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A participatory ergonomics intervention to reduce risk factors for low-back disorders in concrete laborers

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Abstract

Construction laborers rank high among occupational groups with work-related musculoskeletal injuries involving time way from work. The goals of this project were to: (1) introduce an ergonomic innovation to decrease the risk of low-back disorder (LBD) group membership, (2) quantitatively assess exposure, and (3) apply a participatory intervention approach in construction. Laborers manually moving a hose delivering concrete to a placement site were evaluated. The hypothesis tested was that skid plates would prevent hose joints from catching on rebar matting, and the hose would slide more easily. This would decrease the need for repetitive bending and use of excessive force.

Four laborers were evaluated wearing the Lumbar Motion Monitor (LMM), a tri-axial electrogoniometer that records position, velocity and acceleration. Workers were measured during three comparable concrete pours. Worker perceptions of the innovation utility and exertion were surveyed.

During initial use of skid plates, flexion increased significantly ($p < 0.001$) while velocity, acceleration and moments did not change. After implementing a worker modification, low back velocity, acceleration and moments were significantly reduced ($p < 0.05$). Reductions in these factors have been associated with decreased risk of belonging to an occupational group with LBDs. Use of secured skid plates during horizontal concrete hose movement may in part decrease the risk of LBD group membership among concrete laborers. Crew participation resulted in skid plates being a more effective intervention. The LMM is a promising tool for quantitative assessment in construction.

Keywords: Ergonomics; Construction; Low-back disorder risk; Trunk kinematics; Workplace interventions

1. Introduction

Construction workers are at significant risk of work-related musculoskeletal injury (Schneider 2001, Silverstein et al., 2002), and within this group construction laborers in particular are at risk. Construction laborers perform many physically demanding tasks including cleaning and preparing construction sites, digging trenches, operating power tools, tending machines, loading and unloading building materials, and mixing and placing concrete. These activities expose workers to ergonomic risk factors such as awkward postures, frequent heavy lifting, repetitive motions, and hand/arm and whole body vibration (Everett, 1997). Consistent with this, in construction strains and sprains are the most common type of work-related, nonfatal injury, accounting for over 37 percent of all injuries resulting in days away from work (CPWR, 2002). In 2000 construction laborers ranked fourth among all occupational groups in the number of work-related musculoskeletal injuries involving time way from work and first in lost workdays; construction laborers had a median of 10 days away from work compared to a median of 7 days for all industries (BLS, 2000). Twenty-two percent of lost-time injuries among laborers are due to overexertion, and construction laborer is the highest risk occupation for work-related back pain (Ringen and Seegal, 1995; Guo et al., 1995). In Washington State between 1990 and 1994, 31.5 percent of workers'

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compensation claims by union construction laborers were for strains and sprains, and concrete construction was among the top ten risk classifications rated by incidence rates (Schneider, 2001).

1.1. Applied biomechanics emphasis

There have been a number of studies demonstrating the association between occupational factors and low-back disorders (LBD) (Biering-Sorensen, 1984; Troup et al., 1987; Battié et al., 1990; NIOSH, 1997). In construction the pouring of concrete is a job that poses substantial risks of low-back musculoskeletal injury to laborers due to the weight of the material, awkward postures assumed by workers, schedule pressures driven by the time-sensitive nature of the material, and sometimes harsh environmental conditions. Yet there are few rigorous field-based studies among construction workers in general and laborers specifically, that evaluate the dynamics of the low back or quantify the effect of ergonomic modifications on exposure risk for LBD.

The construction industry has a distinctive work structure and culture that makes conducting such rigorous field-based research challenging. Each construction site possesses unique characteristics such as management philosophy, crew composition, weather, site constraints, and building design that make comparison across sites impractical. Even within one site it can be difficult to compare an innovation across time, as building construction is a process of constant transition. Work crews may be on a site for only a few days or weeks and within a crew, workers may change on a daily basis, depending on supervisory decisions. Craft workers develop their work practices through a socialization process in which apprentices learn from more experienced members of the craft. There is a craft identity and attitude toward problem solving as well as the use of tools and work methods (Jensen and Kofoed, 2002). Therefore, for a new tool or piece of equipment to be readily adopted it must be easy to use, easy to learn to use, and it must fit within the craft culture. Otherwise, potential long-term benefits may never be realized because the innovation may not be given a fair chance due to time pressures of the job and time required for familiarization (Cederqvist and Lindberg, 1993; Jensen and Kofoed, 2002). Time pressures also mean that the work is fast paced and uninterruptible, minimizing the time researchers can interact with workers to test and attach data collection equipment.

Because of these difficulties, past studies of ergonomics in construction have mainly used observational evaluations, surveys of worker perception or lab studies in simulated environments (Wiktorin et al., 1993; Buchholz et al., 1996; Spielholz et al., 1998; Hollmann et al., 1999; Chaffin et al., 1999). While these tools provide useful information, they have shortcomings. For example, observational studies are limited to evaluations of posture and the frequency with which an activity is performed using a static 'snapshot' of an activity. This provides no information about dynamic aspects of a task over the duration of the activity. Perception data is limited due to its subjective nature. The artificial work environments created in laboratory simulations may limit generalizations to the actual job and task applications as performed on a construction site. As new biomechanic assessment tools, such as electromyography, electrogoniometers and telemetry evolve, it is becoming possible to apply quantitative measurements to the evaluation of work activities among construction workers during actual fieldwork. Use of biomechanic tools in real work situations, such as in this study, provides greater insight into the dynamics of the low back and the complex nature of work-related back injury among construction workers.

1.2. Participatory model

Evidence from construction and other industries suggests that the involvement of end users is a key to successful implementation of ergonomic changes (Nora and Imada, 1991; Schurman et al., 1994; Brown, 2002; Koningsveld et al., 1998). Workers have unique knowledge about the jobs they do and in many instances they know valid solutions to ergonomic problems. Further, involving workers in ergonomic decisions builds trust, commitment and good will, which leads to increased job satisfaction and ultimately improved performance (Brown, 2002). Moir and Buchholz (1996) provide other compelling reasons why a participatory approach may be essential in construction. The dynamic nature of the workplace, in which workstations are regularly constructed and deconstructed, requires that those doing the work be intimately involved in decisions about and implementation of ergonomic changes. Construction workers have greater autonomy than most other groups of employees and because their workplace changes so constantly, solving problems is an integral part of their job. While this talent is most often applied to solving production problems, it is equally applicable to safety problems. Finally, to improve the chances of acceptance it is important to include the economic and cultural values of both workers and contractors in designing interventions. (Moir and Buchholz, 1996).

