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Original Article

Discomfort Analysis in Computerized Numeric Control Machine Operations

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Objectives: The introduction of computerized numeric control (CNC) technology in manufacturing industries has revolutionized the production process, but there are some health and safety problems associated with these machines. The present study aimed to investigate the extent of postural discomfort in CNC machine operators, and the relationship of this discomfort to the display and control panel height, with a view to validate the anthropometric recommendation for the location of the display and control panel in CNC machines.
Methods: The postural discomforts associated with CNC machines were studied in 122 male operators using Corlett and Bishop's body part discomfort mapping, subject information, and discomfort level at various time intervals from starting to end of a shift. This information was collected using a questionnaire. Statistical analysis was carried out using ANOVA.
Results: Neck discomfort due to the positioning of the machine displays, and shoulder and arm discomfort due to the positioning of controls were identified as common health issues in the operators of these machines. The study revealed that 45.9% of machine operators reported discomfort in the lower back, 41.8% in the neck, 22.1% in the upper-back, 53.3% in the shoulder and arm, and 21.3% of the operators reported discomfort in the leg.
Conclusion: Discomfort increased with the progress of the day and was highest at the end of a shift; subject age had no effect on patient tendency to experience discomfort levels.

Key Words: Discomfort, Computerized numeric control machines, Anthropometry, Human engineering, Work-related musculoskeletal disorders, Discomfort mapping

Introduction

Occupational injuries and illnesses, particularly those known as work-related musculoskeletal disorders (WRMSD), can result in pain or discomfort in the arms, neck, and back for a significant number of workers in a variety of industrial sectors. Although there are many factors, such as age, gender, or physical activity outside of work which influence the development of musculoskeletal disorders, one of the major factors is not having work system designs that fully incorporate anthropometric-based ergonomics. For example, arm discomfort increases with an increase in keyboard height above elbow level, and keyboard height has effects on working posture adopted by the operators and the rate of postural shift was a good indication of discomfort on a video display terminal task. Discomfort and postural shift rates have adverse effects on performance (e.g., error rate) of the operators [1]. Moreover, high levels of neck and shoulder-girdle discomfort have been observed in video display terminal (VDT) work [2] and suggest the need for further atten-

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tion to the control of cervico-brachial pain syndromes in VDT work is suggested. Frequent changes in posture are a good indicator of discomfort, and lordotic postures with a forward leaning pelvis and low mobility are the principal causes of the increase in discomfort [3]. Concerns have arisen that keyboard height is a causal factor in the development of WRMSD among VDT operators [4]. The way by which workers perceive the risks to which they are exposed can be an important input for a better understanding of risk management, and ultimately, to their own safety [5]. It seems reasonable to assume that risk perception in workplaces can, at least to a certain extent, influence workers' behavior and their exposure to these risks [6]. Analysis of tasks or activities can provide information on factors affecting human performance, as well as the information needed for system designers [7]. In recent years, the manufacturing industry has focused strongly on elimination of losses, including an endeavor to increase the proportion of value-added (direct) work in the jobs of individuals [8]. However, this may increase work intensity and thereby, increase the risk for developing musculoskeletal disorders [9]. The activity time pattern may be assessed based on workers' own reports [10] or an interview [11].

The main objective of the present study is to investigate the extent of postural discomfort in the computerized numeric control (CNC) machine operators, and its relationship to the height of the display and control panels, with a view to validate the anthropometric recommendation for the location of the display and control panels in CNC machines.

Materials and Methods

A cross-sectional study was conducted in a Public Sector organization in which approximately 122 operators (all male), from ages 23 to 59 years and who worked in various CNC work centers were involved in this discomfort study. All operators were provided information about the study and informed consent was obtained from all operators prior to their study participation. No operator presented with health issues that were likely to affect or to be affected participation by this study.

Survey of CNC machines

Seventy five CNC machines (100% studied) grouped based on their operations like turning center, machining center, boring machine, gas cutting, welding, edge preparation, press brake and bending machines. Products like valves of different sizes, water wall panels for boilers; headers etc. are manufactured using these CNC machines. In the machines studied, valves of bore diameter 2 inches and tubes for making water wall panels and headers (diameter 76 mm, length 12 m) are manufactured. Various production activities were carried out in all CNC work centers. It was observed that the operators were performing well at the beginning of the shift, and met the expected production as standardized by the department (i.e., based on the time study for every operation), when the time increased, the production rate was reduced and no longer followed the planned schedule. Depending on the operation (cycle time varies from 69 seconds to 210 seconds), the operators stand near the control panel with the arm in a static posture and view the display. The only exception was during the set-up operation. The machines were studied to record the position of the displays and control keys. These were compared to the anthropometrically recommended values of 5th percentile eye height and elbow rest height, respectively, as per the National Ergonomic Database for the Indian Male Population [12].

