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Alternatives to lifting concrete masonry blocks onto rebar: biomechanical and perceptual evaluations

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Alternatives to lifting concrete masonry blocks onto rebar: biomechanical and perceptual evaluations

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This study examined the use of and barriers to H-block and high lift grouting, two alternatives to lifting concrete masonry blocks onto vertical rebar. Peak and cumulative shoulder motions were evaluated, as well as adoption barriers: H-block cost and stakeholder perceptions. Results indicated that using the alternatives significantly decreased peak shoulder flexion ($p < 0.001$). A case study indicated that building cost was higher with H-block, but the difference was less than 2% of the total cost. Contractors and specifiers reported important differences in perceptions, work norms, and material use and practices. For example, 48% of specifiers reported that use of high lift grouting was the contractor's choice, while 28% of contractors thought it must be specified. Use of H-block or high-lift grouting should be considered as methods to reduce awkward upper extremity postures. Cost and stakeholders' other perceptions present barriers that are important considerations when developing diffusion strategies for these alternatives.

Practitioner Summary: This study provides information from several perspectives about ergonomic controls for a high risk bricklaying task, which will benefit occupational safety experts, health professionals and ergonomists. It adds to the understanding of shoulder stresses, material cost and stakeholder perceptions that will contribute to developing effective diffusion strategies.

Keywords: ergonomics; bricklaying; shoulder injury; stakeholder perceptions; biomechanics; diffusion of innovation

1. Introduction

Occupational health and safety researchers have done considerable work identifying injury risks and developing technical ergonomics solutions. However, these are only the initial steps in the process of reducing work-place injuries. In the 1990s, ergonomics was considered a five-step process: identification, analysis, develop solutions, implementation and evaluation (Rosecrance and Cook 2000). The ergonomics process has since been demonstrated to be more complex and researchers must address the perceptual barriers to adoption of ergonomics controls by stakeholders, such as architects, engineers and construction managers (Figure 1), in addition to addressing purely biomechanical problems. Recognising this, in 2004 the National Institute of Occupational Safety and Health (NIOSH) launched the Research to Practice (r2p) initiative to increase successful transfer and translation of research findings to the workplace, in order to enhance injury prevention. This has promoted blending public health models, such as Roger's diffusion model (Rogers 1995), with traditional ergonomics interventions to enhance adoption by stakeholders (Weinstein *et al.* 2007). However, only a few studies in the construction industry have addressed both technical issues and behavioural barriers to date (van der Molen *et al.* 2005, 2006, Hess *et al.* 2010a).

Bricklayers have high rates of work-related musculoskeletal disorders (MSDs) due to the demanding nature of their work (Entzel *et al.* 2007, CPWR 2008). Shoulder disorders are the second most common MSD, after back injuries, with approximately 50% of bricklayers complaining of shoulder symptoms (Stenlund *et al.* 1993, Cook *et al.* 1996, Construction Safety Association of Ontario 2003). Shoulder MSDs are an expensive and disabling problem. For example, in Washington State between 1996 and 2004, shoulder MSDs accounted for 36% of all work-related MSDs in, with rotator cuff syndrome accounting for an average of 323 days of missed work, costing an average of $29,877 per claim in direct costs (Silverstein *et al.* 2006).

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Building with medium weight concrete masonry units (CMU or 'blocks'), often requires bricklayers to work in awkward, repetitive postures, in harsh outdoor environments. They commonly lift 240 or more blocks per day (van der Molen *et al.* 2008), approximating four and a half tons of material each day. Shoulder disorders may be partially associated with lifting block above shoulder height. Studies of various occupational groups have demonstrated that working with the hands above the shoulders increases the risk of shoulder pain and injury (Harkness *et al.* 2003, Svendsen *et al.* 2004, Miranda *et al.* 2005, Silverstein *et al.* 2008, van Rijn *et al.* 2010).

Bricklayers work with their arms elevated $>60^\circ$ approximately 30% of their day (Luijsterburg *et al.* 2005). This may occur when rebar is placed within block cells to provide vertical structural support. When concrete walls are reinforced, a 2.3 m long section of rebar is placed vertically after every 1.2 m or 6th row of block (called 'courses' in construction) and may extend 0.91 m to 1.07 m above the highest row of block. Grout is then poured into each block cell containing rebar. In some situations conventional wall construction requires bricklayers to lift CMU (17.3 kg or more) onto vertical rebar that is above shoulder level, increasing exposure to a combination of risk factors including repetitive, heavy lifting, and awkward arm postures above 60° of flexion (Figure 2).

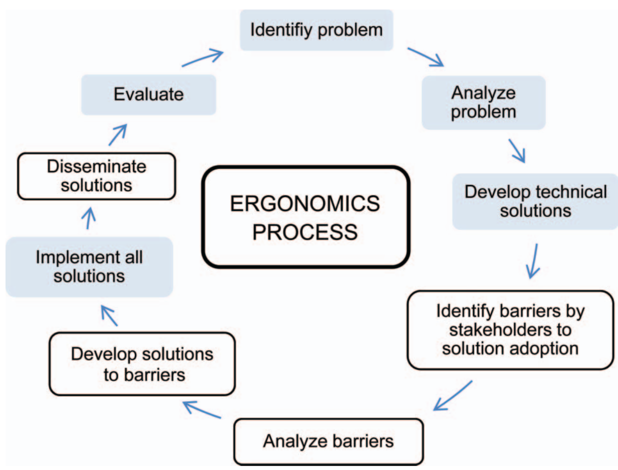

Figure 1. Evolution of the ergonomics process. Blocks in grey represent an older, less, comprehensive model.

