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A comparative study of two shovel designs

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In the present study a modified shovel design with two perpendicular shafts is presented. This modified, two-shaft shovel was compared with a regular shovel. The modified shovel was evaluated and tested in a controlled laboratory environment using surface electromyography recorded from the lumbar paraspinal muscles. The new shovel design was also tested in a field study using ratings of perceived exertion. The results indicate that there was a significant reduction in EMG values of the lumbar paraspinal muscles and a consistent reduction in perceived exertion ratings while the modified shovel was being used for removing dirt in digging trenches up to 90 cm in depth.

Keywords: Shovels, hand tools, musculoskeletal disorders, field study, surface electromyography

Introduction

Musculoskeletal disorders constitute one of the major problems in occupational environments. The National Institute of Occupational Safety and Health (1981) reported that, in the USA, these injuries account for over 25% of the reported occupational injuries. Manual materials handling (MMH) has been identified as one of the leading causes of job-related injuries. Considerable attention has been given to the determination of safe levels of exertion in MMH activities such as lifting, lowering, pushing, pulling, carrying and holding. Nevertheless, other manual tasks, such as shovelling and digging, have not been studied extensively. It is worth noting that although heavy work is becoming rare in industrial countries, it is still widespread in developing countries (Grandjean, 1988). Although most of the digging and conveying of loose material in developed countries is done with mechanical equipment, some of these tasks are still performed manually. Places that cannot be reached by mechanical equipment, levelling work, and precision digging are examples of situations where manual digging is dictated. Shovelling tasks are common activities in many industries and in our daily living as well. Examples of these tasks include, but are not limited to, snow shovelling, landscaping operations, cleaning operations such as ash removal, furnace stoking, chemical manufacturing operations, ditch digging, and underground cable installation and maintenance (Rodgers *et al*, 1988).

Several researchers have studied the physiological costs of shovelling and digging in different postures (Humphreys *et al*, 1962; Morrissey, 1980; Ayoub *et al*, 1981; Morrissey *et al*, 1983). The oxygen uptake recorded in these studies ranged from about 1.0 to 2.0 l min^{-1}. The corresponding work intensity classification as suggested by Astrand and Rodahl (1986) suggests that these activities should be considered in the heavy work category (1.0–1.5 l min^{-1}) or the very heavy work category (1.5–2.0 l min^{-1}). According to Grandjean (1988), shovelling ranks among the least efficient manual tasks. The term 'efficiency' denotes the ratio between the externally measurable useful effort and the energy consumption necessary to produce this useful effort. Shovelling in a stooped posture was found to be 3% efficient, while in an unstooped posture it was found to be 6%. In addition to the posture assumed, shovelling load, frequency and height are some of the parameters that determine the amount of energy required to perform shovelling tasks.

The development of local muscle fatigue as a result of extended periods of bending is one of the principal concerns affecting a proper design of shovelling tasks. Local muscle fatigue is generally determined by the percentage of strength needed to perform the shovelling task and maintain the posture used. Local muscle fatigue in shovelling is affected by the type of shovel, height of the task and how high the shovel must be raised, and the weight of material on it (Rodgers *et al*, 1988). The weight of the material per shovel load may be determined by the amount of material to be removed and the amount of time available to perform the task. These factors determine the frequency of shovelling. Also, the task duration is likely to be an important factor for localized muscle fatigue during shovelling.

Shovels vary in blade design, handle type, and handle length. The shovel and the spade are simple hand tools that have evolved for the tasks of digging and conveying loose matter such as dirt, coal and snow.

