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A new method for overhead drilling

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In the construction sector, overhead drilling into concrete or metal ceilings is a strenuous task associated with shoulder, neck and back musculoskeletal disorders due to the large applied forces and awkward arm postures. Two intervention devices, an inverted drill press and a foot lever design, were developed then compared to the usual method by construction workers performing their normal overhead drilling activities (n = 14). While the intervention devices were rated as less fatiguing than the usual method, their ratings on usability measures were worse than the usual method. The study demonstrates that the intervention devices can reduce fatigue; however, additional modifications are necessary in order to improve usability and productivity. Devices designed to improve workplace safety may need to undergo several rounds of field testing and modification prior to implementation.

Keywords: design; construction; shoulder; musculoskeletal disorders; fall protection

1. Introduction

In the USA, the construction sector has the highest rate of non-traumatic soft tissue injuries to the neck, back and upper extremity, with incidence rates of 622 per 10,000 full-time employees (Washington State Fund 2000). Increasing hours of overhead work is strongly associated with shoulder, elbow and wrist pain and disorders (Hagberg 1981, Olson 1987, Holmstrom 1992). One of the most physically demanding tasks is overhead drilling into concrete for the insertion of anchor bolts in order to hang pipes, ducts, wiring and equipment (Welch 1995, National Institute for Occupational Safety and Health 2002). The work is primarily performed by the sheet metal, plumbing and electrical trades.

The task is usually performed on a ladder or scaffold and involves pushing a hammer drill upward toward the ceiling while the drill bit cuts into concrete or metal (Figure 1). Rotary hammer drills weigh up to 10 kg (100 N) and an additional upward force of 200 N can be applied during drilling. The drill bits are usually 1–2 cm in diameter. The drilling depth is between 1 and 5 cm depending on the size of the anchor bolt intended for the hole. After the hole is drilled, the anchor bolt is hammered into the hole and a hanger is screwed into the anchor bolt, then pipes, ducts or trays are attached to and supported by the hangers. High arm, shoulder and torso forces are required to support the weight of the drill and push the drill upward during drilling. Since the work is usually done on a ladder and near the ceiling, it can also involve awkward neck and shoulder postures. The other health risks associated with this task are falling and exposure to dust, noise and vibration.

Devices for overhead drilling have been developed on an ad hoc basis for commercial construction jobs, but none of the devices has undergone usability evaluations or been involved in a process of redesign and testing in preparation for widespread use. The long-term objectives of this research are to design and evaluate interventions for overhead drilling with the goal of reducing arm, shoulder and back load and risks for musculoskeletal disorders (Rempel *et al.* 2007). Other important goals are to reduce the risk of falls and reduce exposure to noise, dust and vibration while not interfering with productivity. This paper presents the results of the first generation intervention device for overhead drilling – devices that use a foot lever or inverted drill press design to raise a hammer drill on a column.

2. Methods

2.1. *Device designs*

The research team borrowed from past designs and involved experienced construction workers in the design and development of two devices for field testing: an inverted drill press (Figure 2); a foot-lever drill press

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(Figure 3). Both devices utilised two sliding vertical columns with a saddle on top of the inner column that held the drill. With the foot-lever drill press, the inner column was first adjusted to the approximate work height using a gravity pin, then the operator raised both columns during drilling by pressing down on a foot lever that operated as a cantilever at the base of the column. For the inverted drill press, a three-handled capstan turned a spur gear that acted on a rack mounted to the inner column to raise or lower the drill. The base was a flat steel plate with wheels that engaged when the column was tilted, allowing the device to be rolled to the next hole. Both devices could accommodate three different size rotary hammer drills and could be adjusted to drill into a ceiling between 2.0 m and 3.5 m in height.

Figure 1. Construction worker demonstrating usual method of overhead drilling into concrete ceiling. The upward forces may be 20 kg-force or more. This plumber is also exposed to dust and is at risk of falling off the ladder.

Figure 2. New inverted drill press method. The drill saddle accepts different types of drills. A switch on the column near the left hand activates the drill. The column is supported by a flat metal plate at the base.