There are many approaches to worker participation that can be used to address ergonomic issues (Brown, 2002; Koningsveld, 1998). In this study the principles of co-operative inquiry (Reason, 1994) guided our applied construction ergonomics research. In contrast

to traditional biomedical research models in which researchers determine and exclusively control all elements of the intervention and research design, co-operative
inquiry explicitly acknowledges and incorporates the notion that research subjects can substantively contribute ideas and through their own behavior impact the ultimate success of the intervention. The model of co-operative inquiry encourages researchers and participants to mutually recognize respective areas of expertise. Consistent with this, there may be times that researchers bring new ideas to the field, and when this is done, participants are encouraged to provide feedback and to suggest modifications. Our adaptation of the co-operative inquiry model is both pragmatic and consistent with the normative assumptions guiding the engagement of labor in organizational processes. We recognize that the ultimate success of ergonomic interventions depends not only on the efficacy of a given change in work practices in reducing musculoskeletal risk, but also on the willingness of workers and employers to utilize new work practices in the field. This, in turn, requires that the proposed change in work practice appears reasonable to those who are asked to utilize it and that it be consistent with the efficiency concerns of all stakeholders in the construction project. Worker and contractor collaboration in selecting and modifying researcher-initiated ergonomic interventions contributes to both of these aims.

In his discussion of the co-operative inquiry model, Reason (1994) identifies four phases of applied research that we incorporated into our applied ergonomics research: (1) researchers and participants agree on an area of inquiry, (2) researchers and subjects collaborate in the selection of an initial change in work practice designed to ameliorate the identified risk, (3) 'full immersion,' in which workers implement the proposed ergonomics intervention, and (4) researchers and workers collaborate to develop, implement, and assess worker-initiated modifications.

This study utilized a participatory ergonomics intervention designed to identify and implement equipment and work practice modifications to reduce ergonomic risk factors in concrete placement work. Our university-based research team collaborated with a construction contractor and concrete laborer crew in developing and implementing the intervention. The intervention had three specific goals: (1) to assess changes in low-back exposure among concrete laborers, after introduction of a specific ergonomic tool; (2) to evaluate whether participation by laborers in selection and application of the tool would lead to a more effective reduction of risk exposure; and (3) to field test an instrument that could quantitatively assess exposure risk among construction workers.

2. Methods

2.1. Study setting

This study was conducted during the construction of a $40-million four-story office and classroom building on a university campus. The intervention evaluated was use of skid plates by concrete laborers for horizontal movement of concrete-filled hoses. Due to the construction plan for this building, pouring concrete from above was not a possibility because four stories of decking were in place prior to concrete placement, requiring laborers to manipulate a concrete-filled hose from the concrete truck to the placement site on each floor. With the exception of the ground floor, the concrete-filled hose lays upon iron rebar matting and must be pulled and repositioned as the work progresses. Each section of hose was 4 m long and 8 cm in diameter. Hose sections were joined together by a quick release latch that was difficult to pull over rebar matting, causing workers to use excessive force to move the hose. At the beginning of concrete placement there may be as many as eight sections of hose attached to the slick line, depending upon the distance to the pumper. As the concrete pour progresses the hose has to be moved back and out of area where concrete is being placed. The laborer at the head of the hose (lead hoseman) verbally signals workers to move the hose. Laborers work as a team to pull the hose away from the newly poured concrete. The laborer crew typically moved the hose by pulling on a 100–125 cm long piece of rope attached to the hose at the couplings and at points half way between these joints.

The ergonomic intervention was the introduction of skid plates, 60 cm diameter metal disks (Conforms, www.conforms.com, part # LH-54) that can be placed under the couplings between sections of hose. Four skid plates were placed under hose couplings near the pour end of the hose dispensing concrete. We hypothesized that skid plates would reduce stress to the low back by preventing the hose couplings from catching on rebar matting and by decreasing the overall friction of pulling the hose. This would reduce the need for repetitive bending and use of excessive force to dislodge, pull and move the hose. All laborers were invited to participate in the intervention and in accordance with university requirements for research involving human subjects, participation was not compulsory and those who participated provided written informed consent.

2.2. Participatory process

We applied the four phases of the co-operative inquiry model (Reason, 1994) to our ergonomic intervention with construction laborers. In the *first phase*, researchers and participants agree on an area of inquiry.

Initially we met with the project superintendent and foremen to discuss which jobs and trades they were concerned about on this site, with regard to LBDs. In construction, as elsewhere, this is an important place to start since buy-in by management is essential to the success of any type of intervention. It was not possible to involve craft workers themselves at this stage because they were not yet present on the project. After discussion of a number of trades and job tasks on this site, the job task of most concern to the contractor from past experience was the horizontal manipulation of the hose that delivers concrete from the concrete truck to the placement site. Pouring from above was not possible due to overhead obstructions.

In the *second phase*, researchers and subjects collaborate in selecting the tool or work practice that would be changed to attempt to ameliorate the identified risk. A critical part of this phase is the opportunity for workers to share their experiences, ideas, and concerns regarding the proposed intervention and the project. In some instances, this could lead to a change in the newly proposed work practice prior to the initiation of the intervention; in other cases the proposed intervention may proceed unaltered, though workers' initial response to the proposed change may provide clues as to possible later modifications that might be incorporated into the fourth phase of the co-operative inquiry. As part of this effort, our research team conducted a focus group with concrete laborers. We met with the crew of 10 laborers and presented a review of basic ergonomic principles and common risk factors associated with musculoskeletal injuries to supplement workers' knowledge and to provide a context for discussion about aspects of moving concrete hose that place them at risk for low back injury. We discussed with the project superintendent and foremen potential solutions that would reduce LBD risk during hose movement, but no one had specific suggestions in mind.

From past experience conducting construction research we have learned that often workers are hesitant to suggest ergonomic solutions, especially if the solution costs money or could impact productivity. The climate among construction management is often to 'take it or leave it.' Since construction workers can be replaced at a moment's notice, they typically believe it is better to keep quiet than to complain about working conditions. Additionally, the pace with which construction proceeds influences the ability of researchers to intervene and collect data. In this study, once discussions with the project superintendent and foremen identified concrete work performed by laborers as a potentially hazardous task for the low back, we had approximately three weeks to meet with laborers, gain their support for an intervention, decide on the intervention, design the study and implement the intervention. The work schedule was such that once concrete placement began we had only 6–8 weeks until it concluded. Therefore, we came to the focus groups prepared to discuss one or more potential problems and armed with a number of potential ergonomic solutions. After discussing various aspects of their work, laborers agreed that movement of concrete hose was a difficult, potentially hazardous task but they could think of no remedies. Since no solutions to this problem were forthcoming, we proposed the adoption of skid plates to both management and laborers. Neither management nor the laborer crew were not aware of skid plates, but they were interested and enthusiastic to try them.

