Applied Ergonomics 41 (2010) 477–483

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Ergonomic evaluation of masons laying concrete masonry units and autoclaved aerated concrete

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ARTICLE INFO

Article history:
Received 10 June 2009
Accepted 16 October 2009

Keywords:
Masonry
Construction
Ergonomics
Shoulder injury
Low back injury

ABSTRACT

Masons working with concrete masonry unit block have high rates of work-related musculoskeletal disorders to the low back and shoulders associated with repetitively lifting and buttering heavy block. A new material, autoclaved aerated concrete, may reduce the risk of shoulder and back injury but, ergonomic evaluation is needed. This study evaluated shoulder exposure parameters, low back stress, and worker perceptions in two groups of journey level masons, one using CMU and the other using AAC block. Results indicate that for the left arm AAC masons spent significantly more time than CMU masons in static (38.2% versus 31.1%, respectively), and less time in slow motions (48.2% versus 52.2%, respectively) and faster motions (13.6% versus 16.7%, respectively) ($p < 0.05$). CMU masons had significantly greater shoulder and low back pain ($p = 0.009$) and they held block significantly longer than AAC masons ($p < 0.001$). Low back compressive forces were high for both materials. Masons handling AAC demonstrated less left upper extremity stress but both materials were estimated to be hazardous to the low back.

1. Introduction

According to the Bureau of Labor Statistics, construction workers are at significant risk of musculoskeletal disorders (MSDs) with incident rates of 41.4 (per 10,000 workers) compared to 35.4 for all industries (BLS, 2007). In 2005 the masonry industry had the highest rate of back injuries and illnesses (75.4 per 10,000 full time workers) out of all construction trades and bricklayers ranked sixth for overexertion injuries resulting in time away from work (43 per 10,000 full time workers) (CPWR, 2008). Reports of upper extremity pain and other MSDs are common in the masonry trade (Stenlund et al., 1993; Cook et al., 1996; CSAO, 2003; CPWR, 2008). Masonry work is physically demanding, requiring repetitive, awkward, and static postures in potentially harsh outdoor environments. Masons are required to regularly lift and maneuver heavy building materials such as concrete masonry unit (CMU) block with their arms above their shoulders when laying higher courses or when lifting over vertical rebar or electrical or plumbing conduits. Research has shown that in other construction trades working with hands above shoulder level leads to reports of shoulder discomfort (Holmstrom, 1992).

In particular, masons who work with block must contend with repetitively handling heavy CMU block (16.3 kg and $0.2 \times 0.2 \times 0.4$ m) (Anton et al., 2005). The risk factors for back and shoulder injuries associated with handling block include block weight, frequency of lifting, height from which block and mortar are lifted, height at which block is placed, buttering activities (applying and smoothing mortar), distance of the work from the mason, and high expected production rates (Entzel et al., 2007). Construction Safety Association of Ontario (CSAO) researchers reported in 1995 that 58% of all lost time injuries among masons could be directly attributed to installation and manual materials handling activities (CSAO, 1995). It is common for masons to lay 200 or more CMU blocks per day (Marks and Vi, 2000; Van der Molen et al., 2008). If a mason handles 200 CMU blocks weighing 16.3 kg each, he will lift over 3260 kg (3.3 tons) in 8-h workday.

To prevent musculoskeletal injuries alternative types of block are being investigated. For example, Anton et al. (2005) investigated masons using light-weight block (weighing 11.8 kg) versus standard medium weight block (16.3 kg) in a lab setting and found that surface electromyography of some upper extremity (forearm flexors and extensors) and back (erector spinae) muscles was lower when using light-weight block at some course levels. Another alternative masonry material is autoclaved aerated concrete (AAC), which can be obtained as precast forms manufactured building

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doi:10.1016/j.apergo.2009.10.003

block. AAC has been popular in Europe for over 70 years due to shortages of timber but, it has been slow to diffuse in the United States (US). Currently, in the US AAC is primarily used in residential construction though its use on commercial sites, such as hospitals, university dormitories, and office buildings, is growing. AAC is purported by manufacturers to have many construction benefits since it potentially lowers building costs by saving on building materials (no need for drywall) and labor; it is environmentally friendly to manufacture; 33% lighter weight; provides thermal and acoustic insulation; as well as possessing excellent fire and termite resistance.