Therefore, application of modern ergonomics principles to shovel design has been neglected, mainly because of the belief that many years of experience in using this hand tool must have already refined it to its optimum design. Few researchers have studied the ergonomics of shovelling and shovel design. Lehmann (1962) indicated that shovels should be selected according to task needs. Freivalds (1986a) conducted a study on the different shovel design parameters needed to make this task more efficient. The following parameters were studied: lift angle, the size and shape of the blade, the hollow and closed back design, the effect of shaft length on shovelling performance. The effects of these parameters on energy expenditure, predicted low back compressive forces, and subjective ratings of perceived exertion were investigated. Freivalds (1986a) recommended a lift angle of approximately 32°, a large square point blade for shovelling, a round point blade for digging, a hollow back construction to reduce shovel weight, a step for digging in hard soil and use of a long tapered shaft. Freivalds (1986a, b) and Rodgers *et al* (1988) provided general guidelines for the selection of shovels and the design of shovel workload. Rodgers *et al*'s (1988) recommendations were based on the work of Passmore and Durnin (1955) and Lehmann (1962). A detailed description of these guidelines is beyond the scope of this paper but can be found in Rodgers *et al* (1988).

Freivalds (1986a) evaluated the effect of adding a second shaft near the socket to facilitate lifting and to reduce stooping, as recommended by Sen and Bhattacharya (1976). According to Freivald (1986a), the second shaft seemed to hinder more than to help. In the present study a modified shovel design with two shafts is presented. This design was evaluated and tested in a controlled laboratory environment using surface electromyography recorded from the lumbar paraspinal muscles. Following this laboratory study the new shovel design was tested in a field using ratings of perceived exertion.

Shovel design

Two types of shovel are compared in this study, a regular shovel and a modified two-shaft shovel. The regular shovel, which was selected to represent commonly used shovels in local industry, is made of a fibreglass shaft and a metal scoop with a rounded edge. The shaft length was selected to be about the same height as each subject's xiphoid process. This adjustment was achieved by using three different shaft lengths (small, medium, and long). Figure 1 illustrates the regular shovel used in the present study.

The modified shovel resembles the regular shovel in its scoop and main shaft. In addition, a secondary shaft and a plastic handle are mounted perpendicular to the main shaft as shown in Figure 2. The handle grip was designed to rotate around the secondary shaft to reduce the stress on the subject's wrist while throwing the load. The secondary shaft location along the main shaft and its angle around the main shaft are adjustable to accommodate different anthropometric lengths and preferred posture. Figure 3 shows the detailed design of the secondary shaft which was designed so it could be easily removed and/or added to the regular shovel used in the present study. This allowed the investigation of the effect(s) of adding the secondary shaft to the regular shovel under investigation. Such a secondary