The *third phase* is "full immersion," in which workers implement the proposed ergonomic intervention. An essential aspect of this third phase is an assessment of the intervention. As in the other phases of co-operative inquiry, the desire for collaboration between researchers and subjects does not preclude, but requires, an explicit recognition of the specific expertise each party brings to the research project. In this study we contributed the expertise necessary to design, implement and quantitatively assess the efficacy of the intervention, namely skid plates. For their part, workers gained experience using the new tool so that they could provide input on its effectiveness and/or suggest modifications to enhance its effectiveness.

The experience gained in the full immersion phase provides the basis for the *fourth phase* of the collaborative inquiry in which the researchers and workers collaborate to develop, implement, and assess worker-initiated modifications or 'field fixes'. During this phase, the locus of innovation in the development of improved ergonomic tools and work practices shifts from the researcher to the workers in the field, while the responsibility for the evaluation of the intervention remains with the research team. In this case, researchers met informally with laborers during a lunch break to gather their opinions after using the skid plates on several 5-h concrete pours. Additionally, following assessment of the intervention with the field fix (securing skid plates to hose), researchers met once again with the laborer crew to get feedback on the effectiveness of the intervention after the field fix was introduced.

The development of our co-operative inquiry model for applied ergonomics research in the construction industry is an integral part of our effort to apply rigorous research to the validation and adoption of improved tools and work practices by workers and contractors. Practitioner engagement helps ensure that the ergonomic innovations initiated in phases two and three and the subsequent field modifications developed in phase four are workable in the field. Beyond this, worker engagement in the development of these ergonomic solutions enhances the likelihood that modified worker practices will continue to be used on the site and will be introduced on new worksites.

2.3. Measurement apparatus

To measure the worker's lumbar region posture, motion, and force, we used the Lumbar Motion Monitor (LMM), a portable tri-axial electrogoniometer developed at Ohio State University (Marras et al., 1993). The LMM glides between a set of harnesses, one strapped to the low back and one between the scapulae, and allows collection of data during work activities. It collects time and position data in the lumbar region, in three planes, at 60 Hz via an analog-to-digital converter and transmits the information via digital telemetry to a laptop computer.

The mass of the concrete-filled hose was measured using a Chatillon 300-strength dynamometer (Ametek, Largo, FL) by lifting it vertically one foot off the ground. Trials were video taped using a digital camcorder. Frequency of pulling the hose was estimated by two researchers timing each of the four volunteers, in 10-min increments, at each of the three data collection times. One worker was measured on only two occasions. These results were then averaged to provide an estimate of overall hose pulling frequency. The frequency of laborers moving hoses was observed for over 30 h both before and during data collection, and we felt confident that a sufficiently representative number of frequency observations were collected.

2.4. Procedure

All 10 laborers on the crew participated in focus groups and informal discussions. Seven laborers agreed to fill out questionnaires. Five laborers volunteered to be evaluated using the LMM. This number was decided upon for two reasons. First, based on findings by Allread et al. (2000) in manufacturing, evaluation of three trials in three workers was found to be sufficient to acquire valid results. The second reason was pragmatic. Given the time sensitive nature of pouring concrete, we were only able to place the LMM on workers during lulls in the work. It took 45–60 min per worker to gather data, making it impractical to collect data on more than four or five subjects. All 10 laborers were given the opportunity to volunteer to be measured. All participants were right-handed, healthy males with no current low-back complaints. Data were collected during three different concrete pour times in the following order:

(1) Baseline: Before the introduction of the skid plates laborers pulled and moved hoses in the usual manner;
(2) Hose lying unsecured on skid plates: In this condition skid plates were used as suggested by the manufacturer; and
(3) Skid plates with worker modification: In this condition workers remedied limitations they identified with the skid plates and incorporated a 'field fix' intended to increase the effectiveness of the skid plate (Fig. 1).

Fig. 1. Laborer pulling concrete-filled hose secured to skid plate.

On this site concrete placement of floors, requiring horizontal movement of hoses, was divided into sections. Pours were scheduled to occur 2–3 days each week over a period of 6–8 weeks. Pouring concrete began at 5 a.m. and lasted 4 to 6 h, until the section was finished. To minimize threats to internal validity, such as muscle fatigue and temperature changes, data collection commenced when pouring began in the morning. We attempted to minimize order effects by evaluating volunteers in a random order, so that no person was always the first or last to be assessed. Additionally, volunteers also rotated between the front, middle and back of the hose, since this was a standard part of the work controlled by the foreman to prevent fatigue. For our purposes it served to increase the generalizability of skid plate use.

Approximately 20 trials were recorded for each worker at each time interval as they pulled and moved the hose. Therefore, for a single worker, trials contain data from pulls at different positions on the hose. The LMM was sized to fit the worker and then calibrated while still in its box. When it was his turn, and during a lull in the work, each laborer stepped away from the hose to have the LMM strapped to his low back and chest. The lower harness was placed so that the top of the belt was at the L5/S1 junction while the upper harness fit between the scapulae. Data collection for each trial commenced when the lead hoseman verbally signaled workers by yelling 'pull' and ended when the researcher, sitting nearby at the computer, saw that the worker wearing the LMM was no longer pulling on the hose rope. Each trial was between 1 and 10 s long and the average trial time was 4.2 s, although the actual time a worker pulled the hose was shorter.

A brief survey of worker perceptions was completed at the time of the second focus group meeting. After data collection, but while still using skid plates, laborers were asked to complete a Borg exertion scale (Borg, 1982) to estimate overall pulling exertion with and without skid plates. The Borg is a validated scale that has been used for many years in sports to measure perceptions of exertion. This study used the 15-point scale where 6 is considered a very, very light exertion, and 20 is considered a very, very hard exertion. The original Borg 15-grade scale (from 6 to 20) of exertion has been shown to be a good method for evaluating simple applications of perceived exertion (Borg, 1982). Completion of the Borg was done during the post data collection focus group, which occurred 3 weeks after data collection but during a time when laborers were still using skid plates.

2.5. Data analysis

This study used a quasi-experimental pretest–posttest design in which subjects served as their own controls. To analyze the effectiveness of skid plates utilized per manufacturer specifications and with the worker-recommended field fix, we regressed dummy variables representing different workers and different levels of the intervention on a series of dependent biomechanical variables provided by the LMM. Twelve to 15 trials per subject were analyzed at each of the three test intervals.

