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A Shovel With a Perforated Blade Reduces Energy Expenditure Required for Digging Wet Clay

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A Shovel with a Perforated Blade Reduces Energy Expenditure Required for Digging Wet Clay (17 words – please shorten title to 15 words or less) ok

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Precis/Short Abstract for TOC: A shovel with a blade perforated with holes is recommended for digging wet clay because, compared to a conventional blade, workers expended 11.7% less relative energy per kg of clay dug with the perforated shovel. Workers may experience less whole body and muscle fatigue when using a perforated shovel.

Abstract (249 words)

Objective: A shovel with a blade perforated with small holes was tested to see if a worker would use less whole body energy to dig wet clay than with a shovel with an opaque blade.

Background: A perforated shovel is hypothesized to require less whole body energy based on adhesion theory – a smaller surface area would require less physical effort to dig and release soil from the blade.

Methods: Thirteen workers from an electric utility dug wet clay with two 1.5 m long-handled point shovels, which differed only in blade design (perforated and opaque). Oxygen consumption was measured with a portable system while each worker dug wet clay at a self-regulated pace for 10 min.

Results: There was no significant difference in number of scoops dug during the 10 min sessions, but workers dug 9.5% more weight of clay with the perforated shovel than the conventional shovel (404 kg vs 369 kg, respectively). However, stable oxygen uptake normalized to weight of participant *and* to the weight of clay dug revealed that participants expended 11.7% less relative energy per kg of clay dug with the perforated shovel.

Conclusion: A point shovel with a perforated blade is recommended for digging and shoveling wet clay. However, the extra weight that workers chose to dig with the perforated shovel may increase the loading on the spine and may offset the metabolic advantages.

Application: Manual shoveling is a common task, and workers may experience less whole body and muscle fatigue when using a perforated shovel.

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INTRODUCTION

Manual digging and shoveling is a task that has existed ever since tools were developed and will continue in the future, even with the technological advances of modern mechanical equipment for digging. Strictly speaking, digging is defined as breaking, turning or excavating soil while shoveling is transferring loose material from one place to another (Bridger et al., 1997). As life for primitive humans changed from collecting wild edibles to growing plants, they needed a tool for digging holes in the ground and transporting the material to another location. Sticks that were used previously for digging were probably flattened into a spade-like shape (Frievalds, 1986a). Later, when the blade was sheathed in steel, the durability of the tool was enhanced and became the tool that we recognize today as either a shovel or a spade.

With or without modern equipment, workers throughout the world (in both developing and developed countries) will need a shovel (or spade) for digging and shoveling. In the developing countries, workers may use the shovel for the entire task of digging and shoveling while in the developed countries, workers will need the manual shovel to do finishing work in excavations or to dig and shovel in areas where mechanical equipment is not allowed (such as areas where electrical cables, telecommunication wires, and gas and waters pipes are located).

The basic design of the shovel has not changed much over the past 400 years. At an archaeological site in Newfoundland, Canada, a beech wood shovel that was used to spread salt over dressed fish was found (Colony of Avalon, 1999). This salt shovel, which is estimated to be from as early as 1600, has the same basic shape as a present-day, round-point shovel (although the blade of this shovel was made out of wood).

The long-handled, round-point shovel is the most versatile tool for general digging, gardening, and landscape work. A round-point shovel has a straight handle that is made of either wood or composite material and can be as long as 1.5 m. The handle is connected to the blade with a steel socket, which is the top portion of the blade. The steel blade is typically 30 cm long and 23 cm wide and is rounded at the bottom to a point so it can penetrate and loosen soil (digging phase). The blade of a round-point shovel has a concave surface for lifting, moving, and tossing loose material (shoveling phase). The angle between the handle and the blade is called the lift angle, which provides the tool with added leverage. Based on energy expenditure, compressive forces on the spine, and subjective assessment, a lift angle of 32° was found to be optimal for the shoveling phase (Friedvalds, 1986a).