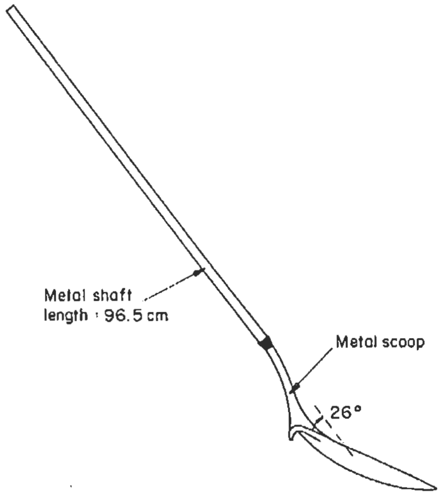

Figure 1 Regular shovel design

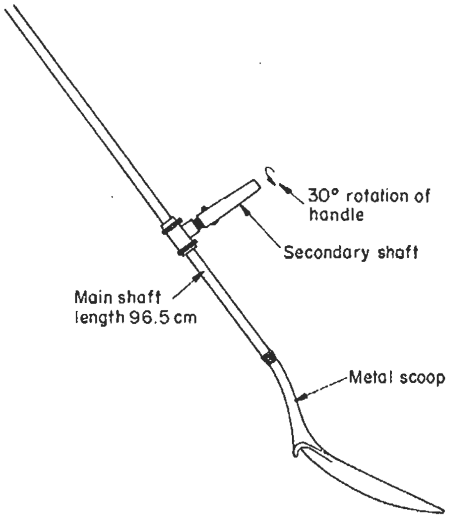

Figure 2 Modified shovel design

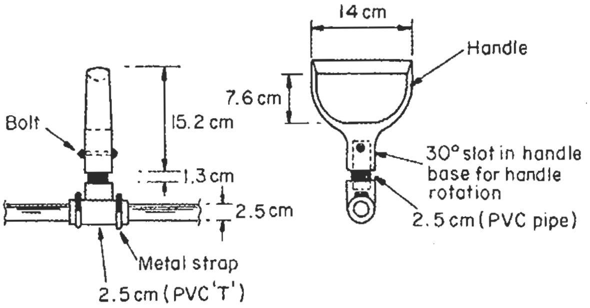

Figure 3 Detailed design of the secondary shaft of the modified shovel (dimensions in centimetres)

shaft could be easily adopted for use with other shovels available in the market.

Laboratory experiment

Subjects

Seven males volunteered to participate in the laboratory experiment. Subjects were screened for prior history of musculoskeletal disorders. They were informed of the experimental procedure.

Procedure

Prior to the beginning of the experiment, the procedure for making various height and angle adjustments on a new shovel was demonstrated to the subjects. Then each subject was allowed to adjust the secondary handle height and angle according to his desired shovelling posture. Next, the skin surface of the subjects was cleaned and prepared for the placement of EMG electrodes on the subject's lumbar paraspinal muscles with the ground electrode on the sacrum. The EMG signal was recorded using a Sensormedics R611 Dynograph Recorder. A load was attached to the shovel by the experimenter and the subject was instructed to hold the shovel and load at three different levels above the floor (2.5 cm, 28 cm and 56 cm). Two levels of load were studied (4.5 kg and 6.8 kg). For each height–load combination, subjects assumed the posture and EMG was recorded for a period of 6 s. A total of 12 trials were performed (six using the regular shovel, and six using the modified shovel). All 12 trials were performed in the same session in random order. The subjects were given adequate rest periods between trials (2–3 min). The EMG electrodes were kept in place throughout the experimental session. The recorded EMG signal was digitized using an analogue-to-digital converter (DT2081-A) and stored on an IBM PC. The full-wave rectified integral (FWRI) of the recorded EMG signals was computed over the 6 s period. The FWRI was then normalized with respect to time.

Experimental design

The response variable used in this laboratory experiment was the FWRI values. The FWRI values obtained while using the regular shovel were compared with those obtained while using the modified shovel. Linear regression was used to study the effect of regressors (shovel type, load, and height) on the FWRI values.

Results

The results of the ANOVA are presented in Table 1. The three-way interaction was not significant at the 0.10 level. The two way interactions of *shovel* × *load* and *shovel* × *height* were not significant either. The FWRI values for the modified shovel (620 ± 300 μV) were significantly lower than those of the regular shovel (710 ± 320 μV) at the 0.01 level. This indicated a significant reduction in the stresses imposed on the muscular structure in the lumbar region. The interaction of *load* × *height* was significant at the 0.05 level. A simple main effect test was conducted to study the effects of both *height* and *load* on the FWRI values. The effects of *load* and *height* were found to be significant at the 0.05 level. The FWRI values for both shovels while holding loads of 4.5 kg and 6.8 kg at the different heights are illustrated in Figure 4 and Figure 5 respectively.

Table 1 ANOVA summary of the FWRI values

Variable	df	*F* val	Pr > *F*
shovel	1	52.94	0.0025
load	1	27.39	0.0001
height	2	7.91	0.0009
shovel × *load*	1	3.33	0.0727
shovel × *height*	2	0.19	0.8291
load × *height*	2	4.48	0.0152
shovel × *load* × *height*	2	0.23	0.7935