The LMM Ballet™ software provided output data in two forms. 'Motion data' files provide time, position, angular velocity (ω) and angular acceleration (α) for rectified data at each collection point, in each trial. Therefore, in a 4-s trial collected at 60 Hz there would be $60 \times 4 = 240$ data points, and there were 12–15 trials per subject for each level of the intervention. For each trial in the motion data, the maximum and average values for position, velocity and acceleration in each plane are placed into a 'summary data' file. Position data are reported such that neutral position, recorded when the LMM was calibrated in its box, equals zero, which may or may not correspond to zero when placed on a worker, depending on their personal lordosis. Right-sided moments are positive while extension and left-sided movements are negative. Additionally, Ballet™ predicts the risk of LBD group membership associated with the measured task, based upon a model developed and validated by Marras et al. (1993). For each variable (e.g. sagittal flexion, maximum lateral velocity) the model finds the maximum value across all trials for an individual. These values are then averaged across subjects to predict the overall low-back disorder risk associated with a particular task.

Due to the fast pace and restricted working conditions it was not possible to measure pulling force during actual hose pulls. Changes in the maximum external moment occurring about the lumbar spine with and without skid plate use were calculated using the relationship between linear and angular acceleration and the equation:

$$a = \sqrt{(r\omega^2)^2 + (r\alpha)^2}, \quad (1)$$

where a is the linear acceleration and r the perpendicular distance between the force pulled and the low back, measured from L5/S1 to a place just above the elbow. In this way the magnitude of tangential linear acceleration was estimated for each trial. Force to the low back was then calculated using Newton's second law

$$F = ma. \quad (2)$$

Mass is the vertical weight of the concrete-filled hose. Moments in each of the three planes were estimated using the equation

$$M = Fd. \quad (3)$$

Distance (d) is the average perpendicular distance measured from the laborer's hands to the low back. This model makes three assumptions: (1) the body is a rigid link segment model, (2) the laborer's arms are rigid so that the moment arm does not change during the pull and (3) calculation of tangential linear acceleration is a reasonable reflection of measured angular acceleration.

3. Results

3.1. Worker descriptive statistics

Four laborers completed the evaluation with the LMM, 10 laborers participated in focus groups while seven laborers answered a short questionnaire. Laborer characteristics are presented in Table 1. The average age of the four laborers measured was 35 years compared to 39 years for the entire crew. The average length of experience in concrete work was 4.8 years for the four evaluated laborers and 8.2 years for the entire crew. The

Table 1
Laborer descriptive information

Subject	Height (cm)	Weight (kg)	Age (years)	Years doing concrete work
S01SB	185	83.9	24	7
S02JM	175	77.1	40	9
S05KW	175	86.2	47	6
S06MT	175	90.7	28	6
Participant average	178	84.4	35	4.8
Crew average ($n = 7$)	180	88.1	39	8.2

crew average is high because one laborer had been doing concrete placement work for 28 years. If this laborer is removed, the average for the remaining six laborers is 4.9 years. Laborers pulled or moved the concrete hose on average 1.8 times per minute (108.6 times per hour), with a range of 1.2–2.9 times per minute. Most of the time activity was steady, making this estimate an accurate reflection of the job frequency. Yet in any given hour there may have been 10–15 min of down time, for example while waiting for another concrete truck or unclogging the hose. During those times laborers may have removed sections of the hose, carried them out of the work area, performed other tasks as needed, or taken a short break. The average duration of floor pours on this site was 4–6 h. The mass of the concrete-filled hose measured with the dynamometer was 36.3 kg for a force of 356 N.

3.2. Skid plate use and crew perceptions

The skid plates have a cradle in which the hose sits. However, when laborers pulled the hose with their ropes the hose frequently came out of the cradle and off the skid plates. After using the skid plates for one complete pour laborers decided it was necessary to secure the hose couplings in place. After some discussion several types of tie-downs were tried: (1) two rubber bungee cords across the hose, (2) nylon strapping with a quick tighten and release mechanism, and (3) rebar tying wire. Laborers felt that wire worked the best, the bungees were adequate, but the strapping did not hold the hose securely.

Six crewmembers liked using the skid plates after they had the opportunity to tie down the hose and would use them again while one, the youngest and least-experienced laborer, did not like them. Six of the seven laborers found that the skid plates required less pulling effort. Since frequent bending is a risk factor for low-back injury, worker perceptions of bending were solicited. Two laborers thought that using the skid plates required more bending, four thought it was the same, while one thought there was less bending. Six workers felt the skid plates made their work easier. Seven laborers completed a Borg exertion scale. The average exertion score without using skid plates was 14 (hard) while the average score using skid plates was 11.9 (fairly light).

3.3. Lumbar Motion Monitor results

The means and standard deviations for the 18 kinematic variables, and lumbar moments, are presented in Table 2. Standard deviations are high, but are consistent with values recorded by Marras et al. (1993) in manual material handlers. In the sagittal plane most kinematic variables initially increased after introducing the skid plates but then decreased substantially after workers secured the hose. For example, flexion increased from 6.67° to 13.88° upon using the skid plates but then decreased to 4.76° when the hose was tied down. Also, velocity and acceleration increased slightly with initial skid plate use, but decreased once the hose was secured. In the frontal plane, use of skid plates decreased right bending, while in the transverse plane it reduced twisting to the right. Again, once the hose was secured there were additional decreases in mean velocity and acceleration. The mean maximum moment in all three planes decreased with skid plate use while further decrease was noted after securing the hose. The greatest change was in twisting movements where the moment decreased from 35.22 Nm without skid plates to 27.23 Nm using secured skid plates. The peak maximum moment recorded was 120.76 Nm in flexion, decreasing to 100.35 Nm when the hose was secured to the skid plates.

3.4. Regression analysis

Kinematic data and estimates of low-back moments were regressed to assess the relative impact of skid plates on injury risk, for both unsecured and secured skid plate use. Two dummy variables represent use of skid plates with no tie-down and use of skid plates with tie-downs, while pulling the hose without skid plates is represented in the base of the model. To control for individual differences, three person dummy variables are included in the model so that individuals served as their own controls.

Ballet™ software calculates 18 measures encompassing average and maximum position, velocity, and acceleration, but not all are relevant for analysis of this intervention. Since injury risk was evaluated using the LBD risk model, the two kinematic variables used in this model, maximum lateral velocity and average twisting velocity, were assessed. The movement laborers used to move the concrete hose across rebar matting was most commonly a combination of trunk extension, started from a flexed position, right-sided bending, and right-twisting. NIOSH (1997) suggests that work-related awkward postures are associated with the risk of low-back injury, while Marras and Mirka (1989, 1990) have demonstrated that asymmetric motions coupled with acceleration increase spinal loading. Given these relationships and the fact that all four volunteers were right-handed, measures of right-sided bending and twisting, plus flexion and extension, were evaluated. High forces have also been associated with low-back injury (NIOSH, 1997). In this study acceleration was used to estimate low-back force in three planes during hose pulling. Overall, nine measures encompassing position, motion, and force were assessed for the task of pulling concrete hose by laborers. Table 3 shows the linear regression