Within the last ten years, a round-point shovel has been marketed with a supposedly new feature, a blade perforated with small holes. However, this idea is not new as it dates back to 1905 (US Patent No. 787,660, April 18, 1905). The perforated shovel, which is marketed by Toolite Inc. (model #LHR01TWO, Ashtabula, OH, USA), has a steel blade that is perforated with over 220 small holes (0.95 cm dia) spaced 1.3 cm on center in a hexagonal grid. Compared to a conventional round-point shovel with an opaque blade, the perforated shovel is hypothesized to require less physical work to release wet soil from the blade based on adhesion theory. According to adhesion theory, motion of surfaces (in this case, wet soil and shovel blade) is possible only if the frictional energy overcomes the adhesive energy. Adhesive energy is proportional to the area of contact (Chow, 2000). The less the adhesive energy, the easier it is for soil to separate from the shovel. Thus, perforating the blade of a shovel decreases the surface area, which in theory decreases the adhesive energy and would require less effort to release soil from the blade. Because wet soils tend to have more adhesion to a shovel than dry soils and thus would have more adhesive energy, then a perforated shovel would in theory be more beneficial for wet soils than dry soils.

To the authors' knowledge, there are no published studies that have tested whether a shovel with a perforated blade reduces the energy expenditure for digging and shoveling compared to a conventional blade. A tool that reduces energy expenditure for digging and shoveling tasks, while maintaining performance and does not increase any other risk factors for injuries, would have widespread benefits as digging and shoveling are common tasks throughout the world. Furthermore, such a tool would be particularly beneficial in those areas where the soils are moist and have a high composition of clay, a combination which makes it difficult to release soil from the shovel's blade during the shoveling phase of the task. Thus, the objective of this study was to determine whether a shovel with a perforated blade reduces energy expenditure compared to a conventional shovel.

METHOD

Approach

The approach in this study was to measure oxygen uptake and external work measures of experienced workers while they dug wet clay, under field conditions, to test the hypothesis that digging with a shovel with a perforated blade reduces energy expenditure compared to a conventional shovel. Oxygen uptake is a measure of whole body energy expenditure. External work includes number of scoops and weight of clay dug. Test conditions were standardized so any significant results could be attributed to the difference in the design of the blades of the shovels.

Participants

Thirteen male participants from We Energies (Milwaukee, WI, USA) participated in this study. All participants, who were cable workers who dug trenches (both manually and with equipment) as a requirement of their job, were free of injury at the time of testing. The participants' ages ranged from 22 to 55 years (mean 38.8 and sd 9.4). They ranged in weight from 73 to 109 kg (mean 93 and sd 10.3), and their statures ranged from 176 to 191 cm (mean 183.4 and sd 4.2).

Shovel and Clay Field Conditions

A long-handled, round-point shovel from Ames True Temper Co. (model #72829, Camp Hill, PA) was used as the conventional shovel. The shovel was 145 cm long, and the blade was hardened steel with the following dimensions: 29 cm long, 22 cm wide and a thickness of 0.16 cm (14 gauge American Wire Gauge standard). As shown in **Figure 1**, the experimental shovel was the same as the conventional shovel but the hardened steel blade was perforated with 116 holes of 0.95 cm dia, spaced 1.3 cm on center in a hexagonal grid. There were fewer holes in the center of the blade compared to the sides in order to keep the longitudinal stiffness of the 2 blades similar. The weights of the conventional and experimental shovels were 1.901 and 1.820 kg (difference of 81.2 g), respectively, and their centers of mass were located 43.3 and 46.35 cm on the handle from the tip of the blade, respectively.

A clay field of approximately 10 x 10 m was made outside one of the service centers of We Energies. The top 0.4 m of soil was removed and replaced with homogenous grey clay from a local landfill. Grey clay was the most homogenous clay that the experimenters could find in the southeastern Wisconsin area. A sprinkler watered the clay for at least 5 hours before each test session so the clay could reach maximum saturation. The moisture content of the clay ranged from 30.9 to 37.6 percentage of weight (mean 0.353 and sd 0.023) at the initial time of testing, based on testing of samples according to the American Society for Testing and Materials (ASTM) D-2216-98 protocol for measuring moisture of soils. The weather was relatively similar across the 8 days of testing during the Fall season. When testing started in midmorning of each day, the temperature ranged from 8.9° to 17.2°C (mean 12.2° and sd 2.9°C). The mean relative humidity was 81.4% (sd 8.4%), with a range from 69% to 90%.