Controls and display of CNC machines

Positions of the controls and displays provided in these machines do not follow a standardized pattern. For example, display and control panel mounting can be on the machines or mounted separately, on a pendant or on a stand. For most of the machines, the data keys are at the level of the display itself.

The positioning of control panel and display are very important in CNC machines to reduce difficulty in static posture and to prevent WRMSDs for the operators, such as back pain, neck pain, and shoulder pain. On the basis of the difference between the anthropometric values, the machines were grouped for control panel as the high variation group (30-55 cm), medium variation group (16-29 cm) and low variation group (< 16 cm). For the display the height varied up to 42.6 cm from the eye height and grouped as high variation group (16-42 cm), medium variation group (11-15 cm), and low variation group (< 10 cm) and the discomfort levels were arrived for the control panel and the display (Table 1). Control panel heights and display heights for various CNC work centers were compared with anthropometrically recommended values, elbow height (95.6 cm) and eye height (143.4 cm).

Discomfort assessment

Discomfort assessment is the process of identifying various body parts stressed by the combination of repeated actions, static or extreme postures, and forceful exertion due to repeated actions and determining intensities and frequencies of pains occurring to those body parts while performing varied tasks. Postural discomfort is one of the crucial problems of the operators in CNC centers.

One of the most commonly and widely accepted methods

Table 1. Comparison of height of control panel key board and display with recommended values (5th percentile elbow rest height and eye height)

Machine type	Actual height (cm)		Recommended height (cm)		Difference (cm)	
	Control	Display	Control	Display	Control	Display
Edge preparation machine	150.0	186.0	95.6	143.4	54.4	42.6
Machining centre	145.0	161.4	95.6	143.4	49.4	18.0
Gas cutting machine	125.7	160.5	95.6	143.4	30.1	17.1
Press brake machine	125.5	159.0	95.6	143.4	29.9	15.6
Turning centre	120.0	156.2	95.6	143.4	24.4	12.8
Drilling machine	118.5	156.0	95.6	143.4	22.9	12.6
Lathe	118.3	150.9	95.6	143.4	22.7	07.5
Welding machine	111.3	150.0	95.6	143.4	15.7	06.6
Boring machine	110.0	147.8	95.6	143.4	14.4	04.4
Bending machine	103.5	145.3	95.6	143.4	07.9	01.9

of obtaining information about body discomfort are a questionnaire method. This method of discomfort assessment is inexpensive, sensitive and suitable for field work. Corlett and Bishop's method of body mapping [13] was used for obtaining information about body discomfort. Several researchers have used this method to identify the sites of pain and their intensities in varying tasks [14-16]. A discomfort study was done to assess the possible sources of the discomfort and time pattern of development of discomfort over time intervals, so as to provide indicators for intervention.

Questionnaire survey

CNC operators were asked to complete the questionnaire for which Corlett and Bishop's (1976) body part discomfort mapping was used.

The operators were asked to state the level of their discomfort level as one of the following phrases: No discomfort, minimal discomfort, moderate discomfort, severe discomfort, and extreme discomfort. On the basis of their observation, the severity score was assigned a value of 0, 1, 2, 3, or 4 respectively for measuring the discomfort level, in their body parts during different periods of their shift such as the start of a shift, at morning break, before lunch, after lunch, at afternoon break, and at the end of the shift.

On the basis of the discussion with the operators, the responses were recorded and the scorings were tabulated to calculate the discomfort level for each body part of operators.

Discomfort mapping

A body map was used for the study. It was given with a 5-point scale, with extremes anchored by the terms "no discomfort" and "extreme discomfort" (as for the questionnaire survey, described earlier), in which each of the operators were asked to judge the present level of overall discomfort. Following this, the operator was asked to indicate the part or parts of the body in which they felt most uncomfortable and the next most uncomfortable, followed by no additional parts reported. The procedure was carried out at the following regular intervals: before the starting of work, before morning break, before lunch, before afternoon break, and before the end of work. The procedure was carried out throughout the day to study the growth of discomfort as a result of the job. The mean weighted score was calculated for each part of the body to make an appraisal of the body discomfort of the operators.