Figure 2. Bricklayer placing CMU block onto vertical rebar.

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Engineers, architects and estimators who are certified to specify building materials and construction work practices (specifiers) are requiring greater use of rebar reinforcement in concrete block construction due to more stringent building codes. This trend seems to be in response to concerns about the potential for injury and building damage following hurricanes or in areas of high seismic activity, which may result in placement of vertical rebar as frequently as every 20 cm.

Alternative methods exist that may decrease shoulder elevation when working with rebar-reinforced walls, including H-block and high-lift grouting. H-block is a type of concrete block without ends that is shaped like the letter 'H'. It can be placed around rebar and other vertical barriers rather than lifted over them. Another alternative is high-lift grouting. In this method, eight or more rows of block are placed, after which vertical rebar is threaded through the cells in the block, and then grout is poured into these cells. High-lift grouting allows bricklayers to construct walls to a greater height before adding vertical rebar, poses few additional organisational challenges, and may enhance productivity by requiring less frequent grouting. However, it is not known if use of H-block or high-lift grouting reduces shoulder or worker stress. Further, little is known about the barriers to adoption of these alternatives, by industry stakeholders. Therefore, this two-part article examines the potential risk of shoulder injury in bricklayers from a biomechanical perspective and investigates two barriers to adoption: intervention cost and stakeholder perspectives about interventions. Such comprehensive assessments are essential for reducing work place injuries. Researchers, ergonomists, and safety and health professionals need to consider stakeholder perceptions and behaviours that prevent the adoption of well studied and tested ergonomic controls.

1.1. *Biomechanical shoulder evaluation*

Most epidemiologic studies associating shoulder elevation with MSDs have used a cross-sectional design or self-report estimates of shoulder elevation (Burdorf and van der Beek 1999, Hansson *et al*. 2001b, Spielholz *et al*. 2001). Thus, it is still unclear what shoulder elevation height above 60° (shoulder flexion or abduction) is associated with shoulder injury, i.e., peak exposure (Svendsen *et al*. 2004, Garg *et al*. 2006). Moreover, it is unknown what duration and frequency of shoulder elevation are potentially hazardous, i.e., cumulative exposure. In general, occupational injuries are typically difficult to attribute to either peak or cumulative exposure (Nieuwenhuijsen 1997, Burdorf and van der Beek 1999). Therefore, both peak and cumulative shoulder postures were evaluated, as well as perceived exertion and construction duration of three methods of constructing walls reinforced with rebar: conventional, H-block and high-lift grouting (Figure 3).

1.2. *Stakeholder concerns – material cost estimate*

Even though H-block and high-lift grouting methods have existed for many years, they are underutilised in the construction industry and barriers to adoption exist (Hess *et al*. 2010a). While there are many important financial factors that contractors should consider when bidding on a job, such as time loss, workers' compensation, quality issues, worker turnover, absenteeism, and productivity losses, to name a few (Goggins *et al*. 2008, Rose *et al*. 2011),

(a) Placing conventional CMU (b) Placing H-block (c) High-lift grouting

Figure 3. Different methods for laying block when vertical rebar is present.

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materials cost is often the deciding factor for many contractors (Hess *et al.* 2010a). According to Ethan Churchill, instructor of Construction Estimating at Eastern Washington University (personal communication, 6 Jan 2012), materials can account for >40% of new building costs. However, it has been previously established that companies may lack knowledge about the actual costs and outcomes of ergonomics when assessing the true cost of building (Andersson 1992), creating concern that some alternatives, such as H-block, with ergonomic potential, may be ignored. For the high-lift grout method, materials and the construction process are essentially the same, so no additional cost would be expected, though there may be other barriers to adoption.

There are structural differences when constructing with H-block that could make it appear prohibitive to contractors. For example, grout is poured into every cell of H-block since the block does not have ends, but only the cells with rebar are grouted when using CMU. Grouting makes the wall heavier which requires a stronger foundation (or 'footing').

Additionally, new materials will be closely scrutinised for productivity effects; contractors might consider a product with a higher per unit cost if there are substantial savings in time or enhanced productivity. H-blocks are widely used throughout California due to seismic standards where vertical rebar reinforcement can be used as frequently as every 20.3 cm. In a previous study, 25% of contractors interviewed believed that use of H-block improves productivity and 30% believed it saves time (Hess *et al.* 2010a). One California Bay Area Representative from Basilite, a leading manufacturer of masonry materials, suggested that productivity improves up to 50% with H-block, depending upon block size and the frequency of lifting block onto vertical rebar (personal communication, Spencer Puccio, 20 Aug 2008). When asked about the additional costs of grouting all cells, contractors who use H-block again suggested that enhanced labour productivity made up for higher material costs. Therefore, we conducted a case study to estimate the cost difference when building with H-block compared to CMU.

1.3. Stakeholder concerns – contractor and specifier perceptions

Building construction is a complex process requiring the interaction of many professionals. There are many reasons why injury-reducing equipment, materials, and work practices are not readily adopted. Material cost, quality concerns, availability and ease of use are frequently cited (Hess *et al.* 2010a). In order to better understand the perceptions and barriers to the use of H-block and high-lift grouting, we surveyed architects and structural engineers who specify building materials, and masonry contractors who build with these materials.

