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Spade design, lumbar motions, risk of low-back injury and digging posture

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Abstract. A laboratory investigation of the ergonomics of digging is reported. Data on lumbar motions, ground reaction forces and posture were obtained simultaneously as subjects transferred sand from one container to another while standing on a force platform. Digging with a conventional spade was found to carry a substantial probability of inclusion in a high-risk group for low back injury. A prototype two-handled spade reduced the probability by approximately 8%. Bending was reduced by 40% when the prototype was used but this was partly offset by an increase in twisting. From a fundamental point of view, the prototype merits further evaluation. Digging is a hazardous task when conventional spades are used and that ergonomic redesign can reduce the risk of back injury.

Keywords: Digging, lumbar spine, hand tools, construction, agriculture, garden tools.

1. Introduction

Although a great deal of research has been carried out on the ergonomics of manual handling, the main emphasis has been on industrial applications where load size and shape are known, or can be specified. Other forms of manual handling have received less attention. A great deal of research has also been carried out on certain types of hand tools, particularly powered tools or small manually powered tools used in industry. Digging and shovelling are examples of manual handling tasks using hand tools which, on a priori grounds, would appear to impose considerable stress on the musculoskeletal system of the user. While there are no reports relating shovelling to risk of low back injury per se, the postures and loads handled are comparable to manual material handling tasks that have been documented to produce a higher risk of low back injury [9]. However, little is known either about the stresses imposed by these tasks or about the scope for amelioration through ergonomic redesign of the tools.

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Research on digging and shovelling dates from the turn of the century with the work of Frederick W. Taylor. Amongst a variety of findings, Taylor specified an optimal shovel load (approximately 9 kg) and pointed out the need to use different shovel designs for materials of different density and consistency. Frievalds [3] has reviewed the literature on the ergonomics of shovel design and shovelling. A shovelling rate of 18–21 scoops per minute with a load of 5 to 11 kg has been found to be most efficient. Lighter shovels increase efficiency especially for low loads. A throw height of 1 to 1.3 meters is acceptable. Low ceilings (as found in mines) constrain posture and increase energy expenditure. Frievalds [4], in an experimental study, presents the following recommendations for shovel design; a lift angle of approximately 32 degrees, a long handle, a large square point blade for shovelling, a large round point blade for digging, hollow back construction to reduce weight, as light a weight as possible without sacrificing too much strength and durability. Frievalds and Kim [5] found the minimum energy cost of shovelling to be obtained when the ratio of blade size to shovel weight was $0.0676\,\mathrm{m}^2/\mathrm{kg}$.

The work described above can be seen as an attempt to optimize the design of shovels and spades by manipulating existing design features and observing the effects on various performance parameters. An alternative, and possibly complementary, approach is described by Sen [11] who reported that shovel design can be improved by fitting a second handle at the neck of the shovel, thus reducing the need to stoop. The second handle pivots at the point where it is connected to the shovel. Frievalds [4] reported that the second handle was more of a hindrance than a help due to usability problems – the hand on the second handle tended to hit the main handle during fast throwing movements. Neither of these investigators provides objective data to support their claims for and against the use of the second handle.

Degani et al. [2] evaluated a modified shovel design with two perpendicular shafts. The secondary shaft could be positioned along the main shaft, towards the blade end of the shovel, to accommodate user preferences and anthropometry. Its handle was able to rotate around the secondary shaft to reduce wrist stress when throwing a load. In an experimental study, a significant reduction in lumbar paraspinal EMG was observed when the secondary shaft was used. In a field evaluation, ratings of perceived exertion were significantly lower (up to approximately 20%). Subjects commented that less bending was required with the modified shovel but that was less suitable for digging in narrow trenches.

By bringing the handle closer to the user, the second shaft would be expected to reduce the need to stoop when digging. This may reduce both the musculoskeletal and the physiological load of the task. A fundamental study of digging, using the approach of Marras, was carried out to determine whether this was the case. Ten subjects were videotaped in the laboratory while digging with a conventional spade both with and without a second handle. Ground reaction forces were measured using a force platform and lumbar motions with a lumbar motion monitor [8]. Marras and his colleagues have presented an abundance of evidence that demonstrates the importance of a three-dimensional approach to the evaluation of occupational loading of the spine [9]. In particular, no evaluation can be complete without an analysis of trunk motion characteristics [6, 10]. This is because many of the forces acting on the spine at work arise from the motions required by the task rather than just the posture or the load characteristics. For example, Marras and Mirka [7] have demonstrated that increases in trunk velocity are accompanied by greater co-activation of trunk muscles with a corresponding increase in spinal loading.

This paper reports an investigation of digging and spade design that attempted to characterize musculoskeletal stress when digging with single and double-handled spades. Specifically, the hypothesis was tested that the addition of a second handle would reduce musculoskeletal stress. It was also deemed necessary to determine whether there were any other beneficial or deleterious biomechanical effects arising out of subjects' postural adaptation to the two-handled spade.

2. Method

2.1. Experimental design

A repeated measures design was used in which ten subjects transferred sand using a conventional single-handled spade and a spade fitted with a second handle. Two second handle conditions were used giving a total of 3 digging conditions: handle 1 (conventional), handle 2 (second handle rotated 90 degrees to main shaft), and handle 3 (second handle parallel to main shaft). The order of handle configurations was randomized within trial and subject. Data were captured for each digging trial that consisted of transferring 5 spade loads from a sandbox to an adjacent container. Trials were repeated once under each condition.

2.2. Subjects

All subjects were male with no history of low-back pain in the previous 6 months and all volunteered for the study. The subjects were not experienced in digging (skilled diggers would have been skilled in the use of the conventional spade but not with the prototypes and the resulting skill difference would have confounded interpretation of any significant differences between the spades). Subject demographic data are given in Table 1.