Oxygen Uptake Equipment and Weight of Clay Protocol

The Cortex Metamax 3B portable telemetry system (Cortex Biophysik, Germany) was used to measure oxygen uptake of workers while they dug clay with both shovels, as shown in **Figure 2.** The Metamax 3B has 2 major pieces of hardware – a mask with a turbine that attaches to the face and a micro-computer with wireless technology that has a collar that hangs around the participant’s neck and is strapped to the chest. The weight of the micro-computer, batteries and straps was 0.57 kg. There was a wire that attached the turbine in the mask to the micro-computer in the collar strapped to the chest. The micro-computer sent all data, oxygen uptake data along with heart rate measured from a built-in Polar sensor, wirelessly to a notebook computer. The Metamax 3B has software that can be loaded on a notebook computer for setting parameters for data collection and monitoring data as they are received and stored.

During the 10-min digging trials, relative oxygen uptake (ml-O_2 /min/kg) was measured by the Metamax 3B and stored on the notebook computer. In post-hoc analysis, relative oxygen uptake was plotted per minute over the 10-min duration for each participant, as shown in **Figure 3**. Three or 4 consecutive points during the latter half of the 10-min trial were used for analysis because oxygen uptake was stable during this period. During the first 3 or 4 min of an activity, oxygen uptake is not stable due to the Krebs citric acid cycle. The average of the relative oxygen uptake over these points was calculated and renamed as *stable* oxygen uptake. From the same time interval used for calculation of stable oxygen uptake, stable energy expenditure (kcal/hr/kg) and stable heart rate were calculated in the same manner. Energy expenditure is derived from oxygen uptake and is equivalent to approximately 5.0 kcal per liter of O_2 inhaled (Kamon and Ayoub, 1976). The stable oxygen uptake and stable energy expenditure variables were normalized, separately, to the number of scoops and the total weight of clay dug during the 10-min trials.

The number of scoops each participant dug during the 10-min digging trials was counted by an experimenter during each 10-min test session. The clay dug from 3 consecutive scoops was shoveled into a plastic bucket and then weighed. The worker continued digging at his normal pace while the clay in the bucket was weighed by the experimenters. This regimen was repeated throughout the 10-min trial, which resulted in a record of clay weight from about half of the total number of scoops dug. For each bucketful, the weight was divided by 3 in order to calculate the weight per scoop. The total weight of clay over the 10-min session was calculated from the product of the average weight of clay per scoop and the number of scoops.

Experimental Design

Design of the shovel blade was the only independent variable with 2 levels (conventional and perforated). The experimental design was a repeated-measures design with each participant digging with both shovels. The dependent variables were categorized into 3 groups – external work, metabolic load and subjective assessments. External work measures were number of scoops dug within a 10-min period and the total weight of clay dug. Metabolic dependent variables included heart rate, relative oxygen uptake and energy expenditure. Subjective assessment included overall preference of the shovels along with participants' preference of the 2 shovels according to 3 attributes -- how well the clay slid off, ease of use and overall level of effort.

Procedure

During the morning of each test day, the Metamax 3B was calibrated for volume and gas composition. A sterilized face mask (Hans Rudolf, Kansas City, MO) was fitted to cover the participant's nose and mouth and held in place by a nylon harness worn on the head. The mask was attached to a bidirectional digital turbine flow meter to measure the volume of inspired and expired air. A sample line connected the turbine to the analyzer unit and determined O_2 and CO_2 content. A two point calibration procedure was conducted before each testing session according to the manufacturer's guidelines (Cortex Biophysik MetaMax®3B Manual).

Two participants participated in the study during each day of testing. Before data collection, experimenters described the protocol to the participants and participants signed a consent form approved by IRB. Then the participants practiced digging and shoveling wet clay with both shovels, following a chalk line painted on the clay field as shown in **Figure 4**. Each participant was instructed to penetrate the soil with the blade until the blade was almost fully covered (approximately 30 cm deep) and loosen the soil with the shovel (digging phase), and then transfer the wet clay to a bucket about 1 m to the participant's side (shoveling phase). Participants dug and shoveled the next scoop, which was about 15 cm behind the previous scoop along the chalk line, in the same manner. An experimenter moved the bucket to keep pace with the worker. The practice session lasted no more than 2 min per shovel for each participant as all the participants were experienced underground workers.