Table 2
Descriptive statistics for low-back kinematic and kinetic variables

Variable	No skid plate $n = 68$		Skid plate $n = 48$		Secured skid plate $n = 78$	
	Mean (SD)	Min/max	Mean (SD)	Min/max	Mean (SD)	Min/max
Sagittal plane						
Max flexion (deg)	6.67 (8.54)	−12.99/35.38	13.88 (15.81)	−10.46/54.28	4.76 (11.52)	−11.20/39.27
Max extension (deg)	−7.05 (6.33)	−19.80/18.80	−4.32 (7.24)	−14.8/17.7	−7.94 (5.91)	−18.40/21.00
AP range of motion (deg)	13.72 (8.76)	0.00/41.91	18.20 (15.91)	0.39/58.28	12.69 (9.57)	0.01/43.24
Max velocity (°/s)	28.50 (16.548)	0.02/78.07	32.76 (24.12)	2.65/115.91	23.69 (17.07)	0.08/67.83
Ave velocity (°/s)	7.51 (4.16)	0.01/23.06	7.71 (5.08)	0.27/27.92	6.03 (3.83)	0.04/17.74
Max acceleration (°/s^2)	224.72 (137.89)	0.22/584.13	225.24 (151.20)	26.29/880.58	173.54 (124.72)	0.98/610.26
Frontal plane						
Max left bend (deg)	−1.31 (6.37)	−14.43/21.24	−2.22 (5.36)	−16.46/10.20	−1.33 (4.44)	−20.66/8.41
Max right bend (deg)	7.86 (4.16)	−3.15/22.38	7.67 (6.23)	−2.53/24.51	5.89 (3.80)	−3.21/14.07
ML range of motion (deg)	9.18 (5.45)	0.10/21.80	9.90 (7.62)	0.10/29.2	7.22 (6.38)	0.00/30.00
Max velocity (°/s)	26.00 (17.27)	0.46/93.00	24.26 (17.19)	0.98/77.64	18.04 (13.82)	0.20/58.42
Ave velocity (°/s)	6.12 (3.81)	0.23/18.41	5.26 (3.20)	0.49/11.74	4.23 (3.41)	0.10/14.54
Max acceleration (°/s^2)	185.82 (123.89)	5.46/701.85	174.15 (118.91)	10.32/559.14	134.04 (104.02)	2.51/448.71
Transverse plane						
Max left twist (deg)	−3.88 (6.78)	−16.48/14.67	−4.05 (7.99)	−19.30/13.31	−3.33 (7.03)	−22.59/11.50
Max right twist (deg)	8.18 (7.81)	−12.87/28.72	7.26 (6.04)	−7.79/18.36	6.28 (7.87)	−17.83/24.12
Twist range (deg)	12.06 (9.09)	0.01/41.58	11.30 (8.34)	0.00/31.52	9.61 (8.65)	0.07/40.64
Max velocity (°/s)	35.03 (24.56)	0.05/103.79	30.07 (18.39)	0.00/63.60	26.66 (20.85)	0.47/112.15
Ave velocity (°/s)	7.35 (5.79)	0.03/29.77	5.51 (4.00)	0.00/16.05	4.72 (3.85)	0.14/16.93
Max acceleration (°/s^2)	273.55 (193.74)	0.61/843.09	224.13 (142.50)	0.00/560.86	204.91 (162.28)	5.38/981.04
Moments						
Max lateral moment (Nm)	24.32 (17.45)	0.72/83.18	21.48 (14.13)	1.53/61.40	17.72 (14.53)	0.33/73.62
Max AP moment (Nm)	29.56 (20.18)	0.02/96.25	28.22 (19.19)	3.34/120.76	24.40 (21.43)	0.13/100.35
Max twisting moment (Nm)	35.22 (24.90)	0.08/119.59	27.85 (17.86)	0.00/81.84	27.23 (22.25)	0.71/112.84

results for these variables comparing skid plate use, with and without the tie-down, to no skid plate, when controlling for individual differences. For position variables, the degree of maximum flexion was not statistically significantly different when using secured skid plates compared to no skid plates. However, there was significantly greater flexion among laborers pulling the hose using unsecured skid plates ($p < 0.001$). Extension, as would be expected with greater amounts of flexion, was significantly decreased when workers used unsecured skid plates ($p < 0.05$). Also, when workers tied the hose to the skid plates there was a significant decrease in the amount of maximum right-sided bending ($p < 0.01$), although no difference was found in maximum right twisting. In terms of velocity, maximum lateral velocity and average twisting velocity decreased

Table 3
Regression results for kinematic variables controlling for individual differences (unstandardized coefficients with standard errors in parentheses)

$N = 200$	Constant (SE)	Skid (SE)	Secure skid (SE)	Person 1 (SE)	Person 2 (SE)	Person 3 (SE)	F-statistic	DF	Adj. R^2
Max	0.276	7.733***	−2.203	13.279***	5.384*	7.293***	12.810***	18	0.234
flexion	(1.782)	(2.074)	(1.794)	(2.064)	(2.226)	(2.200)			
Max	−8.019***	3.029*	−0.944	2.258†	−0.144	1.493	2.954*	18	0.048
extension	(1.051)	(1.223)	(1.058)	(1.217)	(1.312)	(1.297)			
Max right	7.523***	0.781	−2.033**	1.371†	−3.662***	2.357**	11.789***	18	0.218
bend	(0.685)	(0.797)	(0.690)	(0.793)	(0.856)	(0.846)			
Max right	4.725***	−0.373	−1.944	4.362**	3.435*	6.407***	4.818***	18	0.090
twist	(1.171)	(1.363)	(1.179)	(1.356)	(1.462)	(1.446)			
Max lateral	16.374***	0.504	−8.149***	13.536***	6.154*	18.717***	12.079***	18	0.223
velocity	(2.365)	(2.752)	(2.381)	(2.739)	(2.953)	(2.919)			
Ave Twist	6.095***	−1.187	−2.663***	1.748*	−0.559	3.382***	6.761***	18	0.130
velocity	(.734)	(0.854)	(0.739)	(0.851)	(0.917)	(0.906)			
Max AP	165.131***	−4.311	−54.213**	136.146***	80.027**	35.625	8.495***	18	0.163
acceleration	(20.802)	(24.206)	(20.943)	(24.097)	(25.982)	(25.681)			
Max lateral	113.941***	1.704	−53.333**	105.373***	56.289**	128.626***	11.105***	18	0.207
acceleration	(17.142)	(19.947)	(17.258)	(19.857)	(21.411)	(21.162)			
Max twist	217.967***	−26.551	−69.545**	69.152*	2.853	138.926***	5.731***	18	0.109
acceleration	26.680	31.047	26.861	30.906	33.324	32.938			

† $p<0.10$.
* $p<0.05$.
** $p<0.01$.
*** $p<0.001$.