Operators data

All the 122 male operators who operated the machines were participated in the study (participation rate 100%). They were divided into 3 groups by age (< 39, 40-49 and 50-59). The mean age is 45.1 years (standard deviation [SD] = 10.16) and the mean height is 164.2 cm (SD = 5.96) (Table 2).

Statistical analysis

Analysis of variance was used to determine the statistical significance of discomfort.

The three age groups, and difference in discomfort between the time periods were the related attributes and the body

Table 2. Operators data

Age group, years	Number (%)	Parameter	Minimum	Maximum	Mean	Standard deviation
< 39	27	Age, years	23	38	27.4	3.90
	(22.1)	Height, cm	156	175	164.9	4.77
40-49	49	Age, years	43	49	47.3	1.55
	(40.2)	Height, cm	155	190	164.8	6.19
50-59	46	Age, years	50	59	53.0	2.66
	(37.7)	Height, cm	150	178	163.2	6.33

Table 3. Details of operations carried out in the machines at various time intervals

CNC machine group	Cycle time per operation, second	Operation plan for a period, n	Start of shift	Morning break	Before lunch	After lunch	Afternoon break	End of shift
Edge preparation machine	74	48	48	46	32	46	45	30
Machining centre	160	22	22	21	16	22	21	17
Gas cutting machine	142	24	24	23	20	24	23	18
Press brake machine	110	32	32	30	19	31	32	25
Turning centre	210	17	17	16	12	16	16	13
Drilling machine	151	23	23	23	18	24	23	19
Lathe	151	24	24	23	19	23	23	19
Welding machine	69	51	51	50	40	52	51	39
Boring machine	147	24	24	23	18	24	23	19
Bending machine	102	34	34	33	26	35	34	25

CNC: computerized numeric control.

parts were considered as the main effects (factors) in the analysis.

Results

Survey of CNC machines

The number of operations/products completed (in each cycle) for each time period was varied. The maximum was achieved as per production plan at the start of the shift in all machines. At lunch break after 4 hours of work, the operations/products competed in the machining center was 16 out of 22 planned, in the gas cutting machine 20 out of 24 planned, in press brake machine 19 out of 32 planned, in turning centre 12 for 17 planned, in drilling machine 18 completed out of 24 planned, in lathe 19 out of 24 planned, in welding machine 39 out of 51 planned, in boring machine 18 out of 24 planned and in bending machine 26 operations completed out of 40 planned. Similarly at the end of the shift 38 operations completed out 48 planned in edge preparation machine, in machining centre 17 out of 22 planned, in gas cutting machine 18 out of 24 planned, in press brake machine 25 out of 32 planned, in turning centre 13 completed out of 17 planned, in drilling machine 19 out of 24 planned, in lathe 19 out of 24 planned, in welding machine 39 out of 51 planned, in boring machine 19 out of 24 planned and in bending machine 25 operations completed out of 34 planned for a shift (Table 3), at a decreased rate by 20 to 25 % at the end of the shift, with a small improvement after the lunch break.

Questionnaire survey

The levels of discomfort reported in various body parts are shown in Fig. 1. It was observed that 45.9% reported discomfort in lower back, 41.8% in neck, 22.13% in upper-back, 53.27% in shoulder and arm and 21.31% of the operators reported discomfort in the leg. Leg and upper back discomfort are not considered to be a major problem, while shoulder, neck, and lower back are areas with much higher levels of discomfort.

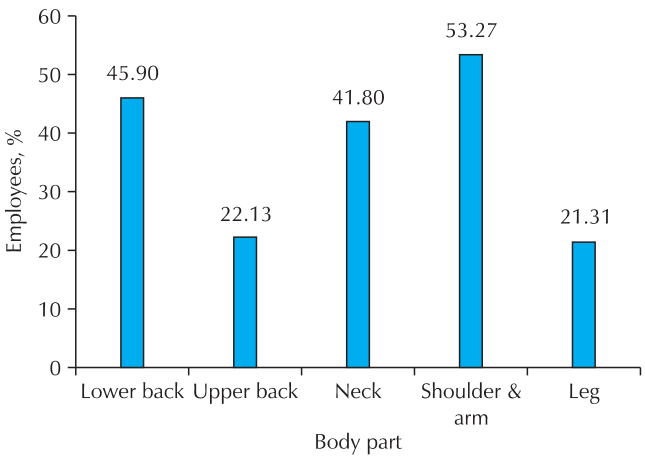

Fig. 1. Percentage of operators having discomfort in different body parts.