2. Methods

2.1. Biomechanical evaluation of the shoulder

2.1.1. Subjects

Twenty-one male bricklayers were recruited at a regional apprenticeship training centre (International Masonry Institute, Seattle, WA). Participant demographics are in Table 1. In previous studies, this number was sufficient for providing statistical power with these evaluation tools (Anton *et al.* 2005, Hess *et al.* 2010b). Study subjects were eligible for inclusion if they were a currently employed third year apprentice or journey-level bricklayer. In the USA, third year apprentices are working full time at their trade and are fully skilled masons. Participants were excluded if they currently had or in the last six months had been treated for an acute MSD or had a history of low back or upper extremity surgery. Subjects provided written consent. The University of Oregon Office for the Protection of Human Subjects and the Eastern Washington University Institutional Review Board approved all study procedures. Each bricklayer was compensated for participation.

Table 1. Participant demographics ($n = 21$).

Variable	Mean	Minimum	Maximum
Age (years)	42.6	21	61
Height (cm)	177.3	162.6	188.0
Weight (kg)	87.4	54.4	138.3
Years in Trade	16.5	3	34

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2.1.2. Instrumentation

The left arm was the focus of evaluation because prior investigation of bricklayers indicated considerably higher upper Trapezius muscle activity in the non-dominant arm when building a wall with CMU (Anton *et al.* 2005). Eighteen of the 21 participants were right-hand dominant although all participants lifted block with their left arm or with both arms.

Peak shoulder elevation during the tasks was measured with a motion capture system (VICON 624c, M2 cameras, Workstation software version 4.6, Oxford Metrics, London, England). Reflective markers (14 mm), placed to identify trunk and shoulder segment dimensions were adapted from prior studies (Nussbaum and Zhang 2000, Rab *et al.* 2002, Wu *et al.* 2005). The trunk segment dimensions were defined by markers placed on top of the iliac crests and the most dorsal aspect of the acromioclavicular joints. Five markers were used to define a co-ordinate system to track motion of the trunk segment. They were placed on the superior aspect of the sternum, spinous processes of the T1 and T8 vertebrae, and bilaterally lateral to erector spinae muscular at the T4 level. The shoulder segment dimensions were defined proximally as a position 6 cm inferior (negative vertical displacement relative to the trunk's coordinate system) to the acromioclavicular marker (Nussbaum and Zhang 2000), and distally by the markers placed on the most caudal point of the medial and lateral epicondyles of the humerus (Wu *et al.* 2005). A rigid, thermoplastic shell with four tracking markers affixed to its surface was attached to the arm via Coban® wrap in order to track the three dimensional position of the arm in space. Marker placement allowed participants full range of motion. Subjects wore sleeveless shirts with holes cut into the fabric so markers could be affixed to the skin and be visible to the eight-camera setup. Each block had tracking markers placed on the surface facing away from the subject. The block markers were used during post-collection processing to determine the start of the lift (initial block motion) and end of the lift (placement of the block on the wall).

Video data were sampled at a rate of 60 Hz. Marker trajectories were low pass filtered at 6 Hz with a recursive fourth order Butterworth filter. Shoulder angles were determined and expressed as bone rotations by comparing the coordinate system of the upper arm segment in reference to the position of the trunk segment. This was accomplished with Euler angle calculations resolved first in the sagittal (flexion motion about the x or medial-lateral axis) and then the frontal plane (abduction motion about the y or anterior-posterior axis) assuming rigid body analysis (Visual3D, Version 3.25, C-Motion, Inc., Rockville, MD). This order of resolution of Euler angles is consistent with recommendations by the International Shoulder Group from the International Society of Biomechanics (Wu *et al.* 2005).

Peak shoulder flexion position was determined between the start and end of the block lift. The lifting task was the focus of the motion capture analysis as we expected this task to have the highest physical demand when building the wall. The amount of shoulder abduction at the instant of peak shoulder flexion was also recorded for each block placement. The results from all block placements in a given row were used to create an ensemble average to represent that row for each wall condition analysed.

The high sampling rate and resolution of the camera system made it well-suited for analysis of brief moments of human motion. However, the volume of data and subsequent post-processing analysis made it impractical for collecting continual arm position. Instead, *cumulative* shoulder exposure was measured using a Virtual Corset (VC, Microstrain, Williston, VT, USA). The VC is a triaxial shoulder accelerometer with a sampling rate of 7.5 Hz that provides continual data related to position, velocity, and acceleration of the arm relative to the vector direction of gravity. Triaxial accelerometers have been previously validated for use in posture analysis (Hansson *et al.* 2001a) and for use at the shoulder during construction tasks (Amasay *et al.* 2009, Hess *et al.* 2010b). The VC was placed on the lateral aspect of each arm, at half the distance between the lateral epicondyle of the humerus and the acromioclavicular joint. This placement was chosen because it minimised both movement of the device over the arm muscles and acceleration error. The VC was secured to the subject's skin using double-sided tape and covered with prewrap taping foam.

Cumulative arm motion and position were calculated using a validated method with the three accelerations (x, y, z) measured (Amasay *et al.* 2009) using custom Labview (National Instruments) software (Fethke *et al.* 2004). Data were processed using a 'jerk' analysis, a proxy for repetitive motions, and to identify the per cent time a bricklayer spent above 30°, 60° and 90° of elevation, which is related to exposure to awkward arm postures. Both of these outcome measures have been used previously to evaluate shoulder exposure (Hess *et al.* 2010b). The 'jerk' analysis involves calculating the per cent time spent in three categories of arm elevation velocities (henceforth called 'repetitive motion'): static ($<10°/s$), slow (10–40°/s), and fast ($>40°/s$). A higher percentage of time indicates longer exposure in the velocity category, and therefore more time spent in the fast category indicates more time spent performing repetitive motions.