Prior to testing, a face mask was fitted to each participant's face. The face masks were cleaned with an approved cleanser to prevent transmission of germs. Then the first participant of the test day put on the Metamax 3B collar with micro-computer and the face mask with turbine. After at least 30 min of rest (no physical activity) after the practice session, CO_2 and O_2 composition along with heart rate were monitored for one minute to make sure the Metamax 3B hardware and software were working as designed. The oxygen uptake, energy expenditure and heart rate data collected during the one minute were used as baseline data.

Each digging and shoveling session lasted 10 min during which metabolic and external work data were measured. The conventional or perforated shovel was assigned to the participant, and then the participant was instructed to dig and shovel at his normal pace in wet clay. **Figure 2** shows a participant digging in the clay field while wearing the Metamax 3B. The participant was also instructed to start each scoop about 15 cm behind the previous scoop, following the chalk line illustrated in **Figure 3**. As described earlier, metabolic loading was measured continuously during the 10 min and recorded on the notebook computer and external work variables were counted or weighed by the experimenters. After the 10-min trial, the second participant of the day then put on the Metamax 3B and followed the same protocol as the first participant. Then the first participant repeated the 10-min protocol with the other assigned shovel, followed by the second participant. There was at least 1 hour of rest between 10-min digging sessions for each participant. The presentation order of the shovels was counterbalanced between participants.

Statistical Analysis

All the external work and metabolic dependent variables were analyzed with a 2-tailed paired-t test at the 0.05 level. Because the scale of the subjective rankings was ordinal, the non-parametric Friedman’s test was used to determine if there was a significant difference at the 0.05 level between the shovels for each subjective assessment (Glantz, 1992).

RESULTS

Number of Scoops and Weight of Clay Dug

As shown in Table 1, the conventional and the perforated shovel had means of 52.8 and 54.3 scoops, respectively, which were not significantly different (p=0.26). Of the 13 participants, 6 participants dug more scoops with the perforated shovel, 5 with the conventional shovel and the remaining 2 participants had no difference. Participants dug an average 9.2% more gross weight of clay with the perforated shovel than with the conventional, as evinced by means of 404 and 370 kg, respectively, during the 10 min (p=0.02). The average weight of clay *per scoop* with the perforated blade was 7.45 kg, which was 6.4% greater than the average 7.0 kg/scoop with the conventional shovel. Out of the 13 participants, 10 dug more clay with the perforated shovel.

Oxygen Uptake

The mean relative oxygen uptake did not vary significantly between the perforated and conventional shovels (26.0 and 26.7 ml/min/kg(participant), respectively) (p=0.50), as indicated in Table 1. The oxygen uptake values were obtained during the stable period, as shown in **Figure 4**. Normalized to number of scoops, the oxygen uptake per scoop did not vary significantly between the two types of blades (means of 5.259 and 5.058 ml/kg/scoop for the perforated and conventional, respectively) (p=0.40) (Table 1). However, workers consumed 12.5% less oxygen uptake normalized to their body weight *and* the weight of clay dug with the perforated shovel vs the conventional shovel (0.14 and 0.16 ml/kg(participant)/kg (clay), respectively) (p=0.04) (Table 1).

Energy Expenditure

The energy expenditure results followed the same pattern as the oxygen uptake data as energy expenditure is largely a function of oxygen consumed. The overall energy expenditure did not vary significantly between the perforated and conventional shovels (means of 7.641 and 7.933 kcal/hr/kg(participant), respectively) ($p=0.25$) (Table 1). The mean energy expenditure normalized to number of scoops did not vary significantly (0.0248 and 0.0262 kcal/kg(participant)/scoop, respectively) ($p= 0.08$). However, the energy expenditure normalized to body weight and weight of clay dug was 11.7% less with the perforated shovel than with the conventional (means of 0.000682 and 0.000773 kcal/kg(participant)/kg(clay), respectively) ($p=0.02$) (Table 1).

Subjective Assessments

Participants overwhelmingly preferred the perforated shovel as 12 of the 13 participants preferred to use the perforated shovel compared to the conventional. The non-parametric Friedman's test showed that participants rated the perforated shovel better than the conventional in terms of how well the clay slid off, ease of use and overall level of effort ($p<0.001$). Ten of the 13 participants rated the perforated shovel higher than the conventional regarding how well the clay slid off. Nine of the participants rated the perforated higher in terms of ease of use, and the perforated was rated by 10 participants as requiring a lower amount of overall effort.

