are actively involved in spraying operations (Majumder and Shah, 2017) [9]. Spraying with knapsack sprayer, the operator ought to work with awkward postures while carrying the load. The combination of continuous load carrying and repetitive extreme movements induce higher perceived exertions. It leads to discomfort and fatigue for the operator. Therefore, women-specific ergonomic evaluation is important in agricultural spraying tasks (Mehta *et al.*, 2018) [11].

Ergonomic assessment of agricultural operations commonly involves physiological, postural and subjective discomfort evaluation methods. Working heart rate is frequently used to assess physiological workload associated with agricultural tasks (Arman *et al.*, 2021) [1]. RULA is widely applied for evaluating postural stress and musculoskeletal risk arising from awkward working postures (Kee, 2021) [1]. Similarly, Body Part Discomfort Score (BPDS) is employed to assess localized musculoskeletal discomfort perceived by workers during occupational activities (Cameron, 1996) [2]. Although these methods are individually used in ergonomic investigations, their relative sensitivity and effectiveness in representing ergonomic stress during women-oriented agricultural spraying operations remain insufficiently explored.

Particularly, the extent to which BPDS reflects localized discomfort beyond physiological and posture-based ergonomic indicators requires further investigation.

Every subject is different based on their cardiac function, muscle strength and capacity. Working heart rate is commonly used for evaluating physiological workload during agricultural operations (Morris *et al.*, 1961) [12]. However, cardiac responses mainly indicate overall physiological strain and may not sufficiently represent localized musculoskeletal discomfort arising from repetitive and posture-intensive activities. Similarly, RULA is widely employed for postural assessment and identification of musculoskeletal risk associated with awkward working postures. Nevertheless, the method primarily depends on postural angle evaluation and may be less sensitive to worker-perceived discomfort during prolonged operations. In contrast, BPDS enables assessment of localized discomfort experienced across different body regions and may provide more comprehensive ergonomic interpretation during agricultural spraying tasks.

Despite the widespread application of WHR, RULA and BPDS in ergonomic investigations, limited studies have comparatively examined their relative sensitivity in assessing ergonomic stress during agricultural spraying operations among women workers. Particularly, comparative evidence regarding the ability of BPDS to reflect localized discomfort relative to physiological and posture-based ergonomic indices remains scarce. Therefore, the present study was undertaken to compare BPDS, working heart rate (WHR) and RULA during agricultural spraying operations among women workers and to evaluate the comparative ergonomic sensitivity of BPDS as an assessment indicator.

2. Material and Methods

2.1 Study Location

The experimental investigation was carried out under field conditions at the Agronomy Division, ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi. Three electric knapsack sprayers were evaluated during pesticide spraying operations in maize crop during morning hours. Uniform field conditions were maintained throughout the experimentation to minimize environmental variability and ensure reliable ergonomic assessment.

2.2 Selection of Subjects

Seven healthy women workers in the age group of 25-35 years with average BMI of 24.5 ± 2.6 were selected for the study. The selected subjects were experienced in agricultural spraying operations and were physically fit to perform the experimental tasks. Prior to the study, the health condition of the subjects was assessed to ensure the absence of any musculoskeletal disorders, cardiovascular complications or physical impairments that could influence ergonomic evaluation. All subjects were familiar with spraying activities and voluntarily participated in the experiment.

2.3 Description of Sprayers

Three commercially available electric knapsack sprayers with tank capacities of 12 (S1), 16 (S2) and 20 L (S3) were selected for the study. The corresponding initial operating weights (including the sprayer and spray liquid) were 17.5, 23.2 and 25.7 kg, respectively. All sprayers were powered by in-built rechargeable batteries and operated using a

manually controlled cut-off valve for regulating the spray discharge. The variation in tank capacity and spraying height among the sprayers provided the basis for evaluating their ergonomic implications during spraying operations.

2.4 Experimental Procedure

The experimental trials were conducted during the morning hours to ensure favorable environmental conditions for spraying operations and to minimize the influence of heat stress on the ergonomic responses of the subjects (De Lima *et al.*, 2021) [4]. Each woman worker performed spraying operations using all three electric knapsack sprayers under similar field conditions at three spraying heights named elbow (H_1), shoulder (H_2) and above shoulder (H_3), thereby enabling a direct comparison of ergonomic parameters among the sprayers. The duration of each spraying trial was maintained at approximately 15 min, followed by a rest interval of 7 min to minimize the carryover effects of fatigue between successive trials. Efforts were made to maintain uniform operational conditions throughout the experiment to ensure consistency and reliability in the ergonomic assessment.

