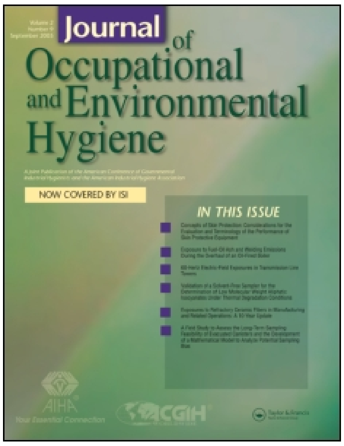

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Ergonomics

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Ergonomics
The Development and Field Testing of an Ergonomic Intervention for the Preparation of Footers in Postframe Building Construction

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INTRODUCTION

The construction work environment is a challenging field for both industry professionals and researchers to improve working conditions in the scope of safety and health. The construction work environment is unique to most work environments in private industry because of its potential to change as work crews progress from job to job. From a standpoint of ergonomics, both identifying and correcting work hazards is often difficult because of these changing work environments.

In the past decade, the incidence rates of nonfatal occupational injuries and illnesses for construction have been consistently higher than those of private industry despite a trend of reduction for both categories.[1,2] The Bureau of Labor Statistics (BLS) data for 2002 shows an incidence rate of nonfatal occupational illnesses and injuries of 7.1 recordable cases per 100 workers for construction compared with 5.3 recordable cases per 100 workers for private industry.[1,2]

The goals of this study were to (1) develop an ergonomic intervention (a footer pad drop device) designed to reduce low back disc compression force for a manual material handling task in which a construction crew member lifts and releases concrete footer pads into predrilled holes, (2) determine the estimated effect of the intervention on low back compression force, (3) determine the effect of the intervention on other work intensity measures such as heart rate and self-reported ratings of perceived exertion, and (4) characterize the pre- and postintervention mean cycle time associated with the task of interest.

MATERIALS AND METHODS

A postframe building construction crew was followed for approximately 7.5 months from mid-December 2004 until the end of July 2005, which included nine different building sites. The area of interest was a five-step process for preparing the footers for the foundation of the building. This process was chosen for analysis because it was reported by the construction crew to include some of the most physically strenuous tasks performed during the construction of a postframe building. The five-stage process included tasks such as shoveling soil away from the edge of the hole as it was being brought up by a hydraulically powered auger bit, removing excess loose soil from each drilled hole with a standard post hole digging tool, dropping concrete footer pads into the holes, setting wooden half-stubs onto the footer pads, and shoveling soil back into the holes to help set the stubs. As this crew performed the work at a given site, the shoveling tasks were carried out by a team of two crew members while a third crew member followed behind performing the post hole tool, footer pad drop, and

FIGURE 1. Example of a posture at the origin of the lift

stub-setting tasks. This column focuses on an ergonomic intervention developed for the task involving the dropping of footer pads into the holes referred to as the "footer pad drop task," and therefore the data corresponds to one crew member who performed this task for the at each of the building sites included in the study.

As part of the footer drop task, a crew member is required to manually lift and drop footer pads of different sizes. The two main sizes of footer pads involved in this study were a small 35.56 ×10.16-cm pad weighing approximately 23.59 kg and a larger 38.74 × 12.70-cm pad weighing approximately 29.94 kg. Figures 1 and 2 show the postures involved with the manual footer pad drop task at the origin and destination of the lift, respectively. At the origin of lift, the footer pads are lifted from the ground at a staged location approximately 5 feet from each footer hole. At the destination of the lift, the pads are held over each hole and visually aligned prior to their release.

FIGURE 2. Example of a posture at the destination of the lift

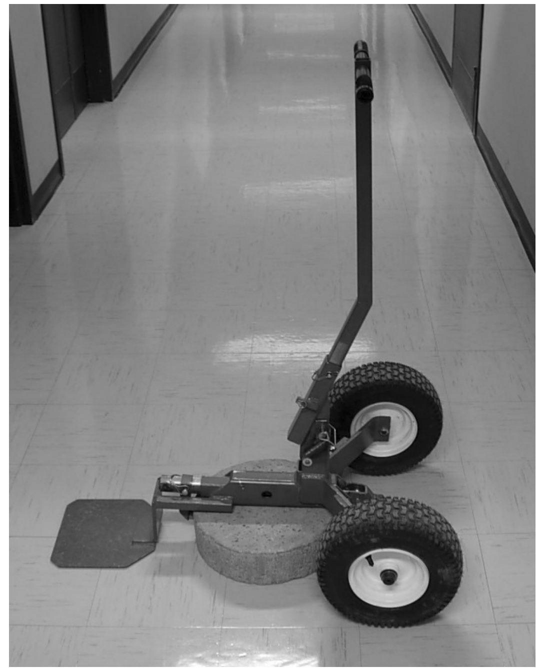

FIGURE 3. Photograph of the concrete footer pad lift and drop device developed for the footer pad drop task (with 14-inch pad)