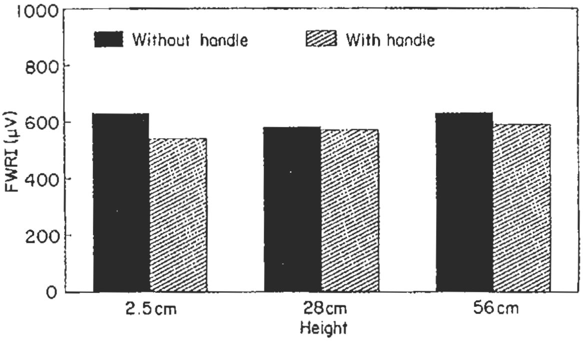

Figure 4 FWRI versus height while holding 4.5 kg

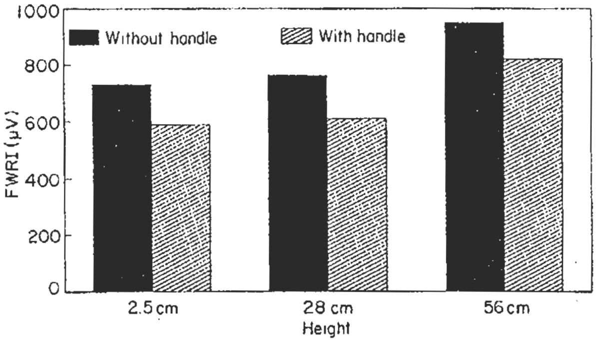

Figure 5 FWRI versus height while holding 6.8 kg

Field study

Subjects

Eight industrial workers involved in shovelling and digging activities in their daily work volunteered to participate in this field study. All subjects were paid for their participation in this experiment. Subjects were screened for prior history of musculoskeletal disorders. They were also informed of the experimental procedure.

Body areas and rating scale

Ratings of perceived exertion (PE) were the response variables in this experiment. These ratings were obtained from the subjects for 14 body areas of interest as shown in Figure 6 and the overall PE (Degani *et al*,

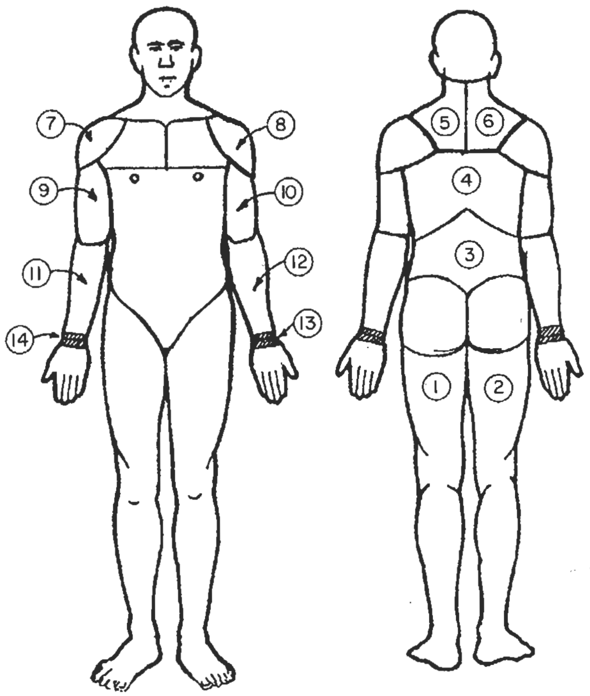

Figure 6 Body areas used in determining the ratings of perceived exertion

1989; Corlett and Bishop, 1976). Since some subjects preferred to use their dominant hand on the upper end of the main shaft while some used their non-dominant hand at that point, symmetrical body areas were classified accordingly: the hand grasping the secondary handle (or the middle of the main shaft while using the regular shovel) acting as a fulcrum point as F, and the hand grasping the upper end of the main shaft of the shovel as NF. The rating scale selected for this experiment was the CR-10 designed by Borg (1982). This rating scale is a combination of a category scale with ratio properties:

0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very, weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Very, very strong (almost maximal)
*	Maximal

The protocol allows the subjects to use fractions as ratings and to have the 'freedom' of assigning a value higher than 10 to the range between 'very, very hard' and 'maximal'.