Discomfort mapping

The mean discomfort scores reported at various time intervals are 0.74 ± 0.594, 0.87 ± 0.484 and 1.08 ± 0.463 at morning break for the age groups < 39, 40-49 and 50-59 respectively, similarly 1.66 ± 0.733, 1.53 ± 0.710 and 1.97 ± 0.649 before lunch; 0.74 ± 0.712, 0.42 ± 0.577 and 0.84 ± 0.665 after lunch; 1.77 ± 0.751, 1.83 ± 0.550 and 1.97 ± 0.807 at afternoon break; and 2.74 ± 0.732, 2.85 ± 0.612 and 3.30 ± 0.785 at the end of shift respectively (Table 4) for the age groups, the mean discomfort score were decreased in the old age group. The difference in discomfort levels between the 40-49 group and the 50-59 group, and between < 39 group and 50-59 group were statistically different ($p < 0.05$), while that of between < 39 group and 40-49 group was not significant.

There was a significant difference of discomfort level between age groups, the least significant difference (LSD) was arrived taking into account the sample sizes of the two groups being compared (Table 5). The modulus value of discomfort for start of the shift to before lunch was 1.59 and start of shift to end of shift was 2.67 which were more than the LSD of 0.35 for age group < 39, similarly 1.48 and 2.82 for age group 40-

Table 4. Discomfort scores for different age group at various times (mean ± standard deviation)

Age group, years	Start of the shift	Morning break	Before lunch	After lunch	Afternoon break	End of the shift
< 39	0	0.74 ± 0.594	1.66 ± 0.733	0.74 ± 0.712	1.77 ± 0.751	2.74 ± 0.732
40-49	0	0.87 ± 0.484	1.53 ± 0.710	0.42 ± 0.577	1.83 ± 0.550	2.85 ± 0.612
50-59	0	1.08 ± 0.463	1.97 ± 0.649	0.84 ± 0.665	1.97 ± 0.807	3.30 ± 0.785

Table 5. Results of ANOVA for body discomfort at various times

Age group, years	Mean discomfort for different time	Difference between mean discomfort (modulus value)		LSD	Comparison with LSD
< 39	Start -0.074 Lunch -1.67 End -2.74	Start of shift to before lunch Start of shift to end of shift	1.59 2.67	0.35	> 0.35* > 0.35*
40-49	Start -0.041 Lunch -1.53 End -2.86	Start of shift to before lunch Start of shift to end of shift	1.48 2.82	0.22	> 0.22* > 0.22*
50-59	Start -0.0217 Lunch -1.978 End -3.3043	Start of shift to before lunch Start of shift to end of shift	1.96 3.28	0.25	> 0.25* > 0.25*
Overall	Start -0.041 Lunch -1.729 End -3.000	Start of shift to before lunch Start of shift to end of shift	2.96 1.689	0.157	> 0.157* > 0.157*

LSD: least significant difference.
*Significant.

49 which were more than 0.22 and for age group 50-59, 1.96 and 3.28 which were more than 0.25. The overall modulus value of discomfort (age group 23-59) for start of the shift to before lunch was 2.96 and start of shift to end of shift was 1.689 which was more than the LSD of 0.157. For < 39 age group, the difference in discomfort levels with increasing time was all significant (at the 1% level), except between the AM break vs. end of lunch. For the 40-49 age groups, all the differences are significant at the 1% level. For the 50-59 age group, all the differences are significant at the 1% level, except between the AM break vs. end of lunch and before lunch vs. the PM break. Over-all, taking all age groups together, all the differences were significant at the 1% level.

The mean discomfort score for all age groups body part-wise is shown in Fig. 2. The discomfort levels with increasing time are more which reflects on the body parts involved. The arm and shoulder score was the highest, followed by leg, lower back, and upper back.