2.3. Apparatus

A force plate (Bertec Corp.) was used to measure the ground reaction forces and moments during the digging trials. The 6 measured components were anterior/posterior, lateral and vertical forces and the sagittal, coronal and twisting moments. A LIDOKAS (Loredan Inc.) 2-dimensional video system was employed to measure the angular position of the shank, thigh, trunk, upper arm and lower arm. The angles were calculated from the position of retroreflective markers placed on the skin or clothes overlying the ankle (lateral malleolus) and knee (lateral femoral condyle), hip (greater trochanter) shoulder (acromion) elbow (lateral epicondyle) and wrist (carpal bones). The Lumbar Motion Monitor (LMM, Ohio State University Biodynamics Lab), a reliable measure of trunk motion [8], was used to measure the 3-dimensional position of the spine with respect to the pelvis.

Table 1
Subject characteristics

	Mean	sd	max	min
Age (yrs)	27.6	5.44	38	23
Weight (kg)	81.3	12.77	101	61
Stature (cm)	179.0	8.37	195	164
Shoulder height (cm)	142.5	9.32	161	126
Elbow height (cm)	112.6	6.59	124	101
Thigh length (cm)	40.9	5.11	52	34
Shank length (cm)	42.1	4.31	51	34
Arm length (upper) (cm)	30.0	4.24	37	24
Forearm length (cm)	27.2	1.48	29	24
Trunk breadth (cm)	30.1	2.73	35	27
Trunk depth (cm)	22.1	2.56	26	18
Trunk length (cm)	50.8	1.87	54	48

A commercially available square-bladed gardener's spade was used for the digging. The blade surface area was 630 cm^2 and the main shaft was 64 cm long. The spade weighed 2.1 kg. A second shaft was designed which could be bolted to the neck of the spade via a pivoting plate. The handle attached to the shaft could be rotated in the plane of the main shaft and fixed such that subjects dug either with the wrist pronated (handle 2) or supinated (handle 3). The second shaft was 51 cm long and weighed 0.9 kg.

The video system captured the position of the markers at 60 frames per second. While the video data was being captured, a synchronization voltage signalling the beginning and end of the video capture was output through an external cable. The analog voltage signals from the video synchronization, LMM and force plate were digitized at 60 Hz by an A/D board (Data Translation DT2839) and collected using a BSI Portable 486 microcomputer.

2.4. *Procedure*

Subjects were outfitted with the LMM and reflective markers. While standing on the force plate with the dominant leg forward, subjects transferred sand from a sandbox directly in front of them to an adjacent container toward the non-dominant side of the body. Subjects were instructed to choose a comfortable foot position and erect body posture that was to be used as the starting and ending position for all trials. They were instructed not to move their feet when digging. Prior to the experiment, subjects carried out practice trials in order to become accustomed to the different handles and to the starting and finishing procedure. The time to execute each of the 5-dig trials was recorded, as was the weight of the entire load transferred per trial.

In order to measure posture, the video camera was positioned perpendicular to the plane of the body markers. Although the assumption that the marker plane remained perpendicular to the camera was violated, because of the small amount of twisting intrinsic to this task, the error in measurement of the joint segment angles was considered to be small and approximately equal between handle conditions. The twisting angle from the LMM did not differ between the handles ($F = 3.26, p > 0.05$).

2.5. *Signal processing and data analysis*

The average weight per dig and average digging time per trial were calculated from the measured 5-dig load and time. The digitised voltage data from the LMM and force plate were entered into a program with calibration equations to obtain the sagittal, lateral and axial (twisting) angular positions of the lumbar spine and the ground reaction forces and moments from the force plate. The LMM data were filtered and differentiated twice to obtain lumbar angular velocities and accelerations respectively. The video data were processed to give angular positions of the shank, thigh, trunk, upper arm and forearm. The primary angle of interest was that between the trunk and the thigh that was easily obtained from a linear combination of the thigh and trunk angles.

From the LMM kinematic data and measurement of load moment and frequency, the probability of the task matching a high risk for low-back injury group was estimated using the multiple logistic regression model of Marras et al. [9]. This model was constructed from the analysis of low back disorder rates and task characteristics of 403 jobs in a variety of industries. The model requires data on maximum lateral trunk velocity, maximum sagittal flexion, average twisting velocity, maximum external load moment and lift rate (specifically, dig rate in the present context). A probability of high risk group membership was estimated for each dependant variable using the logistic regression equations and an aggregate probability of high risk membership was obtained from the mean of the individual probabilities. The model is able to distinguish between high and low risk of low back disorder with an odds ratio of 10.7 [9]. The test-retest reliability (Pearson's correlation coefficient) of the risk estimates were 0.69 for lateral trunk velocity, 0.98 for peak sagittal trunk flexion, 0.98 for load moment, 0.88 for twist velocity, 1.0 for lift rate, and 0.94 for overall risk.

3. Results and discussion

The data were analyzed by ANOVA with repeated measures to generate F-ratios for the main effects due to handle type, trial and interactions and are presented below in the order performance, lumbar motions, probability of high risk group membership (LMM data), ground reaction forces and posture. Handle 1 refers to the conventional spade, Handle 2 and Handle 3 to the two-handled spades where the second handle is at 90 degrees to and parallel to the main shaft respectively.

3.1. Digging performance

The time per 5 dig trial and the total weight of sand transferred were similar for the 3 conditions, although digging time was greater when the second handle was used (means of 18.9 and 18.6 seconds when using the 2-handled spades compared with 17.5 seconds with the conventional spade, $F = 5.34$, df = 2 and 18, $p < 0.05$).

3.2. Lumbar motions

Mean lumbar positions and motions in the sagittal, lateral and transverse (twisting) planes are given in Tables 2, 3 and 4 for each of the three handles. The results of ANOVA for the effects of handle type (df = 2 and 18) are also given.