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2.1.3. Experimental procedures

Prior to data collection, a base wall five blocks wide and five rows high was constructed using standard 0.2 × 0.2 × 0.4 m CMU. In order to simulate actual fieldwork conditions, an instructor of masonry apprentices and a journey-level mason designed the base. Rebar positioners were placed between the 4th and 5th row to keep rebar vertical. Study participants, following masonry 'best practices', then constructed Rows 6–8 on top of the base wall. The higher rows were evaluated since they are associated with laying block onto rebar and awkward shoulder postures. Since rebar is added after Row 6, methods should not differ for the earlier rows. Depending on the construction method, five CMUs (15.0 kg) or H-blocks (13.7 kg) were placed per row for a total of 15 blocks per wall. Based on previous studies with bricklayers this number of blocks was deemed sufficient to quantify shoulder postures (Anton *et al.* 2005). Participants were experienced with each construction method. To help minimise practice effects, the order of wall construction was counterbalanced. Participants rested 10 minutes between building each wall to reduce fatigue while a helper restacked blocks.

For the conventional method, Row 6 was constructed using CMU. Five sections of rebar (#5, 1.6 cm, 200 cm length) were then placed vertically every 30.5 cm. The rebar extended approximately 72 cm above Row 6. The block was then lifted over the rebar in Rows 7 and 8. For the H-block method, Row 6 was constructed with H-block, rebar was placed, then H-block was placed around the rebar for Rows 7 and 8. For the high-lift grouting method, CMU block was placed for Rows 6–8 and rebar was added after Row 8.

During construction, a mason tender stacked block in the supply stack and mixed mortar. The supply stack was maintained at 0.6 m (three blocks' height) so that the bricklayers always lifted from the same height. The time to construct each wall was recorded with a stopwatch. After constructing each wall, subjects rated their exertion using the Borg Rating of Perceived Exertion (RPE) scale (Borg 1998). The RPE scale is a validated 15-point scale that allows the rater to choose exertions from 'very, very light' to 'very, very hard'.

2.2. *Stakeholder concerns – material cost estimate*

A case study design was used as a simplified method for examining the materials and productivity cost differential (here after called 'cost') when building with H-block compared to CMU. An Oregon independent cost estimator, who was recommended by the Construction Specifications Institute, the primary organisation in Oregon for certifying construction specifiers, calculated the cost of two large retail stores. One was a 5175 m^2 retail store he had previously estimated and which had been built in Eugene OR, USA with CMU, while the other was a mock, but identical store specified to be built with H-block. The estimator held constant all building material and labour costs that would remain the same between the two buildings such mortar, materials for windows, doors, roofing, labour for other trades, and materials for all other aspects of the building. He estimated costs based only upon factors that would differ when using H-block including the footing materials, insulation, grouting, rebar and masonry labour costs/savings, which are listed in Table 2. In California, the cost of H-block is the same as CMU since large quantities of H-block are available. For the purposes of this estimation, we considered H-block cost the same as CMU.

Vertical rebar (1.59 cm diameter) was spaced 0.41 m apart and horizontal rebar (1.59 cm diameter) was spaced 1.22 m apart. Block pilasters were spaced at 12.8 m on centre. Grout was placed only in the reinforced cells and non-grouted cells were filled with vermiculite insulation. The typical footing for these block walls was 0.61 m wide and 0.25 m deep with three 1.27 cm rebar placed longitudinally in each wall. Footing widths were increased by 15% for the H-block wall to accommodate the increased wall load from additional grouting. The production rate for CMU was estimated at 168 blocks/day/bricklayer. The estimator chose a conservative labour productivity rate for H-block as being 15% faster than CMU, or 193 blocks/day/bricklayer based on estimates provided by the Means Productivity Standards for Construction (RS Means Company *et al.* 1994) and confirmed via conversations with masonry contractors who use H-block. The cost of H-block and CMU was $1.80 US/block, quoted by a Los Angeles Basalite block manufacturer in 2008.

2.3. *Stakeholder concerns – contractor and specifier perceptions*

Telephone interviews were conducted with 25 architect/engineer specifiers and 25 commercial masonry contractors. Interviews were completed between September 2008 and April 2009. The specifiers were selected from a list compiled from the Construction Specifiers Institute member list for Oregon and Washington and consisted of 103 names. All respondents were certified to specify building materials. A list of 334 commercial contractors was compiled from Oregon and Washington members of the Mason Contractors Association of America (2008), the

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Table 2. Mean (SD) peak and cumulative left shoulder positions, repetitive motions, and perceived exertion during three different wall construction methods.