Difference in height of control panel and display and the discomfort score

There are vast differences in the anthropometric values with actual panel height (varies from 7.9 cm to 54.4 cm). Although the discomfort level was reduced when the control panel was at the actual elbow rest height of the operators (mean 107 cm), shoulder scored with 1.6, 2.8 and 3.1 for low, medium and high difference; neck scored 2.45, 2.57 and 2.71; lower back scored 1.5, 2.81 and 3; and upper back scored with 2.5, 2.57 and 2.62 for low, medium and high difference respectively were the worst affected (Fig. 3).

Fig. 4 clearly indicates that level differences in the display (varies from 1.9 cm to 42.6 cm) are directly related to discomfort reported in the neck scored with 2, 2.57 and 2.71 for low, medium and high difference; shoulder with 2.47, 3 and 3.1; lower back scored 2.36, 2.62 and 2.62; and upper back scored with 2.27, 2.83 and 3 for low, medium and high difference respectively. The highest display was seen to be at a height of 186 cm which was much more than the eye height (mean 157 cm, 5th percentile 143.4 cm). The worst affected body parts are shoulder, neck, and upper back.

For low difference group upper back vs. lower back, shoulder vs. leg, shoulder vs. upper back was all significant (at the 1% level) for medium difference group shoulder vs. leg, shoulder vs. upper back was all significant (at the 1% level) and for high difference group shoulder vs. leg, shoulder vs. upper

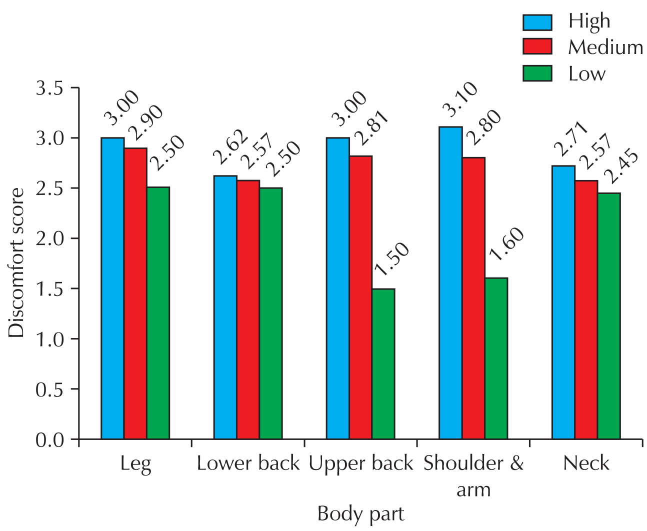

Fig. 3. Difference in control panel height and the body part discomfort.

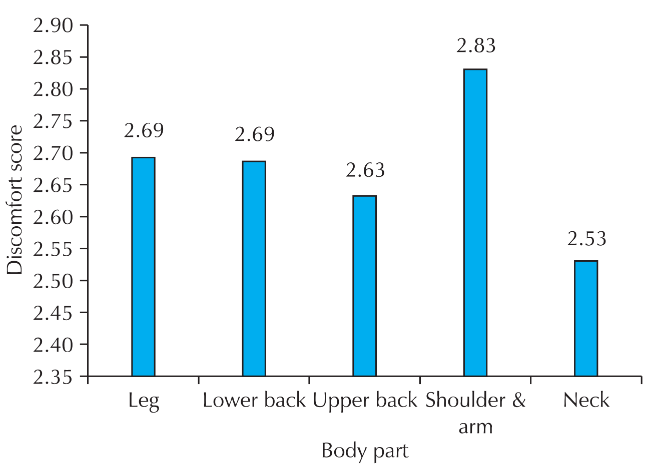

Fig. 2. Discomfort score (mean) body part-wise.

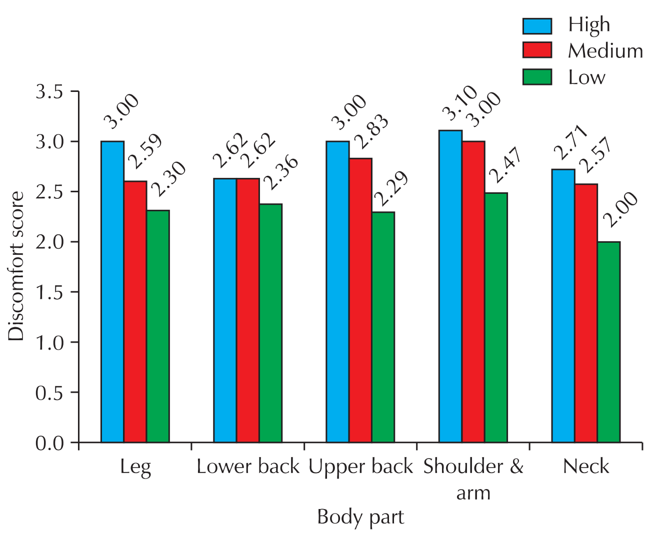

Fig. 4. Difference in display height and body part discomfort.