The sagittal range of motion (flexion range) was less when both two-handled spades were used – a reduction in range of sagittal lumbar motion of about 20%. The largest reduction occurred at the point of maximum flexion rather than during the erect part of the digging cycle (mean maximum flexion was 41.2 degrees when the conventional spade was used compared with 32.6 and 32.2 degrees when the second handle was fitted). The F-ratios for the lumbar velocity and accelerations were not statistically significant. This suggests that, in the sagittal plane, the addition of the second handle changed the digging posture, rather than the dynamics of the digging task. Less sagittal flexion was needed to dig with the

Table 2
Mean and SE (standard error) sagittal positions (degrees) and motions (degrees/second and degrees/second/second) while digging with three spades

Motion	H1	H2	H3	SE	F-ratio Handle
Range of motion	50.1	39.9	41.2	1.3	34.1^a
Minimum flexion	−8.9	−7.3	−7.9	0.4	4.2^b
Maximum flexion	41.2	32.6	32.2	0.6	25.4^a
Mean velocity	15.0	15.4	15.8	0.5	0.7
Maximum velocity	53.3	51.6	54.2	1.8	0.6
Maximum deceleration	−169.0	−169.0	−169.0	11.2	0.0
Maximum acceleration	207.0	212.0	203.0	10.6	0.2

$^a p < 0.01$
$^b p < 0.05$

second handle fitted to the spade. F-ratios for the effects of trial (practice effect) and the trial × handle interaction were not generally statistically significant.

The effect of spade type on lateral range of motion was not statistically significant. However, the maximum lateral velocity, deceleration and acceleration were greatest when the conventional spade was used. According to the research of Marras and Mirka [7], this would suggest greater compressive loading of the spine due to increased co-contraction of antagonist and synergist muscles. In the lateral plane, the findings suggest that the addition of a second handle changed the dynamics of the digging task, rather than the digging posture.

The effect of spade type on postures and motions in the transverse (twisting) plane were as follows. The amount of twisting was greater when the second handle was used as were the mean and maximum twisting velocities. These differences were of the order of 20–30%. The maximum twisting acceleration was also greater, as might be expected from these findings. Twisting of the lumbar spine while carrying out manual handling tasks has long been recognized as a risk factor for low-back injury (see Bridger [1], for example, for a review of this and other risk factors for low back pain and injury). As with the ANOVA results discussed above, the trial effects and the handle × trial interaction were not statistically significant suggesting that there were no unanticipated practice effects due to differences in skill in using the conventional and experimental spades. Taken together, these findings suggest that the addition of the second handle to the spade reduced the amount of motion in the sagittal and lateral planes, but increased the amount of twisting.

Table 3
Mean and SE (standard error) lateral positions (degrees) and motions (degrees/second and degrees/second/second) while digging with three spades

Motion	H1	H2	H3	SE	F-ratio Handle
Range of motion	16.2	15.7	17.0	0.6	1.3
Minimum lateral flexion	−9.4	−4.7	−6.9	0.4	28.5^a
Maximum lateral flexion	6.8	11.0	10.2	0.6	13.9^a
Mean velocity	6.1	7.0	6.9	0.4	1.9
Maximum velocity	30.4	25.0	26.9	1.0	8.0^a
Maximum deceleration	−156.0	−133.0	−134.0	6.0	4.9^b
Maximum acceleration	144.0	116.0	122.0	5.3	7.6^b

$^a p < 0.01$
$^b p < 0.05$

Table 4
Mean and SE (standard error) twisting positions (degrees) and motions (degrees/second and degrees/second/second) while digging with three spades

Motion	H1	H2	H3	SE	F-ratio Handle
Range of motion	8.1	10.0	9.5	0.4	9.0^a
Minimum twisting	1.4	−1.3	−0.9	0.4	16.0^a
Maximum twisting	9.5	8.7	8.6	0.3	2.7
Mean velocity	2.8	3.8	3.8	0.1	41.1^a
Maximum velocity	19.1	25.3	25.7	1.0	13.3^a
Maximum deceleration	−105.0	−144.0	−129.0	13.2	2.3
Maximum acceleration	119.0	144.0	148.0	6.8	5.2^b

$^a p < 0.01$
$^b p < 0.05$

3.3. Risk analysis using lumbar motion data

The LMM data were analyzed using the model of Marras et al. [9]. According to the model, a combination of 5 trunk motion and workplace stressors can predict high low back disorder risk group membership. These factors are lifting frequency, load moment, maximum trunk lateral velocity, average trunk twisting velocity and maximum trunk sagittal angle. The first factor was based on the literature review presented above and the second was estimated directly from observation of subjects when digging. The remaining factors were obtained from the LMM. Table 5 presents the output of the model in terms of probabilities, i.e., the probability that the component belongs to a high-risk group and the overall estimated probability of high risk group membership of the digging task under each of the experimental conditions.

It can be seen from these data that digging is a fairly risky activity as far as the low back is concerned. The riskiest component is sagittal flexion. This finding supports the attempt to reduce bending by redesigning the spade. A reduction in probability of high risk of almost 10% was observed. The load moment was reduced when the second handle was used which is probably a direct consequence of the more upright posture. However, use of the second handle was accompanied by an increase in the average twisting velocity of the trunk (this is consistent with the force plate data below). The overall reduction in risk is therefore not as great as might otherwise have been the case (digging with the second handle increased the average twisting velocity which offset some of the other benefits). Interestingly, although the handle modifications reduced the risk associated with sagittal flexion, the absolute risk is still high. The opposite seems to be the case with twisting, the increased risk associated with the use of the second handle is still low (Table 5).