DISCUSSION

External Work

The weight per scoop measured in this study was consistent with other studies. Workers shoveled 6.6 to 7 kg of sand per scoop in a study by Bridger et al. (1997), which is similar to the 7.45 kg and 7.0 kg of clay per scoop dug with the perforated and conventional shovels, respectively, in the present study. The slightly greater weight measured in this study may be attributable to the increased density of wet lump clay (1602 kg/m^3), compared to loose sand (1442 kg/m^3) (Density of Materials, 2005). The pace of shoveling in the present study cannot be compared to other studies because the rate was not controlled in the present study. In other studies, participants did not dig but shoveled material from one pile to another. The rate was controlled from 18 to 25 scoops per min for shoveling sand and snow (Bridger et al., 1997; McGorry et al., 2003; Frievalds and Kim, 1990; Frievalds, 1986a, 1986b) because these researchers thought that shoveling at these rates was most efficient for shoveling loose material. However, the workers in the present study self-selected an average rate of 5.35 scoops per min during the 10-min sessions. The rate was much lower in the present study because workers dug wet, sticky clay and then shoveled it into a bucket.

Participants dug an average of 34.7 kg more clay with the perforated shovel than the conventional during the 10-min sessions. The pace of shoveling was not significantly different between shovels (one scoop every 11.3 sec), but the participants chose to dig 6.4% more clay per scoop with the perforated shovel than the conventional (7.45 kg/scoop vs 7.0 kg/scoop for the perforated and conventional shovels, respectively). The pace of shoveling was not regulated by the experimenters, and it is noteworthy that the participants chose to dig at the same pace with both shovels. The approximately equal pace between the shovels was probably due to the experience of the participants, who were all seasoned electrical workers whose job was to lay underground cable. The fact that participants did not dig with the perforated shovel at a slower pace shows that the perforated shovel does not lower productivity, compared to a conventional shovel.

Metabolic Results

Analysis of the metabolic data was performed on the data recorded during a stable period, which was typically 6 min into each 10-min session. Thus, results from metabolic dependent variables reflect the period when the respective variable was reliable for steady state work. Oxygen consumption and energy expenditure data are not reliable for analysis during the first few minutes of a task.

Oxygen uptake results not normalized to body weight from the present study are greater than those reported in the literature. Oxygen uptake rates of 1.59 to 1.95 liter/min were reported by Moss (1923, 1924) for shoveling coal, and Bridger et al. (1997) measured a rate of 2.3 liter/min for shoveling loose sand. In the present study, the unnormalized oxygen uptake rate was 2.49 and 2.43 liter/min for digging wet clay with the conventional and perforated shovels, respectively. A possible explanation for the increase in oxygen uptake in the present study may be due to the nature of the material. In the present study, participants dug solid material (wet clay), as opposed to segmented material like the coal and loose sand in the studies by Moss (1923, 1924) and Bridger (1997). Participants had to exert force with the shovel to penetrate and separate the solid clay, which may have required more energy than to scoop the already segmented materials in the other 2 studies.

The finding that relative oxygen uptake and energy expenditure per scoop did not differ significantly between the shovels indicates that the participants worked at the same metabolic rate per scoop. However, participants chose to dig more clay per scoop with the perforated shovel than the conventional per scoop, and thus, their relative oxygen uptake and energy expenditure normalized to kg of clay was less with the perforated shovel than the conventional. This finding indicates that the participants were working more efficiently while digging with the perforated shovel than with the conventional.

The authors do not know exactly why participants chose to dig and shovel more weight of clay with the perforated shovel, as the amount of material dug and shoveled was chosen by each participant. However, the authors speculate participants chose to move more weight of clay with the perforated shovel because it required less physical effort than with the opaque shovel. In subjective assessment, a large majority of the participants reported that the perforated shovel was easier to use and required less physical effort than the conventional shovel.