back was all significant (at the 1% level). Taking all difference group together, upper back vs. neck, upper back vs. lower back, shoulder vs. upper back, shoulder vs. leg, leg vs. lower back, are significant at the 1% level.

Discussion

In edge preparation machines, the edges of the tubes were chamfered for making panels, the edge prepared pipes were then welded together in welding machines to form panels. Plates were cut to the required shapes in the gas cutting machines. Pipes and plates were bent to different shapes for making panels in press brakes. Other machines were used to prepare bolts and nuts, form threads and gate-ways, bore the valve bodies, and machine the valve flanges and valve stems. The nature of the CNC machine task was such that during operation, operators were only engaged for small periods of time at the controls and continual time monitoring the displays. During set-up, the proportions of control operation versus display viewing are more or less equal. It was understood from the survey the discomfort was due to frequent movement of fingers on the keyboard and the eye movement from the panel and display, the operators expressed the discomfort was mainly due to the difference in the height of panel and display and the repetitive movements. The operation was high as specified in the beginning of the shift but reduced as the time was increased, this was due the discomfort interfere with the ability of operator performing his duty.

The analysis of the mean discomfort level at different body parts during different time intervals for the different age groups revealed that except at the start of the shift, operators felt musculoskeletal discomfort in various body parts throughout the shift, and was highest at the end of the shift. The older operators reported higher levels of discomfort, the mid-day break was not sufficient for complete recovery, particularly to the older operators. It is important to remember that the technology is relatively new, and thus greater age does not mean greater exposure to the work condition.

Discomfort increases when the difference in height increases (high difference level with respect to anthropometric recommended value), reduced at the medium level difference and less in the low difference level both for control and display. Thus, the control panel height and display height are the major cause for the reported discomfort. From the statistical analysis over-all, taking all age groups together, all the differences are significant at the 1% level, and upper back vs. neck, upper back vs. lower back, shoulder vs. upper back, shoulder vs. leg, leg vs. lower back, are significant at the 1% level. This clearly indicates the difference level in both for control and display with respect to the anthropometric recommended values.

There are three factors that could not be controlled in the present study and which might have interfered with the results. Firstly, the displays and the control keys are mounted on the same panel. Hence there is likely to be some interaction between neck positions required to look at the displays on very high or very low control panels and the neck positions required to look at the keys on such very high or very low control panels. The same may hold true for back muscles also. Secondly, the nature of the operator's task varies with the type of operation performed on the particular machine-some operations or processes may require more frequent and precise display monitoring than others and some may require greater programming and control steps than other operations or processes. Third, the height of the operators varied between groups. Though the mean height was not remarkably different between groups, there are large variations in the minimum and maximum values, particularly for the middle age group (41-49 years). These individuals may have contributed relatively more to the mean discomfort scores. Being a 100% sample, no height matching was possible. Although there are many factors which influence the productivity of CNC machine work, operator discomfort was one of the major factors among them [17]. Many risk factors for WRMSD are present. The present study reveals that though the physical work environment of CNC operators may be better compared with that of conventional machine operators, CNC operators do experience discomfort, which increases from the start of work reaching a maximum at the end of the shift, irrespective of age. Forty five point nine percent reported discomfort in lower back, 41.8% in neck, 22.1% in upper-back, 53.3% in shoulder and arm, and 21.3% of the operators reported discomfort in the leg. The study suggests that a causative factor may be the positions of the control and display, which vary widely from the recommended values (based on anthropometry). The variation in the height of control panel and display with respect to the anthropometrically recommended values (elbow and eye height respectively) are seen to be related to the degree of discomfort, the high variation group having higher discomfort than the low variation group. It is possible that the problem is caused by the integration of controls and display into the same panel, and it is recommended that controls panels should be separate from the display, to allow the users to maintain optimum elbow height. Control panels should preferably be mounted on booms (swinging arms) with height adjustability.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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