3.4. Qualitative analysis of forces while digging

Ground reaction forces and moments at the subject's feet varied greatly throughout the different stages of the task. These stages can be summarized as stooping, digging, lifting, turning and transferring, turning back and stooping to dig again. It can be seen from Figs 1–7, obtained from a single subject digging with a conventional spade and presented here for illustrative purposes, that digging is a continuous, cyclic activity rather than a series of discrete actions. The above-mentioned stages blur into one another and there is no clear boundary. Forces and moments at the feet peak systematically at different stages during the digging cycle.

Furthermore, Figs 1–7 show that many of the peaks occur fairly consistently at particular digging stages. For example, peak forces in Z (Fig. 3) occur during stooping and in Y (Fig. 2) during turning

Table 5

Biomechanical risk (probability of task being included in high risk of low back injury membership group) associated with 5 components of digging

Motion	H1	H2	H3	SE	F-ratio Handle
Maximum lateral velocity	0.30	0.20	0.24	0.03	8.0^{a}
Maximum sagittal flexion	0.96	0.85	0.85	0.01	53.8^{a}
Load moment	0.55	0.27	0.26	0.01	1374.0^{a}
Average twisting velocity	0.06	0.13	0.13	0.01	29.8^{a}
Lift rate	0.98	0.98	0.98		
Overall probability	0.57	0.49	0.49	0.01	23.2^{a}

$^{a}p < 0.01$

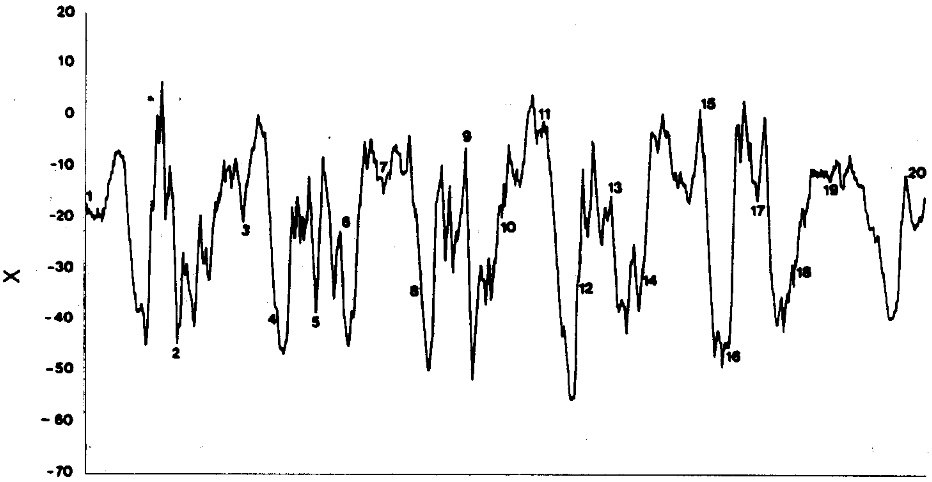

Fig. 1. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Lateral shear force.

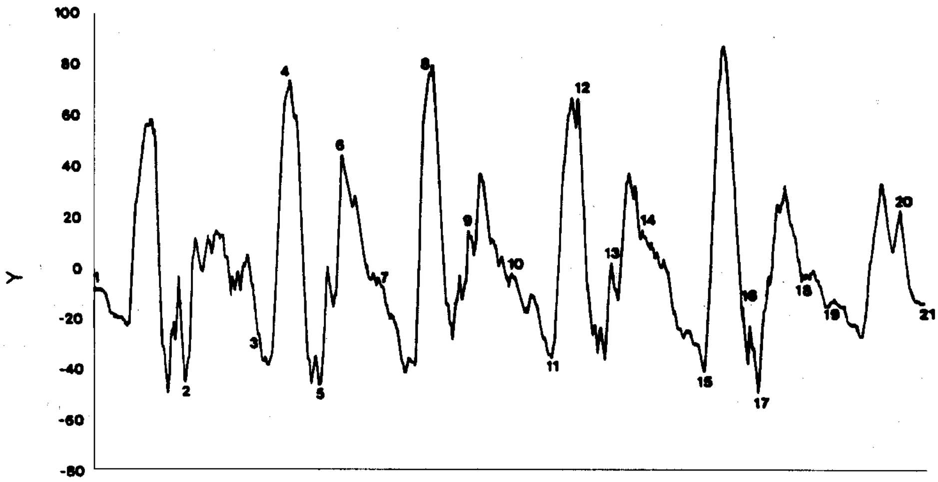

Fig. 2. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Anterior shear force.

movements. Peak (negative) moments about XM (Fig. 4) occur during stooping and about ZM (Fig. 6) as the digger turns back, stoops and lifts.

3.5. *Comparison of ground reaction forces and moments*

For each subject/trial combination 5 or 6 peak forces and moments could be identified (as in Figs 1–7). These were manually extracted and analysed using ANOVA.

Since subject foot position was the same under all digging conditions, the forces and moments at the feet under all three conditions could be compared. However, in themselves these data say nothing about

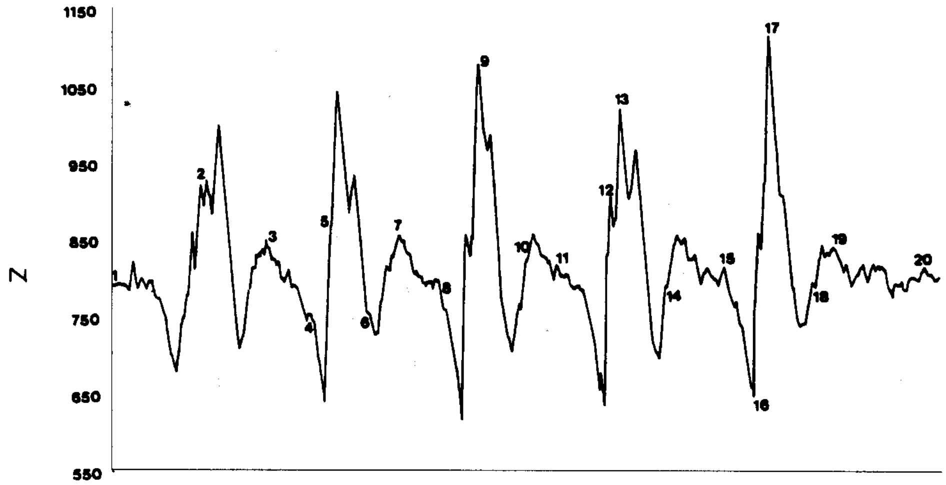

Fig. 3. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Vertical force.