2.2. Sites and subjects

The devices were evaluated in the field at commercial construction sites in Portland, Oregon. Sites where overhead drilling into concrete or metal was to be performed were identified with outreach to electrical, plumbing and sheet-metal contractors and unions. Full-time construction workers who were to be performing overhead drilling for one or more days were identified and recruited to the study. The study was approved by the university Committee on Human Research.

Figure 3. New foot-lever drill press with the same drill saddle on top (not visible) as in Figure 2. The inner column is first lifted to a height for drilling and locked with the gravity pin just above the black handles. Then the foot lever is used to advance the drill during drilling.

2.3. *Field study*

On the day of testing, participants completed a brief demographics questionnaire. Construction workers evaluated the two intervention devices and their usual method while performing their scheduled task of overhead drilling. An attempt was made to schedule the drilling methods so the number of holes drilled and the environment was similar for each method. Generally, the holes were drilled consecutively, interrupted only by laying out and marking the position of the next holes. Each of the three methods was performed for 1–2 h. The order of testing of the methods was randomised.

After using each method, subjects completed a single device questionnaire, which assessed ease of setting up and use, fatigue, positive and negative features of the device and suggestions for improving the device design. The questionnaire assessed fatigue levels associated with use of the device for five body regions: neck, shoulders, hands and forearms, low back, and legs, on a scale of 0 (none) to 5 (very). Appeal of each device was determined for various characteristics (accuracy, control, stability, aesthetics, durability and handling) on a scale of 0 (excellent) to 5 (poor). Ease of use was assessed for various actions (setting up, moving to next hole, fine positioning, activating drill, drilling/vibration and knowing when drilling is complete) also on a scale of 0 (easy) to 5 (difficult). The questionnaire also asked subjects to note what they liked or disliked about the method and prompted for suggestions for improving the device design. At the end of the workday, subjects completed a comparison questionnaire, which rank ordered the three methods on the following characteristics: set-up; moving; ease of use; accuracy; work speed; comfort; overall.

The study provided the appropriate rotary drill during intervention device testing based on the diameter of the hole that was to be drilled. Because of the high variability of the hole diameters, the subject provided the drill bit for all tests. To the extent possible, the same bit was used for all three methods. A half-inch Milwaukee Magnum drill (Milwaukee Tool, Milwaukee, WI, USA) was provided for tests that involved drilling into metal ceilings, the TE-6S Hilti Roto-hammer (Hilti Tool, Sachaan, Liechenstein) was provided for holes up to 1 cm in diameter into metal Q-decking or concrete ceilings and the Bosch 11240 Boschhammer (Bosch LLC, Farmington Hills, MI, USA) was provided for drilling larger holes. A universal saddle was also built to accommodate almost any drill in cases where the provided drills did not meet the required job specifications.

The testing was supervised by a research technician who was present during all the testing, briefly trained the subjects on how to use the devices and administered the questionnaires. The technician noted the type of ceiling, the method of drilling, the platform type that the subject used, the drill diameter and depth of the hole and the environment. Productivity was not directly measured.

2.4. *Analysis*

Statistical comparison of outcome measures between intervention methods was done using a repeated measures ANOVA, with the follow-up Tukey test to adjust for multiple comparisons. The comparison of rankings was done using the Friedman chi-square test.

3. Results

The trades of the 14 participating construction workers were electrical (one), plumbing and pipe fitting (three), carpentry (three) and sheet metal (seven). Nine were journeymen (experienced tradespersons) and five were apprentices. Two subjects were female. Subject median age was 35 (range 24–53) years. Subject mean height was 178 (range 161–190) cm. Median overhead drilling experience was 10 years. Participants reported that on average they performed overhead drilling for 8.5 full-time days (range 1–15 d) per month.

Participants used the three drilling methods while performing their usual work for 1–3 h per method. All drilling was done into concrete ceilings ranging in height from 250 to 300 cm. One subject drilled on a 600 cm ceiling using a scissor lift. The diameter of the drill bits ranged from 0.6 to 1.9 cm and the depth of drilling ranged from 1.9 to 15 cm. The drilling duration and details were similar across the three drilling methods for each subject.