2.5 Ergonomic Assessment Parameters

2.5.1 Working Heart Rate (WHR)

Working heart rate (WHR) of the subjects was measured using a wristwatch-type POLAR heart rate monitor (Model: RS300X G1). The sensor band was securely positioned on the upper or lower arm of each subject before the commencement of the spraying operation. Heart rate data were continuously recorded throughout the experimental period and transmitted to a computer via Bluetooth connectivity for subsequent analysis. To obtain a representative measure of physiological workload, the average heart rate recorded from the 6th minute onward was considered for analysis. The initial 5 min of operation were excluded to allow the subjects to attain a steady-state working condition and to minimize the influence of transient physiological responses at the beginning of the task (De and Sen, 1992) [5].

2.5.2 Rapid Upper Limb Assessment (RULA)

Rapid Upper Limb Assessment (RULA) was employed to evaluate the postural risk associated with spraying operations. Videos and photographs of the subjects were captured during the experimental trials to record working postures. The recorded images and video frames were carefully analyzed to determine the angular deviations of the upper body segments involved in the task. Postural scores were assigned using the RULA assessment worksheet developed by Mcatamney and Corlett, (1993) [10]. The assessment considered the posture of the upper arm, lower arm, wrist, neck, trunk and legs, along with the associated muscle use and force exertion. Individual scores for the body segments were combined according to the RULA scoring procedure to obtain an overall RULA score for each subject. The final score was used to classify the level of postural risk, where higher scores indicated a greater need for ergonomic intervention.

2.5.3 Body Part Discomfort Score (BPDS)

Body Part Discomfort Score (BPDS) was used to assess the subjective perception of musculoskeletal discomfort experienced by the subjects during spraying operations. The

assessment was carried out following the body map technique proposed by Corlett and Bishop (1976) [3], in which the human body is divided into 27 anatomical regions. At the end of each spraying trial, the subjects were asked to identify the body regions experiencing discomfort and indicate the corresponding intensity of discomfort based on their perceived level of strain. The discomfort intensity was rated using a six-point scale comprising Very Mild (1), Mild (2), Moderate (3), Severe (4), Very Severe (5) and Extremely Severe (6).

The identified discomfort scores for all affected body regions were recorded and subsequently used to compute the overall BPDS for each subject. The assessment was performed separately for each experimental trial with the three sprayers. Unlike physiological and posture-based ergonomic measures, BPDS directly reflects worker-perceived discomfort and enables the evaluation of localized musculoskeletal strain associated with different body regions. The overall BPDS was calculated and used as an indicator of discomfort severity during spraying operations.

2.6 Statistical Analysis

The experimental data obtained for Working Heart Rate (WHR), Rapid Upper Limb Assessment (RULA) score and Body Part Discomfort Score (BPDS) were subjected to statistical analysis using Origin Pro 2026 software. A two-way repeated measures analysis of variance (ANOVA) was performed to evaluate the effects of sprayer type, crop

height and their interaction on the ergonomic parameters. Mean comparisons among treatment combinations were conducted using Tukey's Honest Significant Difference (HSD) test to identify significant differences between sprayers and crop heights. Pearson's correlation analysis was carried out to examine the relationships among BPDS, WHR and RULA and to assess the extent to which discomfort perception was associated with physiological workload and postural risk. In addition, linear regression analysis was performed to investigate the strength of association between BPDS and the other ergonomic indices. Statistical significance for all analyses was tested at the 5% probability level ($p < 0.05$). The combined use of ANOVA, mean comparison and correlation analyses enabled assessment of the relative sensitivity and effectiveness of BPDS, WHR and RULA as ergonomic indicators during agricultural spraying operations performed by women workers.

3. Results and Discussion

The present study intended to observe the main and interaction effects of sprayer tank capacity and spraying height on selected physiological, postural, and subjective ergonomic indicators among women workers during agricultural spraying operations. The descriptive statistics of the measured variables, expressed as mean $\pm$ standard deviation (SD), are presented in Table 1.