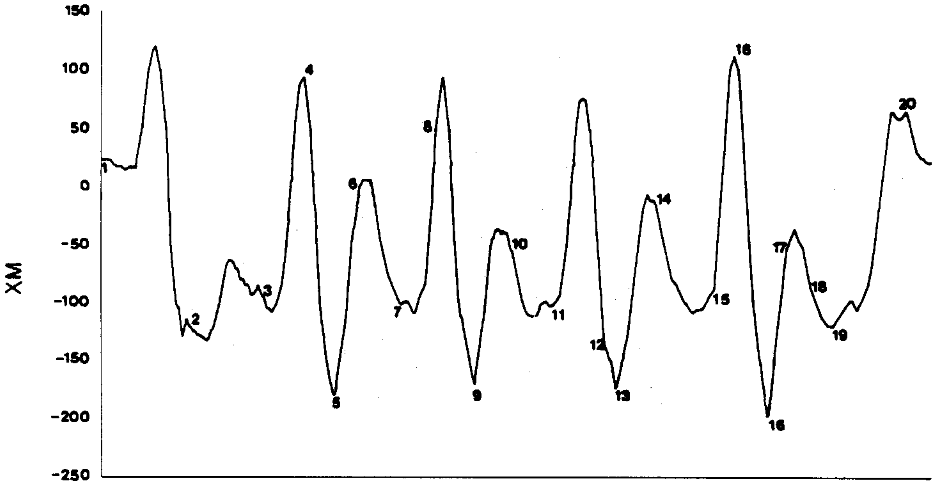

Fig. 4. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Sagittal moment.

the forces acting on the subjects' spine and are only meaningful when viewed together with the other findings.

The sagittal ground reaction moment was significantly lower when the second handles were used (133 and 128 Nm as opposed to 159 Nm, $F = 10.63$, df = 2 and 18, $p < 0.001$) suggesting that the center of gravity of subject and load was further from the center of pressure, indicating that more reaching was needed to dig. The anterior/posterior shear force was significantly greater when the second handles were used (74 and 68 N compared with 61 N, $F = 3.70$, df = 2 and 18, $p < 0.05$). Given equal accelerations of the spades the increase in mass (0.9 kg) due to the addition of the second handle might account for some of this difference. The vertical ground reaction forces were significantly greater when the conventional spade was used (1030 N compared with 1008 N and 1013 N, $F = 3.65$, df = 2 and 18,

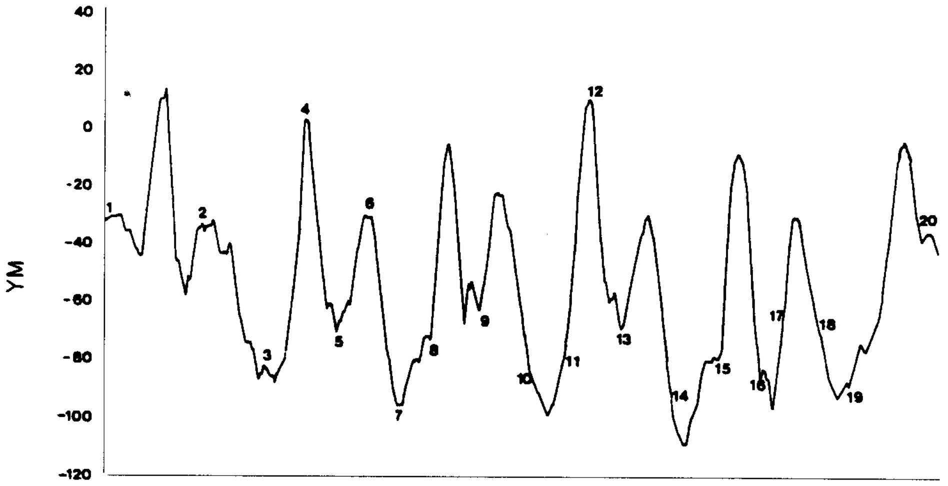

Fig. 5. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Frontal moment.

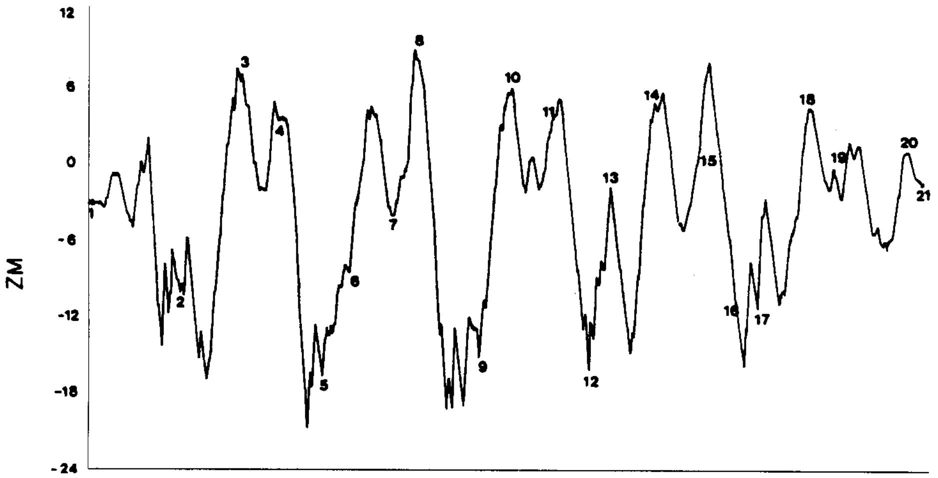

Fig. 6. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Twisting moment.