Subjective ratings of usability, regional body fatigue and rankings are summarised in Table 1 and in Figures 4–6. For the evaluation of ease of performing various tasks, the usual method was rated as easier to set up, easier to move to the next hole and easier to make fine adjustments in comparison to the foot lever or the drill press intervention designs (Figure 4). The foot lever and drill press were only easier than the usual method for drilling and vibration control.

For the six measures of usability (Figure 5), there was little difference between the three drilling methods. The usual method was rated more accurate than the foot lever or the drill press designs.

On the other hand, the two interventions were rated as less fatiguing compared to the usual method. The drill press method was rated as less fatiguing across all five body regions than the usual method

Table 1. Comparison of usability and fatigue ratings and rankings between three methods for overhead drilling (n = 14).

	Device designs							
	Foot lever		Drill press		Usual method			
	Mean	SD	Mean	SD	Mean	SD	*p*-value[a]	Significant pairs[b]
Ease of ... (0 = easy, 5 = difficult)								
Setting up	2.21	0.97	1.50	1.16	**0.36**	0.63	$p < 0.001$	FU, DU
Moving to next hole	2.64	1.08	2.07	1.14	**0.43**	0.76	$p < 0.001$	FU, DU
Making adjustments	2.43	1.28	2.29	1.38	**0.79**	0.97	$p < 0.001$	FU, DU
Activating drill	0.79	0.97	1.07	1.38	0.93	1.27	$p = 0.74$	
Drilling – vibration	**0.71**	0.61	**1.07**	1.21	2.71	1.38	$p < 0.001$	FU, DU
Knowing when drilling is complete	1.64	1.39	1.36	1.01	0.86	1.29	$p = 0.22$	
Usability (0 = excellent, 5 = poor)								
Accuracy	1.79	0.97	1.79	1.19	**1.00**	1.04	$p = 0.03$	FU, DU
Control	1.71	0.91	1.86	1.10	1.57	1.22	$p = 0.76$	
Stability	2.29	1.64	1.93	1.38	1.57	0.94	$p = 0.33$	
Looks – aesthetics	1.14	1.10	1.00	0.88	1.29	1.20	$p = 0.75$	
Durability	1.31	1.32	1.29	0.99	1.50	0.94	$p = 0.82$	
Feel handling	1.86	1.35	1.50	1.29	2.29	1.44	$p = 0.30$	
Fatigue (0 = none, 5 = very)								
Neck	1.71	1.94	**1.50**	1.65	3.00	1.36	$p = 0.04$	DU
Shoulder	**1.00**	1.47	**1.43**	1.65	3.64	1.15	$p < 0.001$	FU, DU
Hands and forearm	**0.93**	1.54	**0.86**	0.95	3.62	1.45	$p < 0.001$	FU, DU
Low back	**1.21**	1.37	**0.64**	0.93	3.21	1.19	$p < 0.001$	FU, DU
Leg	2.00	1.52	**0.57**	0.85	2.43	1.45	$p < 0.001$	DF, DU
Ranking (1 = best, 3 = worst)								
Set-up	2.43	0.76	2.14	0.66	**1.36**	0.63	$p = 0.01$	FU, DU
Moving	2.50	0.76	2.21	0.70	**1.29**	0.61	$p = 0.003$	FU, DU
Ease of use	2.14	0.95	1.93	0.62	1.79	0.89	$p = 0.64$	
Accuracy	1.93	0.83	2.29	0.73	1.50	0.76	$p = 0.12$	
Work speed	2.14	0.77	1.93	0.73	1.86	0.95	$p = 0.72$	
Comfort	1.86	0.77	1.64	0.74	2.36	0.84	$p = 0.12$	
Overall	2.07	0.92	2.07	0.73	1.71	0.83	$p = 0.52$	

F = foot lever; D = drill press; U = usual method.
[a]Repeated measures ANOVA for Ease of ... usability and fatigue; Friedman chi-square test for ranking.
[b]Significant differences in Tukey follow-up test.
Note: The lowest (best values) significant numbers are shown in bold.