The increase in digging efficiency with the perforated shovel can be explained by the theory of adhesion. According to adhesion theory, the adhesive force between two surfaces is directly proportional to the surface area (Chow, 2000). Motion of two surfaces over each other is possible only if the frictional forcestarts to overcome the adhesive force. The lesser the adhesive force, the easier it is for the surfaces to slide over each other. The holes in the perforated blade decrease the surface area, compared to a conventional blade, and would make it easier to penetrate and separate wet clay from a shovel blade. Metabolic results showed that workers were able to dig and shovel wet clay (normalized to body weight and lb. of clay) with less whole body energy with a perforated shovel, thus providing empirical evidence for using a perforated blade for handling wet soils. However, it is not known whether the benefit from the perforated shovel occurred during the digging or shoveling phases. The digging phase is the penetration and loosening of soil in the earth, and the shoveling phase is the transportation of the soil from the earth to its destination. It appears that perforations in the blade would be beneficial during the shoveling phase as a worker separates the clay from the blade at the destination point. Workers have reported that releasing wet clay from a shovel can require several exertions and strikes against objects in order to overcome the adhesive energy between the clay and blade.

However, a perforated blade may also be beneficial during the digging phase. Surface friction theory supports the experimental finding that it may require less energy to dig wet clay with perforated shovel than an opaque blade. As the blade penetrates the soil, there is less area of blade metal that slices and is dragged through the soil. Additionally, the holes in the blade allow air to pass over the blade, avoiding the suction the wet clay creates with the blade. The perforations may decrease adhesion to the shovel by allowing more water to pass through the perforations, thus providing better lubrication of the shovel blade (Sokaski, 1997). It was not possible in the experimental protocol to attribute energy expenditure to specific motions of digging and shoveling as oxygen uptake was recorded every breath during the entire 10 min sessions.

Biomechanical Loading

Participants chose to dig 6.4% more clay per scoop (0.45 kg) with the perforated shovel than the conventional, which may have increased the loading on the spine. However, the perforated shovel was 0.08 kg lighter than the conventional shovel, so the extra weight is actually 0.37 kg. Assuming the participants used the same posture and moment arm of both shovels to dig clay (which is not known as they were not measured), then the additional loading on the spine from the extra weight of clay can be estimated with simple statics. Holding an extra 0.37 kg of clay at a distance of 1 m from the spine increases the moment on the spine by 3.6 N-m (2.65 ft-lbs). (One meter is the approximate horizontal distance from the center of the blade on a 5 ft. point shovel to the lumbral-sacral joint of the user's spine.) An external moment of the extra clay weight (3.6 N-m) results in additional loading of 72 N (16 lbs.) on the erector spinae muscles, assuming the force vector of the erector spinae has a moment arm of 0.05 m to the spine. The additional loading on the lumbral-sacral spine from the extra clay weight and erector spinae force would be 75 N (17 lbs.). Although the magnitude of the additional loading on the spine is relatively small, it may increase the risk of low back pain due to the large number of shoveling repetitions and may, in effect, offset the metabolic advantage of the perforated shovel.

However, shoveling is a dynamic activity, which involves complex torso kinematics. It is possible that the perforated shovel may decrease overall loading on the spine due to less whole body force exertions and less awkward body posture required to penetrate the clay during the digging phase and releasing the clay during the shoveling phase. Thus, it is not known whether the perforated shovel would increase spinal loading. However, ergonomists should be aware that workers may tend to dig and shovel more weight with the perforated shovel, compared to the conventional, which may mitigate the metabolic benefit.

Additional Notes

This study tested only wet clay, so the results cannot be generalized to other soil structures such as loam or sand. The moisture content of a soil also affects adhesion, so the moisture of the soil structure should be measured in all studies involving digging and shoveling.

The weight of the perforated shovel weighed 81.2 g, or 4.3%, less than the conventional shovel, due to the holes in the perforated blade. While the lower weight of the perforated shovel may have reduced energy expenditure (compared to the conventional shovel), the difference in weight between the shovels was much less than the difference in total energy expenditure (normalized to weight of clay dug) between the two shovels (4.3% less weight, 11.7% less energy expenditure per kg of clay). Thus, one can conclude that the design of the blade, namely the perforations in the blade, contributed more to the energy expenditure benefit of the perforated shovel than its lower weight.

Commercial shovels typically have hardened steel blades, which are stiffer than non-hardened steel. Making holes in hardened steel is more difficult than in soft steel, so a perforated blade may be made out of soft steel. Workers noted that the perforated Toolite shovel was not as stiff as their conventional hardened steel-bladed shovels, which may have been due to the geometry of the holes or the quality of the steel. Workers prefer a stiff blade, particularly for digging up rocks and using the tip of the blade for leverage.