Table 1: Responses of WHR, BPDS and RULA at different crop heights for three sprayers during spraying activity

Sprayer	Height	WHR (Mean $\pm$ SD)	BPDS (Mean $\pm$ SD)	RULA (Mean $\pm$ SD)
S1	H1	102.99 $\pm$ 10.98	20.91 $\pm$ 8.96	4.38 $\pm$ 0.08
S1	H2	113.40 $\pm$ 13.17	29.09 $\pm$ 5.04	5.29 $\pm$ 0.29
S1	H3	123.97 $\pm$ 11.68	34.00 $\pm$ 3.72	5.71 $\pm$ 0.72
S2	H1	116.64 $\pm$ 8.33	34.43 $\pm$ 4.07	4.29 $\pm$ 0.29
S2	H2	126.27 $\pm$ 11.59	38.14 $\pm$ 5.15	5.24 $\pm$ 0.65
S2	H3	128.85 $\pm$ 10.36	44.43 $\pm$ 6.43	5.67 $\pm$ 1.15
S3	H1	127.87 $\pm$ 9.31	37.47 $\pm$ 4.47	5.95 $\pm$ 0.71
S3	H2	135.90 $\pm$ 10.58	46.43 $\pm$ 6.59	5.76 $\pm$ 0.65
S3	H3	136.71 $\pm$ 10.00	54.57 $\pm$ 4.86	5.57 $\pm$ 1.17

3.1 Effect of Sprayer Tank capacity and Crop/spraying Height on Ergonomic Parameters

The results of ANOVA (analysis of variance) given in Table 2 revealed that sprayer type, crop height and their interaction significantly influenced BPDS, WHR and RULA scores ($p < 0.05$). Among the three ergonomic indicators, BPDS exhibited the highest F-values for both sprayer tank capacity ($F = 271.763$) and spraying height ($F = 145.815$), indicating greater responsiveness to variations in operational conditions. WHR also showed significant treatment effects with comparatively high F-values, whereas RULA demonstrated relatively lower F-values, suggesting lower discriminatory power among the tested treatments. Similar increasing WHR trend was presented by Kumar *et al.*, (2023) with the increasing operating heights. The significant interaction effects observed for all three parameters indicate that the influence of sprayer type varied with crop height. The comparatively higher F-values obtained for BPDS suggest that discomfort perception was more sensitive to ergonomic stress arising from changes in spraying conditions than physiological workload and postural assessment measures.

Table 2: Two-way repeated measures ANOVA for BPDS, WHR and RULA under different sprayer types and crop/spraying heights.

Parameter	Factor	F-value	p-value
BPDS	Sprayer	271.763	<0.0001
BPDS	Height	145.815	<0.0001
BPDS	Sprayer $\times$ Height	4.205	0.0049
WHR	Sprayer	253.514	<0.0001
WHR	Height	118.408	<0.0001
WHR	Sprayer $\times$ Height	10.013	<0.0001
RULA	Sprayer	8.621	0.00056
RULA	Height	9.277	0.00034
RULA	Sprayer $\times$ Height	4.988	0.0017

3.2 Mean Comparison of Ergonomic Parameters

Table 3: Mean comparisons of WHR, BPDS and RULA under different sprayer types and crop/spraying heights

Sprayer	WHR	BPDS	RULA	Height	WHR	BPDS	RULA
S1	113.45 ^c	28 ^c	5.13 ^b	H1	113.45 ^c	30.94 ^c	4.87 ^b
S2	124.43 ^b	39 ^b	5.26 ^b	H2	125.19 ^b	37.89 ^b	5.43 ^a
S3	133.49 ^a	46.16 ^a	5.76 ^a	H3	116.34 ^a	44.33 ^a	5.65 ^a

Means followed by different letters within a column differ significantly at $p < 0.05$ according to Tukey's HSD test. The mean comparison analysis presented in Table 3 showed significant differences among sprayer tank capacities and spraying heights for all ergonomic indicators. Among the sprayers, S3 recorded the highest WHR (133.49 beats min^{-1}), BPDS (46.16) and RULA score (5.76), indicating greater ergonomic stress during spraying operation. Conversely, S1 exhibited the lowest values for all parameters. Similar trends were observed across crop heights, where ergonomic stress increased significantly from H1 to H3. The increase in BPDS with increasing crop height was more pronounced than the corresponding increases in WHR and RULA, suggesting that discomfort perception was highly responsive to operational changes encountered during spraying. Similar findings of higher WHR and BPDS were recorded by Sharma and Raheman, (2024) ^[14]. These findings indicate that women workers experienced greater physiological strain, discomfort and postural stress when operating sprayers under taller crop conditions.