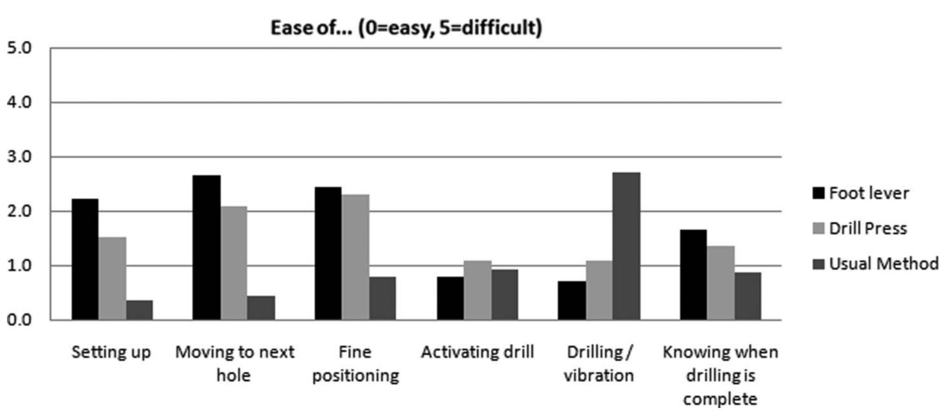

Figure 4. Comparison of ease of performing various drilling tasks by device (n = 14).

(Figure 6). The foot-lever method was less fatiguing than the usual method across all body regions except the legs. The drill press method was rated as less fatiguing in the legs when compared to the foot-lever method.

At the end of the day, the workers rank ordered the three methods across seven usability items (Table 1). The only significant differences were that subjects preferred the usual method for set up and for moving in comparison to the foot lever or the drill press.

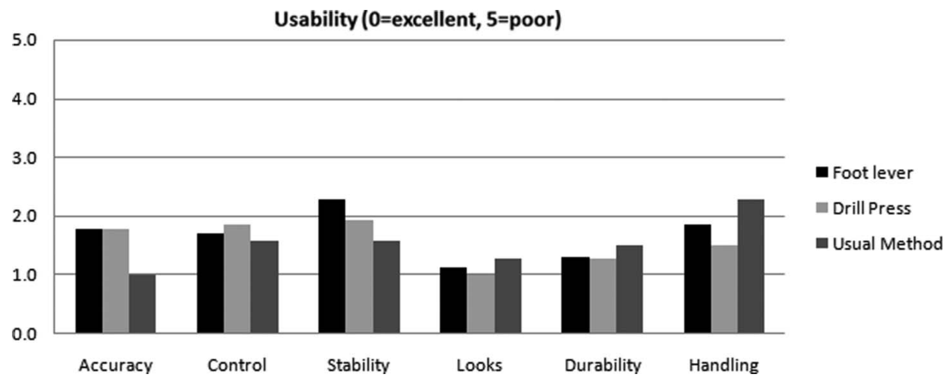

Figure 5. Usability ratings by overhead drilling method (n = 14).

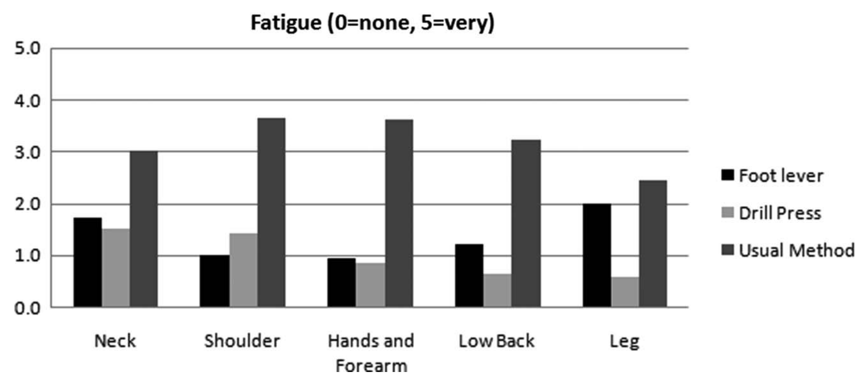

Figure 6. Mean fatigue level by body region and device (n = 14).