Procedure

Two experimental sessions per subject were conducted on two separate days with a one-week interval between the sessions. Each subject was assigned randomly to use either the regular or the modified shovel during the first session. All sessions were conducted during the morning hours (8.00–12.00 am). Each session lasted for 95 min. The task given to the subjects was to dig a straight trench 60 cm wide, 90 cm deep and approximately 450 cm long. All sessions were conducted at the same field to control for the type of soil. The soil used in the study was fine sand.

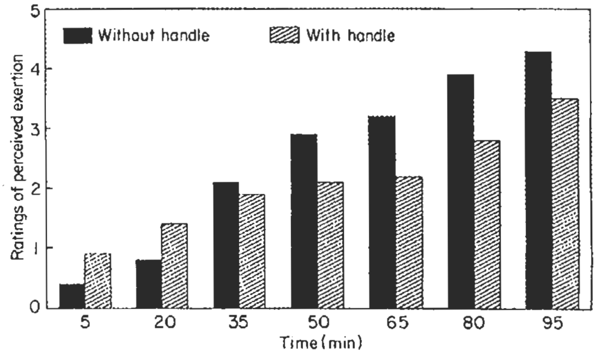

Figure 7 Upper back ratings of perceived exertion versus time

Subjects were instructed to dig the trench at their own pace, using the best scoop load based on experience, yet aiming to remove the required volume of sand (given by the dimensions of the trench) by the end of the session. In addition, subjects were instructed to use any digging technique and shovelling posture that they preferred. Perceived exertion ratings for the 14 areas of interest and the overall PE were obtained at minutes 5, 20, 35, 50, 65, 80 and 95. The ratings of the 14 areas of interest were obtained in a random sequence. Subjects were instructed to rate their feeling of physical stress, physical effort, exertion, and fatigue in each of the body areas or joints displayed in the drawing shown in Figure 6. The overall perceived exertion was defined for the subjects as the 'total amount of inner feeling of physical stress, effort, exertion and fatigue'. At the end of the second session a questionnaire was administered to each subject. The objective was to obtain a feedback from the subjects regarding the advantages and deficiencies of each type of shovel.

Experimental design

The response variables used in the field study were the subjective ratings of perceived exertion for the 14 body areas of interest and the overall PE. A randomized block design was used in the analyses. Separate ANOVAs were conducted for each body area and for the overall PE.

Results

The results of the ANOVAs showed that the shovel effect was significant for the overall ratings ($\alpha = 0.01$) and for the wrist of the hand holding the main shaft of the shovel (NF). The comparison of the means for each one of the 14 body areas is consistent in portraying a reduction in perceived exertion while using the modified shovel. The time effect was significant at the 0.01 level

Table 2 Results of the ANOVA for each area of interest and for the overall rating of PE

Area	Shovel Pr > *F*	Shovel × Time Pr > *F*	Time Pr > *F*	Mean ratings Existing shovel	Mean ratings Modified shovel
Upper leg (F)	0.39	0.99	0.0001	1.12	1.00
Upper leg (NF)	0.88	0.98	0.0001	1.15	1.13
Lower back	0.13	0.93	0.0001	3.49	3.14
Upper back	0.59	0.60	0.0001	2.20	2.10
Trapezoids (F)	0.53	0.79	0.0001	1.54	1.43
Trapezoids (NF)	0.13	0.92	0.0001	1.69	1.46
Shoulder (F)	0.37	0.58	0.0001	1.69	1.53
Shoulder (NF)	0.09	0.95	0.0001	1.77	1.49
Upper arm (F)	0.55	0.34	0.0001	1.57	1.48
Upper arm (NF)	0.49	0.89	0.0001	1.85	1.75
Lower arm (F)	0.45	0.73	0.0001	1.42	1.31
Lower arm (NF)	0.83	0.39	0.0001	1.62	1.59
Wrist (F)	0.72	0.75	0.0001	1.22	1.17
Wrist (NF)	0.02	0.82	0.0001	1.72	1.34
Overall	0.005	0.94	0.0001	2.68	2.18

for all areas of the body as expected (Degani *et al*, 1989). The effect of time on the ratings of perceived exertions for the upper back, lower back, shoulders, upper arms, lower arms, trapezoids and overall body are shown in Figures 7–13. The graphs indicate a general trend of higher perceived exertion ratings at the 5th and 20th minute and lower perceived exertion ratings at the 35th, 50th, 65th, 80th, and 95th minute for the modified shovel when compared with perceived exertion ratings for the regular shovel.