Table 4
Regression results for lumbar moments, controlling for individual differences (unstandardized coefficients with standard errors in parentheses)

$N = 193$	Constant (SE)	Skid (SE)	Secure skid (SE)	Person 1 (SE)	Person 2 (SE)	Person 3 (SE)	F-statistic	DF	Adj R^2
Max frontal	15.572**	−1.330	−7.082*	19.967**	3.369	10.829**	15.459**	188	0.273
moment (Nm)	(2.209)	(2.571)	(2.224)	(2.559)	(2.759)	(2.727)			
Max sagittal	21.808**	−1.746	−5.923*	26.677**	4.601	−0.447	18.485**	188	0.312
moment (Nm)	(2.802)	(3.260)	(2.821)	(3.245)	(3.499)	(3.459)			
Max axial	29.095**	−4.876	−8.470*	6.911**	−4.714	9.370*	7.356**	188	0.141
moment (Nm)	(3.431)	(3.992)	(3.454)	(3.974)	(4.285)	(4.235)			

* $p<0.05$.
** $p<0.001$.

significantly when workers used secured skid plates compared to not using skid plates ($p<0.001$). Acceleration for anterior–posterior (AP), lateral and twisting movements also decreased significantly using secured skid plates compared to not using skid plates ($p<0.01$). When comparing workers one, two, and three to worker four, there were statistically significant individual differences between workers ($p<0.10$ to $p<0.001$).

Forceful movements are factors associated with risk of low-back injury, especially when considered in relation to asymmetric lifts or rapid speeds (Fathallah et al., 1998). Table 4 shows results from a linear regression of lumbar spine moments. Lumbar region torque decreased significantly in all three movement planes when workers used secured skid plates compared to not using skid plates ($p<0.05$). For two laborers individual differences were statistically significant.

3.5. LBD risk model

Risk of LDB group membership was calculated using Ballet™ software and peak kinematic data, peak moment estimates and pulling frequency in these laborers (Fig. 2). In this model the interaction of five variables—lifting frequency, maximum sagittal flexion, maximum lateral velocity, average twisting velocity, and lumbar moment—were found to be the best predictors of risk of a job leading to low-back injury (Marras et al., 1993). Marras et al. (2000) determined the probability that a job would be a member of a group of jobs found to have high numbers of LBD. The risk of LBD group membership was rated as high (⩾70 percent), medium risk (30–70 percent) or low (⩽30 percent). The overall probability of risk of LBD group membership decreased from 67 percent prior to skid plate use to 46 percent when using secured skid plates. Lifting frequency did not change with skid plate use and remained constant at

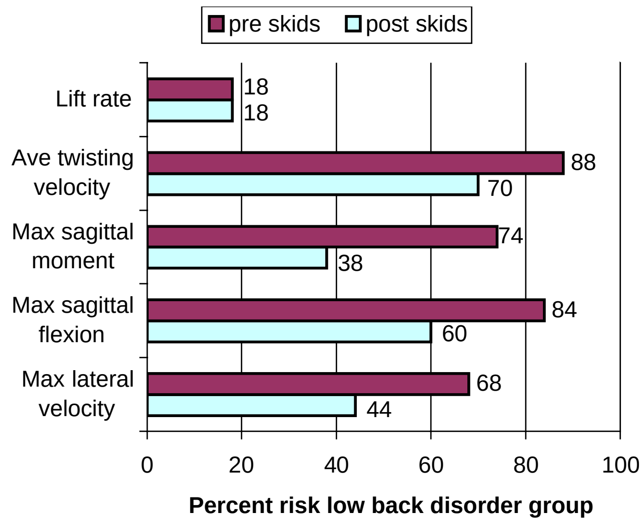

Fig. 2. Risk of LBD group membership model before skid plate use and with secured skid plates.

1.8 lifts per minute. Average twisting velocity, maximum lateral velocity, and maximum sagittal flexion all decreased the risk for LBD group membership. When using secured skid plates, maximum lateral velocity decreased from 68 percent to 44 percent risk, maximum sagittal flexion also decreased 24 percent, while average twisting velocity demonstrated the least change by decreasing only 18 percent with use of secured skid plates. The greatest reduction was in sagittal lumbar moment, which decreased from 74 percent to 38 percent with use of secured skid plates.

4. Discussion

4.1. Low-back biomechanics and LBD group risk

As results from biomechanical studies become available, it is evident that in addition to manual handling of heavy loads and repetitive activities, asymmetry and motion effects such as trunk velocity and acceleration and, more importantly, the interactions among these factors, are integral to understanding injury risk (McGill and Hoodless, 1990; Mirka and Marras, 1990; Marras et al., 1993; Fathallah et al., 1998). The present study evaluated the interactions among these factors. Use of secured skid plates decreased flexion an average of 2°. Mean asymmetric motion in right-sided bending and right-sided twisting also decreased an average of 2° in each plane. The mean maximum velocity decreased by 4.81°/s during AP movements, 7.96°/s with lateral movements, and 8.37°/s with twisting movements. Even though these are statistically significant decreases, if taken individually the magnitudes may not be substantial. However, Marras and Mirka (1989, 1990) and Mirka and Marras (1990) demonstrated the importance of interactions among these variables. For example, as trunk asymmetry in the transverse plane increases, trunk strength decreases and the external load shifts from the erector spinae muscles to less capable and smaller oblique muscles (Marras and Mirka, 1992). Trunk strength also decreases as velocity increases. Additionally, the degree of flexion interacts with velocity and asymmetry. Trunk strength is greatest when flexed at 22.5° and decreases with more or less flexion. The upshot is that more muscle activity is required to maintain the same level of force production, resulting in additional loading of the spine.

Asymmetric motions have been shown to create significant compressive and shear forces to the lumbar joints (McGill and Hoodless, 1990), while others have demonstrated substantial levels of compressive and anterior and lateral shear loads at the L5/S1 joint caused by the interaction of velocity and asymmetry during lifting (Fathallah et al., 1998). The interaction of these factors may result in damage to facets and the intervertebral disc (Shirazi-Adl, 1989, 1991). In the current study, pulling the hose involved varying degrees of asymmetry in conjunction with moderate amounts of force prior to skid plate use. These laborers employ movement patterns with sufficient asymmetry, velocity, and force to result in large compressive and shear forces in the low back. Skid plate use decreased workers' asymmetry and velocity, and calculations from acceleration data suggest that low-back torque was also reduced, potentially decreasing L5/S1 loading.