Variable	Conventional	Method H-block	High-lift grouting	*p*-Value
Peak exposure (motion capture)				
Peak flexion (°)			(simple effect)	
Row 6	107.7 (15.7)	103.4 (11.9)	106.1 (13.7)	0.140*
Row 7	130.1 (8.5)	113.9 (9.9)	118.7 (9.7)	< 0.001
Row 8	130.8 (8.7)	123.8 (9.7)	126.3 (9.7)	0.005
Peak abduction (°)				
Row 6	47.1 (12.5)	46.7 (9.5)	46.5 (11.2)	0.944
Row 7	27.2 (12.7)	40.1 (8.7)	39.8 (10.8)	< 0.001
Row 8	28.2 (11.6)	37.0 (8.5)	34.3 (9.2)	< 0.001
Cumulative exposure (virtual corset)				
Per cent time with left arm elevated				
>30° (% construction time)	56.9 (8.2)	57.7 (9.1)	56.6 (8.3)	0.504
>60° (% construction time)	26.4 (7.2)	26.9 (7.5)	27.3 (7.0)	0.652
>90° (% construction time)	9.5 (4.5)	9.6 (5.0)	10.5 (4.5)	0.273
Per cent time of left shoulder repetitive motion				
Static (% time <10°/s)	27.8 (5.7)	30.4 (6.2)	28.5(6.2)	0.036
Slow (% time 10°/s to 40°/s)	54.5 (4.1)	52.7 (3.8)	53.6 (3.9)	0.061
Fast (% time >40°/s)	17.7 (3.1)	16.9 (3.1)	17.9 (4.4)	0.074
Perceived exertion (Borg)	12.7 (3.3)	10.5 (2.9)	9.8 (2.5)	< 0.001
Construction time (min)	13.7 (2.4)	13.2 (2.4)	12.8 (2.6)	0.288

Note: *Huynh-Feldt correction.

Blue Book® of Building and Construction (Contractors Register Inc. 2008), and the Masonry Institute of America (2008). Lists were randomised and the first 25 participants who agreed to be interviewed were included in the sample. Excluded from participation was any specifier or contractor who did not work with any type of block, or did not primarily work in Oregon or Washington.

A slightly different survey was developed for each group (specifiers or contractors) to examine their distinct perspectives. Survey questions asked about familiarity and perceptions of different materials and work practices. For example, each group was asked whether they (1) were familiar with H-block and high-lift grouting; (2) used or specified H-block, high lift grouting, or light weight block; (3) how often did they use or specified them and (4) if they did not use them, why not. If respondents could not think of an answer, the interviewer provided a standard list of suggestions. The survey took approximately 10–15 minutes to complete. The University of Oregon Office for the Protection of Human Subjects approved the surveys.

2.4. *Data analysis*

For the biomechanics study, prior to the main analyses all variables were checked for out-of-range values, assumptions of normality, and outliers. To correct for non-normally distributed variables, a number of transformations were applied, but the transformed variables were still non-normally distributed and had outliers. Since results were similar with and without transformations and outliers, untransformed raw data were used in the final analyses. The cost estimate and survey are descriptive studies only.

Separate two-way repeated measures analysis of variance (RANOVA) were used to evaluate differences in *peak* shoulder motions of flexion and abduction, and separate one-way RANOVA was used to evaluate differences in *cumulative* shoulder elevation, 'jerk' time, and perceived exertion. The Mauchly test was used to test the sphericity assumption and a Huynh-Feldt epsilon estimate was used if this assumption was violated. Construction method was a within-subjects factor with three fixed levels: conventional, H-block, and high-lift grouting. Row built was also a within-subjects factor with three fixed levels: 6, 7 and 8. The interaction between method and row was a fixed factor, and subjects were random. Although main effects and interaction were evaluated, simple effects were the primary comparisons of interest. The family-wise α level was 0.05 and a Bonferroni adjustment was used for pre-planned comparisons of methods at Rows 7 and 8. Frequencies were calculated for the survey data. All analyses were conducted with SPSS 18.0 (SPSS Inc., Chicago, IL, USA).

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3. Results

3.1. Biomechanical shoulder evaluation

3.1.1. Peak shoulder exposure

Due to instrumentation issues (sunlight directly into camera, reflective markers covered by mortar, cable malfunction) peak data are reported on 17 bricklayers while cumulative shoulder exposure data are reported on 19 bricklayers. There was a statistically significant main effect of construction method and row on both peak shoulder flexion and abduction (method $p < 0.001$; row $p < 0.001$, Huynh-Feldt correction). Shoulder flexion increased and abduction decreased as row height increased. Since there was a significant interaction between method and row (flexion $p = 0.001$, Huynh-Feldt correction; abduction $p < 0.001$) simple effects were conducted. Peak flexion and abduction results are presented in Table 2. As expected, there were no significant differences between methods at Row 6, since no rebar was present in any case and this served as a 'control' condition. At Row 7, there were significant decreases in shoulder flexion and significant increases in shoulder abduction using either alternative compared to the conventional method. At Row 8, there was a significant decrease in shoulder flexion with H-block compared to conventional method ($p = 0.002$), but there was no significant difference between high-lift grouting and conventional method ($p = 0.069$). Shoulder abduction increased significantly using either alternative compared to the conventional method at Row 8 ($p < 0.001$ H-block & $p = 0.003$ high-lift grouting). Shoulder flexion was significantly less with H-block compared to high-lift grouting at Row 7 ($p = 0.002$) but no difference was found at Row 8 ($p = 0.170$). There was no significant difference in shoulder abduction between H-block and high-lift grouting at Row 7 ($p = 0.852$) or at Row 8 ($p = 0.097$).

3.1.2. Cumulative shoulder exposure

Only time spent in static motion was significant for the repetitive motion, with use of H-block method demonstrating the most time in static motion (Table 2). There were no statistically significant differences between methods for the time spent in shoulder elevations above 30°, 60° or 90°.