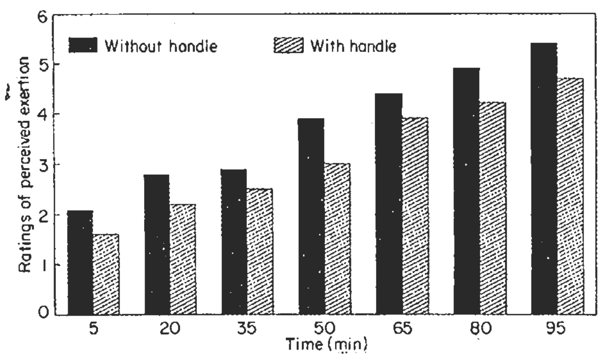

Figure 8 Lower back ratings of perceived exertion versus time

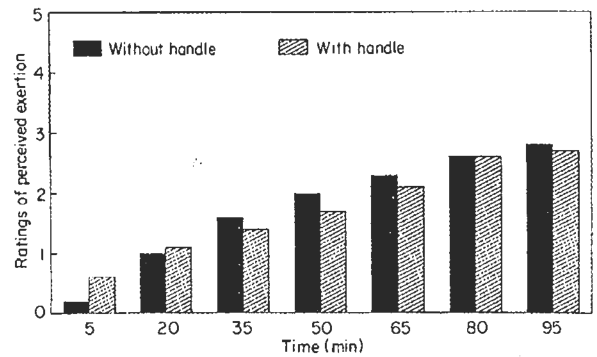

Figure 9 Shoulder ratings of perceived exertion versus time

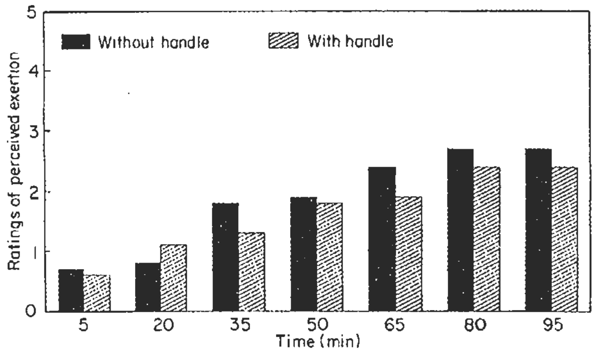

Figure 10 Upper arm ratings of perceived exertion versus time

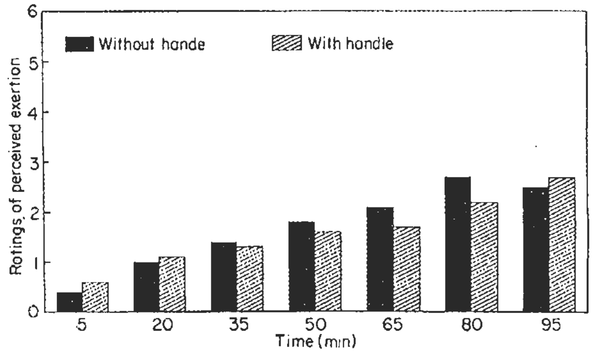

Figure 11 Lower arm ratings of perceived exertion versus time

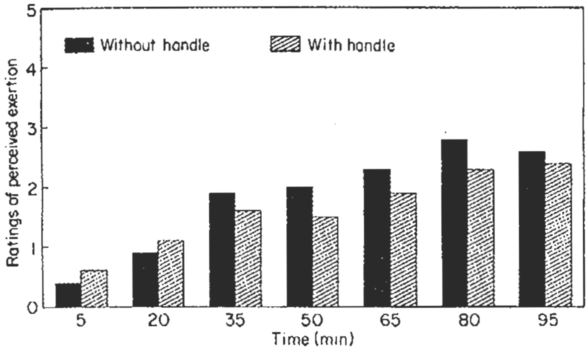

Figure 12 Trapezoid ratings of perceived exertion versus time

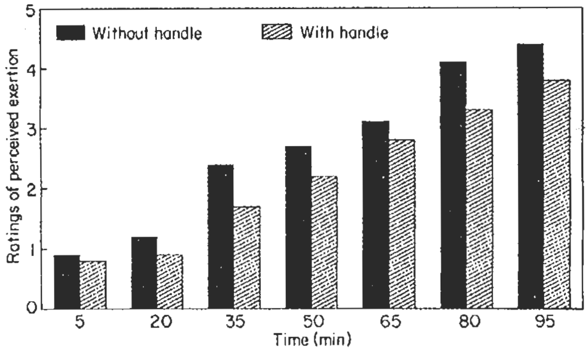

Figure 13 Overall ratings of perceived exertion versus time

The questionnaire results are presented in Tables 3 and 4 for the regular shovel and the modified shovel respectively. Each table is subdivided into the perceived advantages and disadvantages of each design. Several subjects made more than one remark and therefore the total number of remarks in each section usually exceeds the number of subjects. Subjects were also asked to select the type of shovel that suited the type of work they normally perform. Five subjects preferred to use the modified shovel while only one subject selected the regular shovel. Two subjects selected to use both shovels in their daily work depending on the specific job to be performed.

Table 3 Using the regular shovel

Remarks	Number of responses
General	
Too much bending	8
Pain in the left and right arm	2
Absence of the hand grip (so stated)	1
Able to throw the dirt to both sides	1
Useful for the narrow trench	1
Most uncomfortable body segments	
Lower back	10
Lower arm and hand	1
Upper arm	3

Table 4 Using the modified shovel

Remarks	Number of responses
General	
Not suitable for narrow trench	5
Can't change the position	1
Can't lift the shovel high enough	2
Not enough twist is available	1
Less bending	6
Most uncomfortable body segments	
Lower back	7
Mid back (so stated)	1
Upper arms and shoulders	1

Discussion and conclusions