The low back is also affected by the interaction between asymmetry and acceleration. Marras and Mirka (1990) demonstrated that as acceleration and asymmetry increase, so does muscle activity in low-back agonists and antagonists. Even with a torque of only 4.1 Nm, in some conditions muscles are activated up to 50 percent of their maximum to produce angular accelerations. It seems likely that large amounts of muscle activation, and in particular coactivation, may reflect significant increases in spinal loading during larger trunk torque generation. In the present study, without skid plates the average maximum acceleration was 185.82°/s^2 in lateral motions, 224.73°/s^2 in AP motions and 273.55°/s^2 in twisting motions. These amounts decreased by 51.77°/s^2 for lateral movements, 51.19°/s^2 for AP motions, and 68.64°/s^2 for twisting motions with use of secured skid plates. Considering the level of muscle activation that occurs in conjunction with rapid accelerations during asymmetric movements, decreasing these factors is an important aspect of decreasing LBD risk, if for no other reason than to decrease muscle fatigue and the accompanying risk of overexertion injury.

Skid plates did not affect pulling frequency. Yet, these findings are contradictory to those found by Fulmer

(2002) when evaluating skid plate use at a large Boston highway construction project. He found that laborers using skid plates increased their 'no lift time' by 15 percent. They also decreased the number of lifts higher than 1 ft but increased the number of small lifts less than 1 ft from the ground. He attributed these findings to the hose being easier to move thereby allowing laborers to make additional corrections in hose placement without lifting it. These contradictions may be accounted for by differences in methodology. Fulmer used PATH, (Buchholz et al., 1996) an observational sampling method, and sampled the entire job performed by the concrete laborers. This technique may have provided a more comprehensive assessment of the laborer's job, whereas our study was limited to evaluation of one task, pulling hoses.

Mean sagittal flexion did not change significantly with secured skid plate use, although the risk associated with maximum sagittal flexion, based on the LBD model, which uses peak values, decreased by 24 percent. This reflects the dynamics of variable interaction as opposed to findings from strictly evaluating the magnitude of individual factors. Flexion actually increased significantly when using non-secured skid plates, underscoring the importance of worker feedback.

Taken individually, the changes in asymmetry, velocity, and acceleration measured using secured skid plates, while statistically significant, may not be meaningful. The interactions between asymmetric postures, velocity, acceleration, and force increase the risk of injury because of the large trunk moments created in association with decreased available strength. During dynamic activities a substantial portion of back strength goes to support and move the trunk, resulting in less strength capacity for lifting, pulling, or otherwise moving an object. The net result is an increased risk for injury. Seen in this context the interactions of these motion variables combined with worker characteristics such as lumbar moment, suggest that the changes observed using skid plates translate into the potential for decreased injury risk during hose movement.

Actual low-back injury rates among concrete laborers still need to be linked to skid plate use. Because laborers perform many different duties and come and go from a work site, collecting injury incidence data over an extended period that are specific to a particular activity or group of workers is impossible. Therefore, we are forced to draw conclusions from data gathered from other types of workers. Marras et al. (2000) correlated decreases in risk of LBD group membership with decreases in injury incidence following ergonomic interventions in over 36 manual material handling (MMH) jobs in 16 different companies. They found that for jobs in the medium LBD risk category, a decrease in risk from 67.2 percent to 50.7 percent corresponded to a decrease in injury incidence rate from 11.0 to 4.3 per 100 full time employees. Using the same model, the present study found a similar LBD job risk in laborers pulling concrete hoses that decreased from 67 percent to 46 percent. We cannot conclude that this drop in risk would result in a significant reduction in injury incidence, especially considering the wide variety of activities laborers routinely perform, but it is reasonable to assume that the application of secured skid plates to the hose-pulling task by laborers is one component of decreasing their overall risk of low-back injury associated with this job task.

4.2. Fit of the risk model

Concrete laborers repetitively (108.6 times/h) pull hoses that weigh 36.3 kg across rebar matting for up to 6 h a day. It is reasonable to ask if this activity is similar enough to the repetitive movement activities evaluated in manual material handlers to apply the LBD risk model. Few studies have evaluated the biomechanics of pulling, and three-dimensional dynamic models are needed to fully understand the constraints imposed upon the spine during pulling activities. Current models of pulling consider only low-back compression and the interaction of the foot with the floor when pulling carts, and there is no consensus as to which factors are most important (Chaffin et al., 1999). Arguably, these pulling models do not adequately fit the activity of pulling hoses by laborers. When pulling hoses, laborers started from a slightly flexed posture and extended from the low back in order to reposition a concrete-filled hose. This task, like those of MMHs, is dynamic in nature, consisting of rapid movements and repetitive bending combined with substantial force production in the L5/S1 region during movement of a mass.

In terms of dynamic factors, the MMHs measured by Marras et al. (1993) had, on average, faster peak velocities and accelerations in all planes, and workers flexed and extended to a greater degree than did the concrete laborers. They evaluated over 450 jobs from 61 different industries, from such diverse jobs as automobile assembly, machined products manufacturing, handling clothing, glass production, electronic equipment manufacturing, and food processing. An analysis of task variability found that the majority of variability in trunk motions was due to work task design and that variation due to repeated cycles or different employees was small (Allread et al., 2000). Even so, they demonstrated the predictive ability of the LBD model for this wide variety of dynamic MMH activities (Marras et al., 1993, 2000). It therefore seems reasonable to use the LBD model for assessing pulling activities among concrete laborers.

According to Mirka et al. (2000) a shortcoming for applying the LBD risk model is its reliance upon repetitive jobs performed continuously throughout the day in job cycles of 1 min or less. Therefore, characteristics of non-repetitive jobs may not be represented in the model predictions. Concrete laborers perform largely non-repetitive activities, in that they poured concrete only 2 days a week, for 4–6 h a day and moved hoses at a rate of 1.8 pulls/min. Yet within this timeframe their job is fairly repetitive and only one repetitive task of their job, pulling hoses, was evaluated. Thus, if we accept the validity of the LBD risk model, we could conclude from our data that if concrete laborers performed the hose pulling task all day every day, their LBD risk is moderate and is significantly reduced by the use of secured skid plates. Since these workers do other tasks as well, we cannot reach this conclusion without some analysis of the low-back risk posed by those other tasks. Some other laborer tasks would be amenable to analysis with the LMM, e.g. shoveling, but others may not be. This again points to the challenge of ergonomic exposure assessment among construction workers. In fact, it is precisely the variation in tasks and cycle times of much construction work that makes the LMM attractive because it collects real-time exposure measures. But at the same time its limitation is that its validity may apply only to parts of the individual worker's job. Further research to fully characterize low-back disorder risk in construction workers could build on the Task-Based Exposure Assessment Model developed for airborne contaminants (Susi et al., 2000).