3.3 Relationship among BPDS, WHR and RULA

The correlation analysis (Table 4) revealed a strong positive relationship between BPDS and WHR ($r = 0.885$), indicating that increases in perceived discomfort were associated with increases in physiological workload. This finding suggests that body discomfort experienced during spraying operations closely reflects cardiovascular strain. In contrast, BPDS exhibited only a moderate relationship with RULA ($r = 0.444$), while WHR and RULA also showed a moderate association ($r = 0.494$). The comparatively weaker relationship between BPDS and RULA indicates that postural risk alone could not fully explain the discomfort perceived by workers as it depends on many other factors. The result suggests that BPDS captures additional ergonomic information related to localized muscular fatigue, repetitive movements and worker-perceived discomfort that may not be adequately represented through posture-based assessment methods.

Table 4: Pearson correlation coefficients among BPDS, WHR and RULA.

Pair	Correlation coefficient (r)
BPDS vs WHR	0.885
BPDS vs RULA	0.444
WHR vs RULA	0.494

3.4 Relative Sensitivity of Ergonomic Indicators

To compare the responsiveness of the ergonomic indicators, the percentage change between the lowest and highest treatment means was calculated as given by (Soriano, 2017):

$$\text{Percentage Change (\%)} = \frac{\text{Highest Mean} - \text{Lowest Mean}}{\text{Lowest Mean}} \times 100$$

The resulting values were used to assess the relative sensitivity of BPDS, WHR and RULA under different spraying conditions.

Table 5: Relative sensitivities of BPDS, WHR and RULA based on percentage change between the lowest and the highest treatment means

Parameter	Lowest Mean	Highest Mean	% Change
BPDS	20.90	54.57	161.10
WHR	102.99	136.71	32.74
RULA	4.29	5.95	38.69

The relative sensitivity analysis (Table 5) demonstrated substantial differences among the ergonomic indicators. BPDS showed the highest percentage change (161.10%) between the lowest and highest treatment means, compared with only 32.74% for WHR and 38.69% for RULA. Thus, BPDS exhibited approximately 4.9 times greater variation than WHR and 4.2 times greater variation than RULA across the experimental conditions. The larger magnitude of change observed for BPDS indicates its superior ability to detect ergonomic stress arising from differences in sprayer type and crop height. Furthermore, the higher ANOVA F-values obtained for BPDS support this observation and confirm its greater sensitivity relative to physiological and posture-based ergonomic indicators.

BPDS demonstrated greater sensitivity to changes in sprayer type and crop height than WHR and RULA. Although all three indicators significantly differentiated ergonomic stress conditions, BPDS exhibited the highest F-values and the greatest relative change (161.10%), indicating its superior responsiveness in reflecting ergonomic stress experienced by women workers during agricultural spraying operations.

3.5 Regression Relationship between BPDS and Other Ergonomic Indicators

The regression analysis (Fig. 1) revealed a strong positive association between BPDS and WHR ($R^2 = 0.782$), indicating that approximately 78.2% of the variation in physiological workload could be explained by perceived body part discomfort. In contrast, the relationship between BPDS and RULA was comparatively weaker ($R^2 = 0.197$), indicating that postural risk scores explained only 19.7% of the variation in discomfort scores as shown in Fig. 2. The stronger BPDS-WHR relationship suggests that discomfort perception closely reflects physiological workload during spraying operations. However, the weaker BPDS-RULA relationship indicates that discomfort perception is influenced by factors beyond postural deviations, including task duration, repetitive movements and localized muscular fatigue. Therefore, BPDS appears to integrate both physiological and musculoskeletal responses, providing a more comprehensive assessment of ergonomic stress than either WHR or RULA individually.