The results indicate that the modified shovel design can aid in reducing musculoskeletal stress. The consistent reductions in EMG values recorded from the lumbar paraspinal muscles in the laboratory experiment and the lower overall perceived exertions for the modified shovel, as well as the results of the questionnaire, seem to indicate that the modified shovel is worthy of further investigation. One limitation of this study was the restriction of the trench depth. The 90 cm depth was selected in this study based on the types of task regularly performed by the industrial workers involved in this investigation. It is difficult to generalize the results obtained in the present study for depths greater than 90 cm where the modified shovel might not be efficient in the throw. Further investigations are needed to test the effects of greater depth while using the modified shovel. The effect of the modified shovel on the pace of work needs to be investigated. In the field study of the present investigation, the subjects were instructed to use their own regular pace of shovelling. However, it is important to note that approximately the same amount of soil, by volume, was removed in the experimental time period (95 min).

Our visual observations of the subject's postures during the experiments seem to indicate that the modified shovel reduced the need to stoop. A detailed biomechanical analysis of shovelling, using the recommended design modification, is needed. Some design modifications could be implemented to improve the proposed shovel design. The authors believe that the joint between the secondary shaft and the main shaft could be made a three-axis joint with locking device. This would allow better adjustability for the user, and would enable the worker to retract the secondary shaft and handle while using the shovel in very narrow trenches. Also, bending the main shaft at the grip between 10° and 20° down from the main axis of the shaft would help to minimize the ulnar deviation while the scoop is at its lowest position.

Further investigations are needed to study the effectiveness of the proposed design in other tasks such as snow removal and digging in different types of soil.

The physiological cost associated with shovelling and digging activities using the proposed shovel design should also be investigated.

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