4.3. Worker and contractor involvement

The importance of worker and supervisor involvement in the successful adaptation of ergonomic tools has been widely reported (Moir and Buchholz, 1996; Nora and Imada, 1991). In this situation the first step was support from the construction superintendent and his willingness to invest financially and philosophically in trying a new intervention. The superintendent appreciated the impact of musculoskeletal injuries in construction and identified concrete laborers as among those workers he felt were at the greatest risk. Several other trade groups and tool possibilities were explored before settling on the use of skid plates with these workers. While the superintendent knew of no alternatives to pulling concrete-filled hoses, when shown a picture of skid plates he was immediately enthusiastic, feeling that they could reduce friction associated with moving hoses across rebar matting. When asked why these devices had not previously been used, his reply was that he was unaware of their existence, and that he had not supervised jobs in recent years that required horizontal movement of concrete hose.

Crew involvement in the use of skid plates led to modifications that made the tool more useable and effective. Due to the time pressures of concrete pouring, the superintendent initially instructed workers to seat the hose on the skid plates but not attach them. However, laborers became frustrated because the hose frequently pulled out of the skid plate cradle, requiring workers to bend and lift more often in order to reposition the hose. An informal discussion with the laborers indicated they thought the hose should be secured to the skid plates. The three tie-down methods that were tried came from discussions with the crew and received approval from the superintendent. The straps took too long to attach and didn't hold the hose securely enough. The bungee cords worked reasonably well but were too elastic. The preferred method was the rebar wire that could be quickly attached to the skid plate handles and removed with wire cutters when sections of hose were removed. Laborers found the skid plates helpful at some times and hose positions but a hindrance at others. When placed at the pouring end of the hose, the skid plates were less efficient because of the frequent need to remove hose sections. Workers found them most useful several sections from the pour end of the hose.

As part of enhancing worker involvement in the adoption of skid plates and overall musculoskeletal injury reduction, researchers discussed the biomechanic findings from preliminary data analysis and individual body mechanics. Workers were able to see video of their own work practices during concrete placement and critique their activities. Quantitative information about worker low-back dynamics was used to address specific biomechanic factors and provide a dynamic dimension to body mechanics training beyond evaluations of static posture. For example, average twisting velocity decreased from 88 percent to 70 percent in the LBD risk model but still presents considerable risk. Using feedback on movement velocity during body mechanics training targets a component of the job task that until now has not been addressed and that could lead to further reductions in injury risk.

The challenges of making changes in construction practice, described in the introduction, make it particularly important to address the applicability of a research intervention to the 'real world' of construction. All aspects of the implementation and evaluation process require both supervisory support and crew involvement to maximize effectiveness. This case illustrates some of the differences between construction and fixed industry in terms of how participation is invited and organized. Timing is critical and researchers or ergonomic practitioners must be creative in accessing craft workers and finding collaborative opportunities. The role played by the researchers in this study eliciting worker and contractor input about worksite changes to improve ergonomics, introducing new tools, and getting worker feedback on effectiveness or modifications could be played by a safety coordinator, superintendent, or other supervisory personnel. Supervisors may need some training, both in ergonomic fundamentals and in particular techniques of eliciting ideas and evaluating impact, but their knowledge of the work and the crew gives them an advantage in integrating these processes into the work itself.

4.4. LMM utility

In order to evaluate ergonomic interventions in construction, evaluation techniques are needed that can capture the dynamic aspects of worker activities in real work situations. For these concrete laborers the LMM was an effective field tool for evaluating work activities beyond static postures or worker perceptions. The LMM telemetry worked flawlessly, enabling researchers to observe workers at a distance while gathering very accurate and specific position, velocity, and acceleration data for the low back. The process of strapping the LMM on laborers and removing it after data collection took only in a few minutes, minimizing disruption of work activities. Laborers were able to move about without restriction and did not find the LMM cumbersome. One concern was that the 'spine' of the LMM had a tendency to pop out of the upper harness when laborers fully flexed to the floor. This was dealt with by slightly lowering the upper harness, making the unit more secure in the harness.

Another strength of the LBD risk model is the relationship between injury rates and quantifiable dynamic trunk motion characteristics during actual work activities. The application of the LMM to field construction tasks among laborers or other crafts has not previously been reported in the literature and presents new insight into worker movement dynamics and job risk. The LMM would be difficult to use with other construction workers wearing large tool belts or harnesses, but there are undoubtedly modifications that could be made in some cases.

4.5. Limitations and future areas of inquiry

In field studies there are limitations that require certain assumptions to be made. In this study, in order to calculate low-back force we assumed that the average perpendicular distance from the workers' arms to their back was constant. In reality this distance could vary depending on worker position. However, we observed workers for many hours and noted that laborers consistently fixed their arms in a position close to their trunk. Also, for each worker, the moment arm was measured several times at different data collection times and the averaged results were consistent.

Because trial length varied from 1 s to 10 s, the possibility exists for bias based on the variation in trial length. A regression analysis controlling for length of trial time found no significant differences in outcomes based on time ($p<0.05$).

Marras et al. (2000) calculated moments in the lumbar spine using a two-dimensional linear model by multiplying the mass of lifted objects by the maximum horizontal distance of the object in the worker's hands from the lumbar spine. Since pulling is a more complex motion, calculations of low-back torque were made using acceleration data. The transformation of angular acceleration to linear acceleration assumes that these two measures are similar. Our moment estimates are meant to provide a measure of the changes in low-back force over the different test times, rather than a reflection of absolute moment values.

An alternative hypothesis for our findings is the effect of learning to use skid plates. We attempted to address this issue by conducting a *t*-test comparing the first half of the trials, across all three data collections, with the last half of the trials. While we cannot conclude there was no learning effect across trial times, our analysis demonstrated no learning effect between the first and last half of data collection trials, suggesting that the changes noted were due to the effect of the skid plates alone.

Finally, the question remains as to whether the levels of velocity, acceleration, and torque found here actually lead to injury among concrete laborers. Correlation of these results with injury data would be helpful for better understanding this relationship. However, since workers come and go from a site with regularity and a job may last from a few days to months, gathering this type of data in construction has thus far eluded researchers.

5. Conclusions

In this study an ergonomic innovation to decrease low-back disorder risk among concrete laborers was introduced and evaluated using a quantitative instrument, the Lumbar Motion Monitor (LMM), which captures the dynamic aspect of job tasks. The LMM proved to be an effective field tool for use among construction laborers. With unsecured skid plates flexion, velocity, and acceleration increased, but when workers attached them to concrete-filled hoses the probability of risk of a low-back disorder decreased significantly. The variables most influenced by skid plate use were low-back moments, lateral velocity, and sagittal flexion. Most workers liked using the skid plates and thought they decreased the exertion of pulling hoses. Worker involvement and feedback were important for increasing the effectiveness of the skid plates. Future studies are needed to better understand the dynamics of pulling activities, to quantify other aspects of laborers' jobs, and to establish a relationship between changes in risk factors and actual incidence of low-back injury.

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