A footer pad drop device was developed with the intent to pick up, transport, and consistently release two different sizes of concrete footer pads into the footer holes (see Figures 3 and 4). The field testing of the footer pad drop device was

FIGURE 4. Photograph of the footer pad drop device in use

completed in three stages. The first stage involved the preintervention collection of data as the crew member manually performed the task. The second phase was the intervention development phase, which included the development of a unique ergonomic solution from the idea stage to reality. The third and final phase of the study involved the postintervention collection of data with the footer pad drop device in place. Informed consent was obtained from the workers who were subjects of the overall study, and the study protocol was approved by Purdue University's Institutional Review Board.

The University of Michigan's 3D Static Strength Prediction Program (3DSSPP version 5.0.0) was used to estimate low back compression forces based on representative work postures. A total of seven different preintervention postures were modeled in the 3DSSPP to determine an estimated range of compression force placed on the L4/L5 and L5/S1 vertebral regions of the lower back. The postures modeled were based on pictures taken from the video during the recording of the protocol at each work site. The "worst" and "best" postures at both the origin and destination of the lift were modeled for a 35.56 cm diameter pad as well as two postures for a larger 38.74 cm diameter pad. The horizontal distance of the load from the midline of the subject's body was the main criterion for the documentation between the worst and best postures.

To compare the effect of the intervention on the estimated amount of lower back compression force experienced during the initial lift of the concrete pads (at the origin of the lift), a force meter was used to measure the peak force required to pull back the handle of the intervention device and lift each size pad. The average amount of force required to pull back on the device's handle was then entered into the 3DSSPP to estimate the amount of compression force placed on the L4/L5 and L5/S1 vertebral regions of the lower back. A neutral, nonlifting posture was modeled for the purpose of obtaining an estimate of the amount of compression force placed on the subject's lower back during the release of the footer pad from the intervention (at the destination of the lift).

Heart rate data was collected using a heart rate monitoring system (Polar Vantage NV; Polar Electro Inc., Woodbury, N.Y.) that consists of an electrode transmitter chest strap that delivers heart rate data to a data logging wrist receiver via a coded wireless transmission. The wrist receiver's time stamp was synchronized with the time stamp of a digital video camera for off-site visual analysis of the heart rate data. Ratings of perceived exertion (RPE) were acquired using the latest version of the Borg RPE scale.[3]

The Borg RPE scale is a 15-point graded scale with values ranging from 6 to 20 with strategically placed verbal anchors ranging from 6 "No exertion at all" to 20 "Maximal exertion."[3] The values were chosen by Borg to correspond to approximately one-tenth of the heart rate as performed during exercise on a bicycle ergometer.[4]

Cycle times were recorded from video-based task analysis performed off site. For the task considered in this column, the subject was evaluated at each site over the first six holes at which the subject performed the sequence of three tasks. This provided the researchers a standardized amount of data for comparison between sites and also helped reduce variability in the data because work was performed as close as possible to the beginning of the shift.

Statistical analyses were run for the single subject studied between pre- and postintervention conditions using analysis of covariance (ANCOVA). The mean heart rates relating to each pre- and postintervention site (six-hole protocol) were entered into an ANCOVA along with the covariates of ambient temperature, relative humidity, and the minimum heart rate achieved during a rest period prior to the protocol. Similarly, the mean ratings of perceived exertion relating to each pre- and postintervention site were entered into an ANCOVA along with covariates of ambient temperature and relative humidity. However, because only four holes were observed at one of the postintervention sites, the rest of the sites were also factored to a total of four holes to conduct a direct comparison that included the maximum number of sites. The mean cycle times associated with each pre- and postintervention site of the footer pad drop task were entered into an ANCOVA along with the covariates of ambient temperature and relative humidity. For a direct comparison between the preintervention and the postintervention use of the concrete footer pad lift and drop device, a comparable cycle time was used. This cycle time was defined as the time when the subject first touched the device in the staging area until the footer pad was released into the hole. In addition to the cycle time criteria described above, it was also thought necessary to include the time that it takes to harness the device to the next pad directly following a drop of one of the pads. This resulting cycle time represented the total cycle time required for use of intervention.