$p < 0.05$). The peak moments about the twist axis were significantly greater when the second handles were used (-14.1 Nm compared with -15.9 and -15.9 Nm, $F = 4.62$, df $= 2$ and 18, $p < 0.05$).

3.6. Comparison of postures: trunk-thigh angle

For each subject/trial combination, the mean value of the trunk-thigh angle was found and subjected to analysis using ANOVA. Table 6 gives mean and standard deviation trunk-thigh angles when digging with the conventional and two-handled spades.

With the conventional spade, the trunk-thigh angle was small throughout the entire digging cycle (a mean of 76 degrees) indicating a flexed trunk posture. With both prototype spades the mean angle was

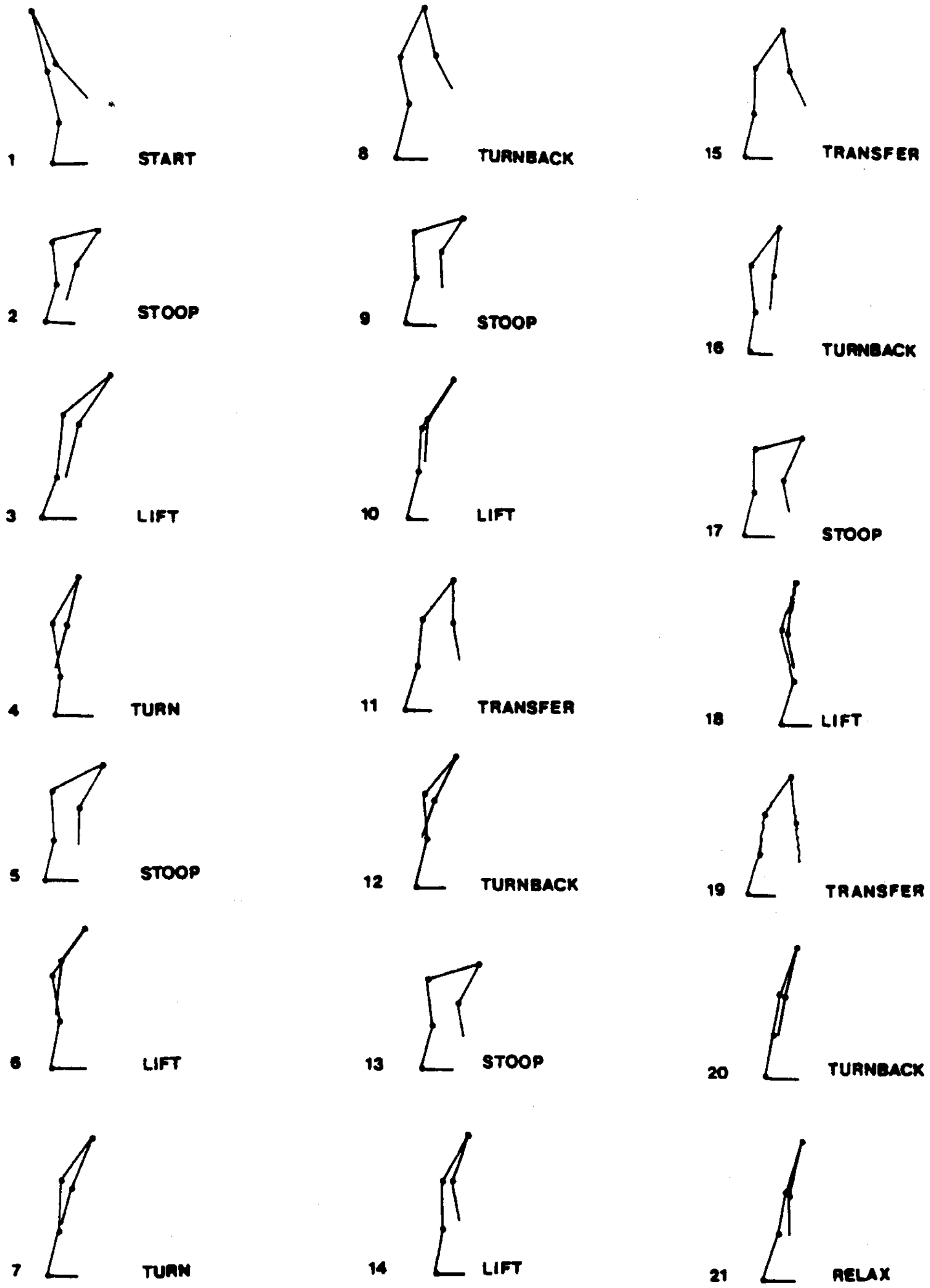

Fig. 7. Ground reaction forces when digging five spade loads with a conventional spade (numbered stick figures refer to numbers on force plate data). Stick figures.

larger (approximately 106 degrees). The difference was statistically significant ($F = 64.4$, df $= 2$ and 18, $p < 0.001$). The digging and sand transference task could be carried out with approximately 30 degrees less bending of the trunk with respect to the thigh when the second handle was used. A

Table 6
Mean (degrees) and standard deviation trunk-thigh angles under three digging conditions

Handle type	Mean	Standard deviation
Handle 1	76.5	14.8
Handle 2 (wrist pronated)	106.0	10.5
Handle 3 (wrist supinated)	107.0	13.8

difference of this magnitude is likely to be due to reductions in both lumbar and hip flexion when the two-handled spades were used. Figs 8–11 illustrate this finding with photographs taken at those points in the digging cycle with the most and least bending. To further assist visualisation, it can be said that with the conventional spade, the level of the hands is below that of the knees for a large part of the digging cycle. With the second handle, the level of the hands is above that of the knees for large part of the digging cycle – a reduction in bending of about 40%. The hypothesis that addition of a second handle reduces the amount of stooping required for digging, and therefore the musculoskeletal stress, is thus supported.