Across five of the seven items, the drill press ratings were better than the foot lever, but the differences were not significant.

The open-ended questions provided more insight into usability. Workers who preferred the foot-lever drill press noted that both hands were available to guide the drill to its mark in comparison to the inverted drill press, which required one hand to turn the handle and the other to operate the column lock. Subjects who preferred the inverted drill press noted that it required less force to operate. Two subjects reported low back pain after using foot-lever drill press.

The open-ended questions also revealed that subjects would be willing to use the intervention devices if there were design changes. The recommended design changes included changes to reduce the set-up time, a better method for moving the devices between holes and a reduction in the weight and awkwardness of the devices. Subjects also requested a method for knowing when the hole they were drilling had reached the required depth, because it was difficult to see the drill bit depth when operating the intervention devices from the ground. Another request was to develop a method to allow the devices to be used closer to walls and to move over obstacles on the ground.

When asked what they liked and did not like about the usual methods, the answers were relatively consistent across workers. The usual method was fast, accurate and easy to set up (n = 12). On the other hand, the usual method was painful and fatiguing on the hands, shoulders and back (n = 10). The other problems with the usual method were the noise, dust and requirement to use a ladder (n = 9).

4. Discussion

These findings indicate that the two intervention device designs were successful in reducing the regional body fatigue. Drilling with the intervention devices was more comfortable and associated with less fatigue than drilling with the usual method. However, the usability problems associated with the intervention devices are severe enough to prevent their adoption by experienced construction workers.

Across most of the usability and comparison items, the inverted drill press ratings were slightly better than those of the foot-lever design. The inverted drill press also had an advantage over the foot-lever design on reducing leg fatigue. One of the problems with the foot-lever design was the method for adjusting column height. The resting height of the column was set manually with a gravity pin and was fixed at the height until it was re-adjusted. Frequently, the resting height of the foot-lever device interfered with overhead obstacles, such as cable trays or ductwork; it had to be adjusted to a lower height or tilted before it was dragged to the next position. This manoeuvre was both awkward and inefficient. On the other hand, the column of the inverted drill press design could be easily lowered by simply turning the capstan handle. These observations, coupled with the inherent instability of having to operate the foot-lever design with a raised foot, provided support for the drill press over the foot-lever design for future development.

Other interventions have been developed to reduce overhead work. Examples include pneumatic supports for jack hammers during mining, stands to lift drywall or sheet metal ducts and systems to bore holes into masonry. However, none has been systematically evaluated to determine their effect on regional body fatigue or productivity. Device designs that are not easy to learn or that reduce perceived productivity will be rejected by construction workers as was the case in the present study.

The construction workers in this project suggested a number of changes to the design of the devices to improve their usability and acceptance. Recommendations included improving the method for moving the device between holes, modifying the design to decrease the set-up time and providing a method to monitor drilling depth. The present authors are considering adding four locking castors to the base so that the device can be easily moved between holes without having to tilt and drag it into position. The device can be constructed with modular elements to make set up easier. Adding an adjustable positive stop rod to the drill saddle will let the operator know when the hole is drilled to the proper depth.

This pilot study demonstrates that it is possible to develop and rapidly evaluate equipment used in high-risk construction tasks, such as overhead drilling. The devices developed were promising in that they reduced muscular fatigue. The overhead drilling design demonstrated the best promise. However, the current designs were not acceptable to workers because they were difficult to use and reduced perceived productivity. If the devices can be modified so that the work speed is at least the same as the usual method, then they may offer a viable option on construction sites. An important lesson from this study is that new equipment, designed to improve workplace safety, may need to undergo several rounds of field testing and modification prior to implementation.

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