RESULTS

The ANCOVA test for significance in the mean heart rates between the pre- and postintervention sites yielded a nonsignificant result (p-value >0.05, see Table I). Similarly, the mean RPE values were compared between the pre- and postintervention sites and also showed no significance between the conditions, although a decreasing trend in the postintervention mean RPE values was noticed (see Table II). As for the mean

TABLE I. Comparison of Pre- and Postintervention Heart Rates

Pre	Mean ± SD (bmp^{-1})	Post	Mean ± SD (bmp^{-1})	p-Value^{A}
1	145 ± 8	1	139 ± 8	
2	137 ± 8	2	137 ± 6	
3	139 ± 7	3	132 ± 5	
4	139 ± 5	4	149 ± 10	
Avg.	140.0	Avg.	139.3	0.14

^{A}p-value < 0.05 is considered significant difference.

TABLE II. Comparison of Pre- and Postintervention RPE Values

Pre	Mean ± SD (Scale 6–20)	Post	Mean ± SD SD (Scale 6–20)	p-Value[A]
1	11.75 ± 0.96	1	12.00 ± 0.82	
2	11.75 ± 0.96	2	9.92 ± 0.58	
3	12.25 ± 0.50	3	9.00 ± 2.31	
4	9.00 ± 1.83	4	8.00 ± 0.00	
5	11.50 ± 1.29			
Avg.	11.25	Avg.	9.73	0.55

[A]p-value < 0.05 is considered significant difference.

cycle times of the footer pad drop task, the postintervention cycle times were significantly greater than those associated with the preintervention condition, although a trend of reduction was noticed (see Table III).

Table IV summarizes the estimates of low back compression force for the footer pad drop task at the origin and destination for both the pre- and postintervention conditions. As expected, the preintervention estimates of low back compression force were in general higher for the destination of lift postures than for those associated with the origin. The postintervention estimates of low back compression force were substantially less than the estimates for the preintervention conditions and therefore translated into estimated reductions in compressive force in the 71–95% range depending on the location of the lifting effort.

DISCUSSION

In terms of the heart rate data, an effect on lowering the intensity of work from a cardiovascular standpoint was not detected. The researchers originally believed that if a reduction in heart rates was to occur, the reduction would most likely be due to the elimination of repeated changes in posture,[5] such as bending at the waist when picking up footer pads and/or to the reduction of the work intensity involved with lifting and transporting the pads by hand. During the testing of the footer pad drop device, it was noticed that the interaction between the ground conditions and the intervention device itself could help to explain why a significant reduction in heart rate was not achieved. At postintervention Sites 1 and 2, the size of gravel fill for the buildings foundation was too large for the intervention device to roll smoothly across without a noticeable extra effort being applied by the subject. At the postintervention Site 3, the materials were staged on the outer perimeter of the building below the grade level of the building. This change in elevation required the subject to provide a noticeable amount of extra effort to push the intervention uphill when attempting to place the pad over the hole. The final postintervention site had optimal ground surface conditions in the sense that the foundation was composed of flat, compact soil.

The introduction of the footer pad drop device appeared to have no significant effect on the reported RPE values (4-hole analysis) of the subject performing the work. However, a decreasing trend from 12 to 8 was noticed in the mean RPE values over the postintervention study sites for the footer pad drop task. This trend suggests that a possible learning effect may have been occurring, as the subject could have been gradually adapting to the intervention. The site foundation conditions generally tended to improve (large gravel fill to no gravel fill) with the trend of reduction in the mean RPE values. Therefore, part of the trend of reduction may also have been due to improvements in ground condition.