3.7. *Comparison of postures: other postural angles*

Of secondary interest is the posture of the knee, shoulder and elbows when using the different spades. The above findings support the hypothesis that the addition of a second handle can reduce postural stress, particularly trunk stress, when carrying out a digging and transference task. However, analysis of other postural angles is appropriate in order to characterize more fully, the postural adaptation to the different handle configurations. Since the retroreflective markers were always placed on the left side of the subject's body, 3 left-handed subjects were excluded from this analysis.

Examination of the data indicated that dorsiflexion of the foot and knee flexion were lower when the two-handled spades were used than when the conventional spade was used. This is entirely consistent with the trunk-thigh angle data and supports the hypothesis that the addition of a second handle reduces stooping while digging. It is likely that the physiological cost of digging is lower when the second handled spade is used than when a conventional spade is used. In this sense, it may be hypothesized that the former spade is physiologically more efficient than the latter.

The shoulder data also indicate that less shoulder flexion is needed when a two-handled spade is used. However, there also appear to be differences between the two second-handled spades. With handle 3, which is used with the wrist supinated, shoulder flexion was less than with handle 2 which requires the wrist to be in a pronated position. (Note the angles given are not true postural angles, rather they are the angles between retroreflective markers placed on the skin or on clothing overlying the skin. It is the difference in angle under the 3 conditions rather than the absolute values that is relevant to this discussion.) The findings suggest that the design of the second handle itself also merits further attention, particularly with respect to postural and task loading of the upper limbs and the need to avoid deleterious effects during repetitive digging.

4. General discussion

The present findings explain why some researchers favor the addition of a second handle to a spade by showing how this modification reduces postural stress. Although digging time increased by approximately 6 percent when the second handle was used, which may have increased the total low back load, it

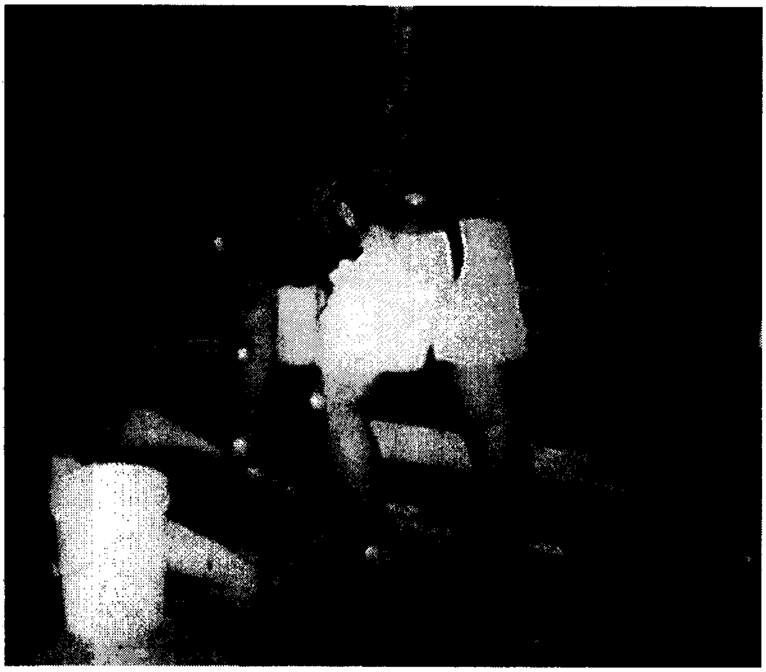

Fig. 8. Body posture when digging sand with conventional spade; handle 1.

Fig. 9. Body posture when transferring sand with conventional spade; handle 1.

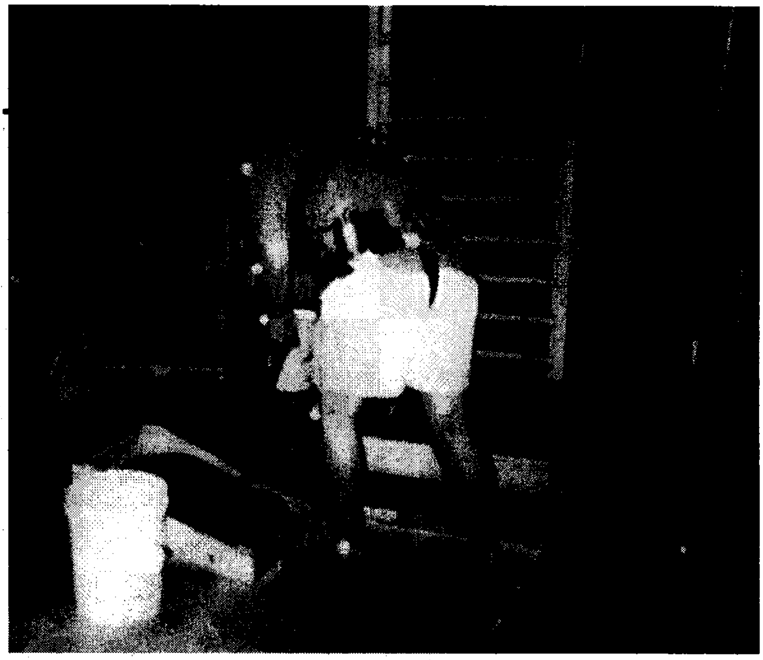

Fig. 10. Body posture when digging sand with experimental spade; handle 2 (second handle rotated 90 degrees to main shaft).