3.1.3. Perceived exertion

Participants rated perceived exertion significantly different between the methods (Table 2). The mean rating for the conventional method was 'somewhat hard exertion' while the rating for the alternatives was 'very light exertion'. The 0.7 difference between the H-block and high-lift exertion ratings was not significant ($p = 0.455$).

3.2. Stakeholder concerns – material cost estimate

The H-block building cost $7445 more to build than the same building constructed with CMU, which is less than 2% of the total building cost (Table 3). Extra costs were mainly due to the additional cost of solid wall grouting.

Table 3. Cost comparison between conventional block and H-block.

	Conventional block (168 blocks/mason/day)		H-block (193 blocks/mason/day)	
	Labour	Material & equipment	Labour	Material & equipment
Footing ($)				
Forming	6209	2271	6830	2499
Redi-Mix	2877	6348	3639	8030
Rebar	1623	4580	2132	6015
Wall & pilaster ($)				
Block & mortar	161,384	92,555	143,918*	90,968
Grout/pump	3394	32,270	6175	58,713
Insulation	3981	3981	0	0
# 5 Rebar	14,183	38,534	14,183	38,534
Totals	193,650	180,540	176,877	204,758
Grand total (labour/materials)	$374,190		$381,635	

Note: *Assumes 15% savings in labour.

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3.3. Stakeholder concerns – contractor and specifier perceptions

Nineteen specifiers interviewed were the senior or principle structural engineer, while others were managers or engineers (Table 4). All specifiers indicated that they considered structural integrity and cost when specifying materials, 96% considered availability of materials, and 24% considered worker safety. Of the 25 contractors interviewed, 60% were owners, and others were managers or superintendents. Most contractors worked more than 75% on commercial job sites (72%) and employed less than five bricklayers (64%). Table 4 includes the reported advantages and disadvantages of using H-block and high-lift grouting given by specifiers and contractors. The majority responded that high-lift grouting had the advantage of increasing productivity, safety for bricklayers, and compatibility with job practices, while a low number of disadvantages were reported.

3.3.1. Rebar

Contractors responded that the most common vertical rebar spacing was 0.81 m (64%) and the most common rebar diameter used was 1.6 cm (88%). When asked how frequently their bricklayers lifted block over their shoulders, 36% responded occasionally, while 48% responded rarely. To avoid lifting CMU over shoulder height, 80% responded that proper scaffolding adjustments were used. However, most contractors had their bricklayers lift CMU onto the rebar (84%). Contractors were asked about techniques to reduce injuries to bricklayers handling block, and suggested hydraulic/proper height scaffolding (20%), lift training (12%), lift teams (8%), stretching programmes (16%), and basic safety as beneficial.

3.3.2. H-block

The common reasons engineers gave for not specifying H-block were that they simply never thought about H-block (20%), material fragility (12%), locally unavailable (20%), cost (12%), and contractor responsible for decision (8%). When asked if H-block would meet the same building code standards, 80% responded 'yes'. Contractors who did not use H-block suggested the materials were not readily available, broke easily, were not specified, or there was no need for them.

3.3.3. High-lift grouting

Many engineers (48%) responded that they 'only sometimes' specified the high-lift method because it was up to the contractor to decide on use. Other issues cited included the risk of not getting block cells fully grouted (12%), and the need for bracing or reinforcement (8%). Most specifiers (96%) agreed that high-lift grouting met building code standards. Twenty-eight per cent of masonry contractors indicated that they did not use high-lift grouting because engineers, general contractors, or building inspectors did not specify/approve. Twenty-four per cent of contractors cited problems associated with creating and repairing cleanout holes at the lowest row, which allow inspectors to ensure that grout reached the lowest level. The majority of the contractors who used high-lift grouting found that it

Table 4. Percent of architect and engineer specifiers or contractors who responded 'Yes' to survey questions.

Specifiers (n = 25)	H-Block	High-lift grouting
Are you familiar with?	88	96
Do you use it on most parts?	4	20
Specified in OR or WA?	32	76
Do they meet same code standards?	80	96
Contractors (n = 25)		
Are you familiar with?	92	96
Do you use it on most jobs?	12	28
Does it increase productivity?	20	72
Is it safer for bricklayers?	20	56
Is cost a disadvantage?	40	8
Are quality concerns a disadvantage?	24	32
Are there safety concerns?	12	12
Is availability a problem?	20	8
Is it compatible with job practices?	44	80
Are there codes that limit use?	0	32

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increased productivity, since the grout truck is brought onto the job site less frequently, and was compatible with their current work practices.

4. Discussion

Injury rates among bricklayers remain high because ergonomic solutions for their demanding jobs are not easy to adopt. Bricklayers spend 43% of their work day building walls (van der Molen *et al.* 2008), a job task that frequently requires awkward upper extremity postures. Past studies have identified ergonomics controls to reduce upper extremity risk in bricklayers, such as use of adjustable hydraulic scaffolding and material handling between the knees and shoulders (van der Molen *et al.* 2004, Anton *et al.* 2005, Luijsterburg *et al.* 2005, Faber *et al.* 2009). However, alternatives should be available in instances when these controls are not practical (Hess *et al.* 2010a), such as when there is a structure overhead or mechanical scaffolding is unavailable. This article examined shoulder biomechanics using two ergonomics alternatives, and perceptions and barriers effecting adoption of these alternatives by stakeholders.