Overall, the introduction of the footer pad drop device had a significant negative effect on the task cycle time. However,

TABLE III. Comparison of Pre- and Postintervention Cycle Times

Pre	Mean ± SD (sec)	Post	Mean ± SD[A] (sec)	p-Value[B]	Mean ± SD[C] (sec)	p-Value[B]
1	5.0 ± 1.3	1	31.5 ± 10.4		49.7 ± 20.2	
2	9.3 ± 2.3	2	23.8 ± 8.8		45.6 ± 15.1	
3	8.7 ± 2.7	3	19.8 ± 9.1		34.3 ± 15.0	
4	9.5 ± 1.9	4	14.3 ± 4.5		24.8 ± 4.5	
5	6.8 ± 1.9					
Avg.	7.9	Avg.	22.4	0.027	38.6	0.010

[A]Cycle: First touch to release.
[B]p-value < 0.05 is considered significant difference.
[C]Cycle: First touch to release, plus time to harness next footer pad.

TABLE IV. Low Back Compression Force Estimations for Pre- and Postintervention Conditions of the Footer Pad Drop Task

	Origin of Lift		Destination of Lift	
	L4/L5	L5/S1	L4/L5	L5/S1
Preintervention estimation (range kg)	243–305	262–372	298–589	299–612
Postintervention estimation (kg)	70	84	45	32
Estimated magnitude of reduction (range kg)	173–235	178–288	253–544	267–580
Estimated percent reduction (range %)	71–77	68–78	85–92	89–95

it appeared that the decreasing trend in mean cycle time over the postintervention sites may have been a result of the subject becoming more practiced in using the footer pad drop device. Again, both the possibility of a learning effect and the general improvement in site foundation conditions could be responsible for the decreasing trend seen in the postintervention cycle times. It was unclear at the time of testing whether the increased cycle time would dramatically hinder the flow of the work due to the dynamic nature of each construction site. In general, the crew member using the intervention is unable to move faster than the other two crew members performing the shoveling tasks ahead of him. In this sense, the increased cycle time should not prove to be an obstacle to the performance of the work in a timely fashion.

The University of Michigan's 3DSSPP compares low back compression force values with the biomechanical criteria of 349.27 kg of compressive force used in the development of the revised NIOSH lifting equation.[6,7] The majority of the preintervention postures associated with the destination of the lift exceeded the compressive force criteria of 349.27 kg. For the preintervention postures associated with the origin of lift, nearly all were less than 349.27 kg of compressive force. With the use of the intervention, the postintervention estimates of low back compression force were well below 349.27 kg for the postures at both the origin and destination of the lift.

Limitations for this study are typical for field studies and included not being able to control for environmental temperature and humidity, soil and ground surface conditions, and differences in the materials and procedures employed. Another significant limitation for the scope of this study was the low number of subjects included in the overall study, one crew member per task of interest. From the standpoint of the biomechanical modeling in 3DSSPP, the main limitation was that the software program used did not allow the feet of the subject to spread farther than shoulder width apart. An assumption was made by the researchers that the estimate of the compression force placed on the vertebrae of the lower back would not be dramatically affected by the limitations of the lower leg postures. In terms of the amount of time given for training with the footer pad drop device, the subject was allowed to practice briefly using the intervention prior to beginning the testing protocol at the first postintervention site. Given more frequent opportunities for data collection, the researchers would have allowed the subject using this intervention a longer period of time to become accustomed to handling the device.

CONCLUSIONS

The main benefit of the footer pad drop device seems to be the estimated amount of reduction in compression force on the L4/L5 and L5/S1 vertebrae levels of the lower back. Based on the biomechanical modeling in 3DSSPP and the revised NIOSH lifting equation biomechanical criteria, the proper use of the intervention could potentially serve to lower the risk of a worker experiencing back pain due to an overexertion injury during lifting. Although the footer pad drop device did not yield a significant difference in ratings of perceived exertion between the pre- and postintervention testing conditions, a decreasing trend in the mean RPE values was observed over the postintervention sites. The trend of reduction implies that significant differences might have been achieved given a larger data set. The footer pad drop device had significantly greater mean cycle times associated with its use. However, a decreasing trend in mean cycle times was observed over the postinterventions sites. Although it is possible that a learning effect may have been occurring, part of the reduction in cycle time may also have been due to improvements in ground conditions.

The engineered footer pad drop device showed promise through the estimated reductions in low back disc compression force of up to 95% when compared with the manual lifting and dropping of the concrete footer pads. The effectiveness of such ergonomic interventions should continue to be communicated throughout the construction industry with the goal of reducing and preventing musculoskeletal injuries, especially to the lower back.

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