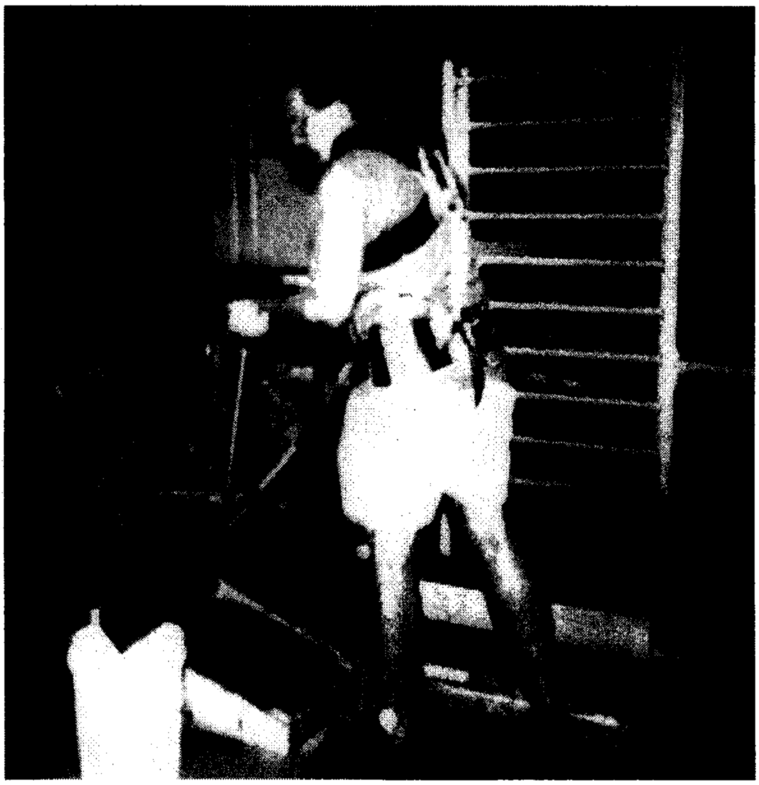

Fig. 11. Body posture when transferring sand with experimental spade; handle 3 (second handle parallel to main shaft).

is more likely that the 20% decline in sagittal flexion played a more important role in reducing postural stress. Furthermore, less stooping would result in less movement of body COG, which may reduce the physical workload. In support of this view, in Degani et al.'s study [2], ratings of perceived exertion were lower when a two-handled spade was used than when a conventional spade was used. Another interpretation of the present findings is that digging with a conventional spade involves a large amount of unnecessary movement compared to digging with the two-handled spade.

The reduction in stooping was accompanied by an increase in twisting. From the video and LMM data it can be seen that some of the stooping was achieved by flexing the lumbar spine and some by flexing the hip joint. It may have been the case that when the second handle was used, the reduced hip flexion, thus shortening the hip flexors, bought about a compensatory recruitment of muscles higher-up the kinetic chain, manifesting as axial rotation of the trunk at the lumbar region. This speculative point can be argued but serves to highlight the possibility of compensatory movements when tasks are redesigned to reduce stooping and the need to use instruments capable of detecting and evaluating these movements in order to estimate the magnitude of any overall reductions in risk of back injury.

The task is shorter in duration and did not induce the amount of muscle fatigue that would be expected during the performance of shoveling. Hence the computed risk may be thought of as a baseline measurement. The effects of fatigue on the shoveling task may alter some of the conclusions about the use of the second handle, but also would require additional methods such as surface electromyography and oximetry.

The present findings provide a firm foundation for future ergonomics research aimed at reducing the risk of back injury in activities such as gardening and small scale farming and in industries such as construction. The concept of adding a second handle to a spade seems to be a valid one from a fundamental point of view, but further work is needed to examine detailed designs, to investigate the usability issues mentioned by Frievalds and also the physiological efficiency of different designs of spade. In particular, it would be worthwhile to carry out user trials of a variety of prototypes to determine the circumstances, tasks and soil types under which benefits can be expected – particularly now that quantitative data are available to evaluate complex trunk motions.

Finally, the work demonstrates the inadequacy of static, two-dimensional approaches to the evaluation of occupational trunk stress. Although the addition of a second handle greatly reduces easily observed variables such as trunk-thigh angle and sagittal trunk flexion, it increases other, less easily observed variables, such as average twisting velocity. Without the use of appropriate instruments to characterise trunk motions in three dimensions, the present investigation would have overestimated the potential benefits of the two-handled spade.

5. Conclusions

Digging with a conventional spade is a task associated with a substantial probability of being included in a group of jobs that involve a high risk of low-back disorder. The addition of a second handle to a spade can reduce this probability by reducing the amount of unnecessary movement (particularly stooping) when digging. Further work is needed to determine whether a reduction in energy expenditure accompanies the reduction in stooping and to investigate the usability of 'alternative' designs of spade. A three-dimensional, dynamic approach will be needed if these investigations are to be carried out adequately.

There was a high degree of concordance between the LMM data, the force plate data and the video data of whole body posture with respect to the hypothesis. This suggests that the LMM is a useful instrument for measuring task and postural load, particularly in field conditions where the availability and usability of alternative instruments is limited.

6. Concluding remarks / relevance to industry

Unlike the manufacturing industry, little is known about manual handling in the construction or agricultural industries or about the scope for amelioration of musculoskeletal and physiological workload through ergonomic redesign of handtools.

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