4.1. *Biomechanical shoulder evaluation*

Musculoskeletal disorders can result from either peak or cumulative exposures and there is disagreement among occupational safety and health professionals as to which is more harmful. Peak motions have been used by others to demonstrate physical exposure (Marras *et al.* 1993, Fathallah *et al.* 1999), while cumulative exposures remain more difficult to quantify. In this study, we attempted to examine both types of exposure with pronounced differences observed between conventional and alternative methods in the peak exposure assessments and more modest differences noted using cumulative measures of physical exposure.

It is well established that overhead work is associated with MSDs of the upper extremity (Merlino *et al.* 2003, Svendsen *et al.* 2004, Miranda *et al.* 2005, van Rijn *et al.* 2010). Hence, even though the reduction in physical exposure found in this study was small, using alternatives is important. Specifically, shoulder elevation is a contributing factor to injury involving the rotator cuff and other subacromial tissues. Cadaveric and *in vivo* studies indicate that the subacromial space is reduced with arm flexion or abduction between 60° and 120° (e.g. 'the pinch zone') (Flatow *et al.* 1994). Moreover, just holding a weight in the hand reduces the subacromial zone, especially with those in early stages of shoulder impingement syndrome (Graichen *et al.* 1999). At Rows 7 and 8, bricklayers did not have to reach above rebar when using the alternative methods, which resulted in significantly less peak arm elevation. At Row 8, the difference between the conventional and alternative methods was smaller, likely because some of the decreased shoulder flexion associated with the alternatives was lost due to the increased wall height. Furthermore, in the Pacific Northwest, where data were collected, it is customary (and may be dictated by job) to place the sightline on the same side of the wall as the bricklayer. This required lifting block over the sightline, regardless of method. In some US regions, the line is placed on the far side of the wall unless there are obstructions, which could impact and possibly further reduce arm elevations when using alternative methods.

There appears to be additional advantage for reducing physical exposure to the shoulder when using H-block compared with the high-lift method. While both alternatives reduced peak shoulder flexion during lifting, H-block resulted in less peak shoulder flexion at Row 7 and was the only alternative method to be significantly different than the conventional method at Row 8. In addition, the H-block method resulted in reduced shoulder stress in the cumulative analyses from the VC dataset.

In general, the amount of shoulder abduction at peak flexion follows an inverse relationship to flexion, with less abduction present at Rows 7 and 8 in the conventional method compared to the alternatives. This relationship is likely due to the task requirements of lifting a 17.3 kg block above shoulder level. At the higher rows, rather than handling block with one hand and hefting it onto the wall, bricklayers tend to hold the block with both hands and place it as they face the wall, limiting their ability to move into shoulder abduction (i.e. moving away from midline). This inverse relationship does not appear to be method dependent as there tended to be less abduction whenever higher flexion values were required. Greater shoulder abduction does not equate to higher arm elevation, but rather expresses how close the longitudinal axis of the upper arm is to the mid-sagittal plane of the trunk (0° abduction) at the point of peak shoulder flexion.

If the differences in peak exposure between methods were distinct, the cumulative differences were subtle. The peak physical exposures were captured with each block lift, so even our limited duration simulation demonstrated differences in exposure. Unfortunately, these brief exposures were not sufficient to detect cumulative exposure. The

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only significant cumulative exposure finding was for participants who spent more time in slow movements using H-block compared to the conventional method. We used 'jerk time' as a proxy measure for repetitive motions, assuming that fast movements equated to more repetitive movements. Therefore, participants using H-block spent more time using slower velocity motions despite a similar overall wall building time. Since there was no significant difference in perceived exertion between H-block and high-lift grouting, both methods result in less perceived exertion than the conventional method. A 2.2 difference in perceived exertion is considered clinically important (Ries 2005).

Wall construction time did not differ across methods, suggesting no difference in productivity in this brief snapshot of laying block. Longer construction times could be perceived as barrier to adoption. Since all methods involved laying the same amount of block, we did not expect large differences in construction time.

Field use of the alternatives examined will not solely eliminate shoulder injury in bricklayers since much work still occurs in the 'pinch zone'. Though there is evidence quantifying typical shoulder postures during bricklaying tasks (van der Molen *et al.* 2004, Anton *et al.* 2005, Luijsterburg *et al.* 2005), little is known of the magnitude of postural change needed to reduce injury risk. While it is unknown if the significant findings in this study are meaningful in terms of reducing injury, task-by-task, multiple, small reductions in exposure from these and other ergonomics interventions may result in substantial job injury risk reduction.

4.2. Stakeholder concerns

The construction industry continues to rank high for injuries. In 2010, US construction workers had an incident rate of 149.6 occupational injuries and illnesses with days away from work per 10,000 full time workers compared to 107.7 for all of private industry (BLS 2011). Among construction trades, bricklayers rank sixth for overexertion injuries with days away from work (CPWR 2008). A telephone survey of US masonry contractors indicated that identified ergonomic controls were substantially underutilised (Hess *et al.* 1010a; Entzel *et al.* 2007). There is disparity between researchers providing viable solutions to reduce MSDs and those solutions being adopted by industry stakeholders, such as contractors, engineers and architects. NIOSH, recognising this problem, developed the Research to Practice (r2p) initiative to engage researchers in more comprehensive efforts to evaluate barriers to adoption in order to better disseminate findings. Research must include aspects of the stakeholder decision processes to be optimally effective.