The perforated shovel may enable workers to handle wet soil more productively and have less whole body fatigue if they were to follow the trends noted in this study. Participants handled 6.4% more clay with the perforated shovel than the conventional (7.45 vs. 7.0 kg/scoop, respectively) while not expending significantly more whole body energy and shoveling at approximately the same rate (5.43 vs. 5.28 scoops/min for the perforated and conventional, respectively). Thus, the perforated shovel may enable workers to take frequent rest periods during a shift while still shoveling the same quantity of wet soil. Shoveling is considered “very heavy work”, as indicated by the metabolic measures from the present study. With both shovels, participants were working at a rate of over 700 kcal/hr (mean weight of 93 kg X average 7.7 kcal/hr/kg) (Table 1), which was above the criterion of 600 kcal/hr for the classification of “very heavy work” (Kroemer et al., 2001). Frequent, short rest periods are required for “very heavy work” because this level of work requires anaerobic exertions, which can exceed a worker’s physiological capacity over time, even with interspersed rest periods (Kroemer et al., 2001).

Compared to the conventional shovel, the perforated shovel may reduce the level of fatigue among workers while maintaining productivity.

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KEY POINTS

- A point shovel with a perforated blade is recommended for digging and shoveling wet clay. On average, experienced utility workers expended 11.7% less whole body energy per kg of clay dug with a shovel perforated with small holes compared to a conventional shovel with an opaque blade.
- Workers dug 6.4% more clay per scoop with the perforated blade. However, the extra weight that workers chose to dig with the perforated shovel may increase the loading on the spine and may increase the risk of low back pain.
- Workers overwhelmingly preferred the perforated shovel to the opaque-bladed shovel.

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Table 1. Summary statistics of dependent variables during the 10-min trials. Means marked with an asterisk are significantly different (p<0.05).

	Conventional Shovel	**Perforated Shovel**
Number of Scoops		
Mean	52.85	54.31
Std Dev	14.81	15.43
Min	35	31
Max	80	75
Weight of Clay Dug (kg)		
Mean (p=0.02)	370.0*	404.7*
Std Dev	129.4	122.6
Min	242.7	269.9
Max	595.3	649.2
Heart Rate (beats per min)		
Mean	141.2	139.8
Std Dev	26.1	23.2
Min	93.0	101.0
Max	182.0	173.09
Relative Oxygen Uptake (ml/min/kg(participant))		
Mean	26.7	26.0
Std Dev	6.0	5.5
Min	17.0	18.7
Max	38.0	37.7
Relative Energy Expenditure (kcal/hr/kg(participant))		
Mean	7.933	7.641
Std Dev	1.765	1.614
Min	5.083	5.542
Max	11.042	11.208
Relative Oxygen Uptake per Scoop (ml/kg(participant)/scoop)		
Mean	5.259	5.058
Std Dev	1.303	1.445
Min	3.163	3.333
Max	8.486	8.371
Relative Energy Expenditure per Scoop (kcal/kg(participant)/scoop)		
Mean	0.0262	0.0248
Std Dev	0.0072	0.0069
Min	0.0155	0.0165
Max	0.0433	0.0415
Relative Oxygen Uptake per Kg Clay (ml/kg(participant)/kg(clay))		
Mean (p=0.04)	0.160*	0.140*
Std Dev	0.044	0.039
Min	0.090	0.090
Max	0.250	0.219
Rel. Energy Expenditure per Kg Clay (kcal/kg(participant)/kg(clay))		
Mean (p=0.02)	0.00077*	0.00068*
Std Dev	0.00023	0.00018
Min	0.00045	0.00045
Max	0.0013	0.0011

FIGURE CAPTIONS

Figure 1. The experimental shovel (left) and the conventional shovel (right). The conventional shovel is model #72829 from Ames True Temper Co. (Camp Hill, PA, USA).

Figure 2. A participant digging wet clay with the conventional shovel. The participant is wearing the Metamax 3B system (Cortex Biophysik, Germany).

Figure 3. The pattern of digging in the clay pit, as marked by a chalk line.

Figure 4. Relative oxygen uptake (ml O_2 /min/kg) for one participant. The box highlights the data points that were used to calculate stable oxygen uptake.

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