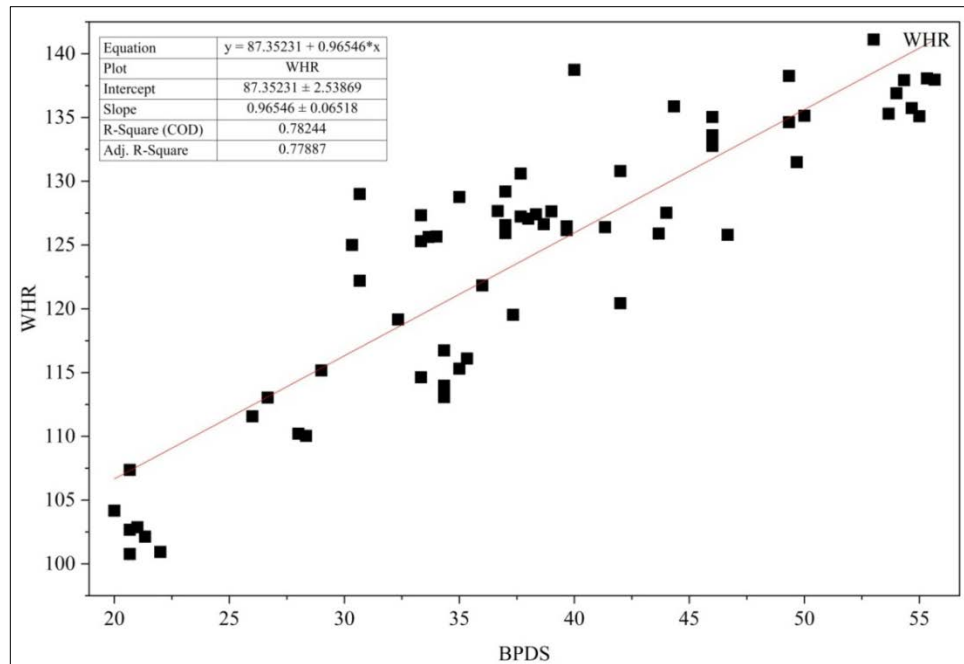


Fig 1: Relationship between body part discomfort score (BPDS) and working heart rate (WHR) during spraying operations among women workers.

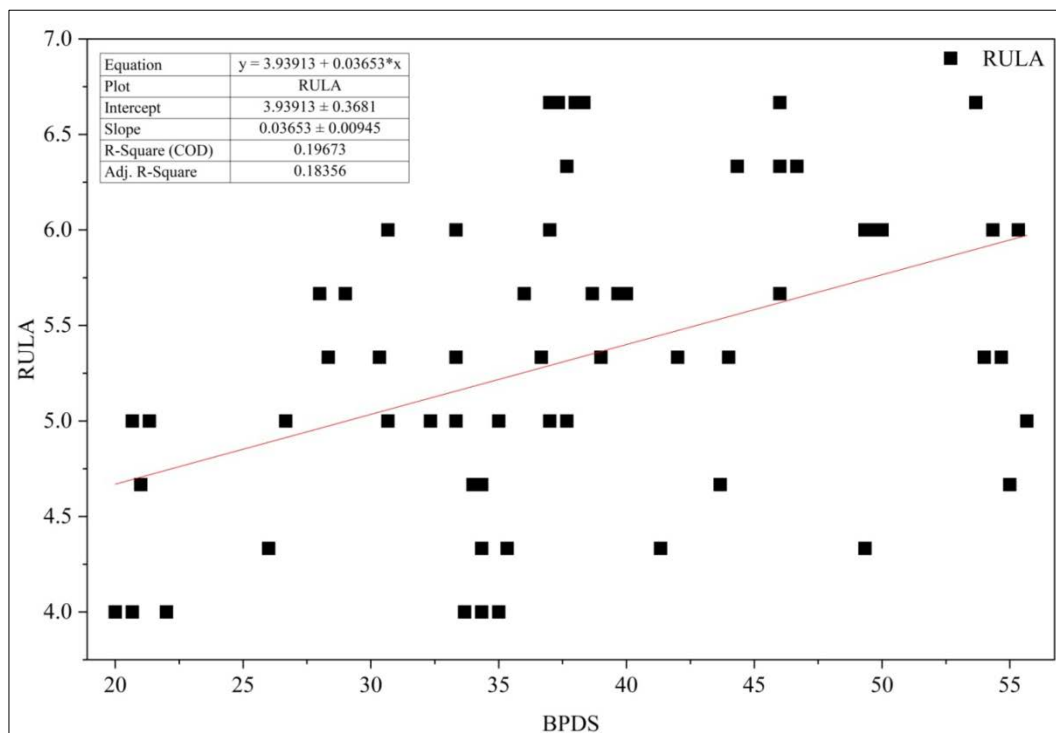


Fig 2: Relationship between body part discomfort score (BPDS) and RULA score during spraying operations among women workers.

4. Conclusion

Overall, the present study determined the effect of sprayer weight and crop/spraying height on women operators based on important ergonomic parameters. The experimental outcomes revealed that the relationship between BPDS and WHR exhibited a strong positive association indicating that increased discomfort perception was accompanied by elevated physiological workload during spraying operations. In contrast, RULA score alone could not fully explain the discomfort experienced by workers. These findings suggest that BPDS provides additional ergonomic information that may not be adequately captured by physiological or posture-based assessment methods.

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