4.2.1. *Stakeholder concerns – material cost estimate*

We conducted a simplified cost estimate using accepted US construction estimation methods. The estimate only considered differences in labour and materials resulting from the use of H-block. There could be other cost differences associated with using H-block. Rose *et al.* (2011) provides a detailed list of interconnected costs related to the work environment such as productivity, quality issues, absenteeism, brand image and maintenance costs. However, based upon interviews with masonry contractors in California who regularly build with H-block, we have no reason to believe that these other cost variables would change when building with H-block (Hess *et al.* 2010a). Quality is an issue raised by contractors in Oregon and Washington since H-block is slightly more fragile than CMU. Yet, California contractors have stated that once workers learn how to handle H-block, breakage rates are not different than when using CMU.

Very few studies of ergonomic solutions include assessments of stakeholder perceptions or material cost and productivity considerations. This simplified estimation demonstrated that there was little difference in cost when building with H-block compared to CMU. Productivity is important to contractors. Even when using conservative estimates of productivity savings with H-block, based upon the Means Productivity Standards for Construction (RS Means Company *et al.* 1994), we demonstrated that the cost of building with H-block is only 2% more expensive than building with CMU. Additional evaluation should be done to establish actual productivity savings. Occupational safety and health practitioners can use the information from the biomechanical study, as well as the material cost estimate and stakeholder survey to educate contractors and specifiers about using H-block and high lift grouting as alternatives to CMU.

4.2.2. *Stakeholder concerns – contractor and specifier perceptions*

This qualitative survey provides evidence of specifier and contractor perceptions, misperceptions, and utilisation levels of alternative masonry materials and work practices. For example, only 32% of specifiers had ever specified use of H-block, while only 20% had specified use of light weight concrete block. Twenty per cent believed H-block

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and 32% believed light weight block did not meet the same strength and structural stability standards as CMU. However, the American Society for Testing and Materials (ASTM), an international standards development organisation that develops the building codes used by specifiers, indicates that H-block with grouting and light weight block meet the same ASTM weight-bearing standards as medium weight CMU (ASTM 2003). Even though 76% of specifiers indicated that use of high-lift grouting was up to the masonry contractor, 48% of contractors surveyed did not use it because they believed specifiers did not approve of the method. Other views appear to be associated with unfamiliarity of use rather than actual problems, such as perceived difficulty getting grout into all cells or potentially higher H-block breakage. Contractors and engineers frequently state that they use a particular practice or material 'because I've always done it that way.'

These findings underscore the need for researchers to develop educational materials that address stakeholder concerns and perceptions (material cost, quality, code compliance, responsibility). Indeed, Dul *et al.* (2012), writing about promoting ergonomics solutions, suggest the importance of including stakeholders in the process and educating them about the benefits of ergonomics. Similarly, our evaluation of cost and perceptions identifies beliefs held by stakeholders that are barriers to adopting ergonomic solutions. Efforts to promote these solutions must include an understanding of stakeholder beliefs in order to develop appropriate educational interventions. They must also target appropriate audiences. For instance, architects and engineers are infrequently considered by researchers when developing outreach efforts. Occupational safety and health professionals working independently or for construction companies can use these findings to develop more effective educational materials.

4.4. Limitations

There were several limitations in design of these studies. In the biomechanical assessment, participants placed only 15 blocks in each of the three wall conditions. Placing such few blocks may not capture adaptations to upper extremity posture that could occur due to fatigue (van der Molen *et al.* 2008) and may overemphasise one of the more stressful tasks performed by bricklayers. Although we did not formally analyse the participants' lifting techniques, we anecdotally noted that there was considerable between-worker and within-worker variability in wall construction technique which may contribute to Type II errors. Additionally, since motion capture involved ensemble averaging for each row, absolute peak exposure may be lower than that seen in the field. In a sense, ensemble averaging delivers a measurement of cumulative peak exposure instead of the true peak. However, we felt this method of data management was appropriate to avoid potential outliers from skewing the findings. Alternatively, we could have collected data on a construction site using a video based work sampling technique. Several techniques have demonstrated satisfactory statistical performance in shoulder evaluations (Rezagholi *et al.* 2012).

Since estimating building cost is not an exact science, assumptions were made about productivity rates and costs associated with use of each material, which limit the validity of these findings. Our estimate did not include other costs such as workers compensation, but our purpose was narrowly focused to solely assess building material cost differences. While the specifier used accepted productivity estimates from the *Means Productivity Standards for Construction,* the cost assessment would benefit from additional research to establish productivity rates for each type of block. We acknowledge that the cost estimate succumbs to the limitations of any case study. However, we made every effort to produce an accurate estimate of the differences in building cost when H-block is utilised. A limitation of the contractor/specifier survey was the small sample size. Additionally, only specifiers and masonry contractors in Oregon and Washington were surveyed, which could limit generalisability to other geographical regions.

5. Conclusions

Peak shoulder flexion was significantly less using both alternatives compared to the conventional method of lifting CMU onto rebar, where H-block was slightly more effective than high-lift grouting for reducing peak shoulder flexion and cumulative exposure. The results suggest that either alternative could be used in cases where other options, such as adjustable scaffolding, are impractical or unavailable.

The contractor and specifier survey elucidated perceptions about use of these alternatives and confirmed that they are not widely used. Three barriers to adoption of H-block and high-lift grouting were identified: (1) cost concerns, (2) misperceptions about who is responsible for the decision to use an alternative and (3) confusion over local building codes.

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When developing ergonomics strategies in the construction industry, researchers, ergonomists and safety and health professionals should consider a multifaceted approach that includes stakeholder concerns as these may be adoption barriers. These concerns, combined with biomechanical analyses, should be essential components of intervention effectiveness studies in order to effectively transfer research into practice.

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