AAC block is solid unlike the CMU, which typically has two hollow sections that make the appearance of CMU from above look like the number 8. AAC and CMU are frequently ordered in different sizes, weights, and architectural finishes to meet the diverse structural or aesthetic needs of a particular construction site. AAC block is longer than CMU: 0.61 m versus 0.41 m, respectively, and while AAC is lighter per unit of weight, due to its larger size it may weigh as much as a medium weight CMU block. In general, AAC has a mass between 15.7 kg and 25.7 kg, while CMU can have a mass between 11.8 kg and 29.5 kg, depending on block size, aggregate composition and moisture exposure. Since AAC is one-third longer than CMU, masons can build more wall with each block laid. Its larger size may make it more awkward to handle, thus the potential for MSD risk reduction in terms of its lighter weight is not known.

AAC block is handled and installed differently than CMU block. Since it is solid it is picked up from the supply stack using both hands whereas CMU is usually picked up with one hand by grasping the web in the center of the block. Handling AAC with both hands should result in lower upper extremity forces since the mass is distributed across both arms. Instead of a traditional masonry trowel and concrete mortar, AAC is set using Thinset Adhesive and a tile trowel. Masons do not have to repeatedly lift trowels with heavy mortar and the buttering process is substantially reduced, which could result in lower arm forces and less repetitive motions. Fig. 1 illustrates masons handling and buttering AAC and CMU blocks.

These differences between AAC and CMU may result in reductions in cumulative injury risk to the upper extremities and low back in masons using AAC but, to date no study has evaluated any aspect of AAC use on the physical demands of masons. The purpose of this study was to compare shoulder and low back variables in masons handling AAC to masons using medium weight CMU, to assess the value of AAC for reducing the incidence of work-related MSD risk in masons.

2. Methods

2.1. Subjects

Forty-one journey level masons (masons who have completed the 3–4 year apprenticeship training including 640 h of classroom time) were recruited by contacting masonry contractors and union representatives across the United States. Participants were excluded on site if they did not have a minimum level of competency (at least one year as a journey level mason laying the studied block type, either AAC or CMU). Masons were also excluded if they were presently experiencing pain in the lower back or upper extremity. After meeting criteria, the study was explained and participants were asked to sign an informed consent approved by the University of Oregon Office for the Protection of Human Subjects. Each mason was paid $40 for participation.

Fig. 1. Masons handling and buttering aerated autoclaved concrete (AAC) and traditional concrete masonry unit (CMU) block.

Prior to data collection, each participant completed a questionnaire about their medical history with respect to their shoulder and low back. Information about job-related physician visits and work difficulty due to pain or discomfort were recorded for the 12 months prior to data collection. Participants were also asked to report past surgeries to their elbows, wrists, shoulders or low back. Participant demographics are presented in Table 1.

2.2. Study setting

CMU data were collected on commercial construction sites in Oregon. However, due to the paucity of construction sites in the Northwest using AAC, data for AAC were also collected in New York, Texas and South Carolina. Videotaping and observational assessments were recorded from 5 to 15 feet away from the mason being evaluated. In most instances, data were collected on two masons in the morning and two after the lunch break, for 3–4 h of work time each in order to simulate actual working conditions.

The size and mean weight of each block type at the various study construction sites are presented in Table 2. The AAC blocks were of various sizes at the different construction sites and at one site in New York City the contractor used two different sizes of AAC block to simultaneously build inner and outer walls.

2.3. Study equipment

Shoulder elevation angle was derived using a triaxial accelerometer called the Virtual Corset (VC) (Microstrain, Williston, VT, USA). The device can store triaxial accelerations at 7.5 Hz, for up to 4-h and does not interfere with the mason's arm movements. Triaxial accelerometers have been previously validated for use in posture analysis (Hansson et al., 2001) and for use at the shoulder (Amasay et al., 2009). The VC was secured to the subject's skin using double-sided urology tape and then covered with pre-wrap taping foam. The VC was placed on the lateral aspect of each arm, half the distance between the lateral epicondyle of the humerus and the acromioclavicular joint. This placement was chosen because it minimized both soft tissue artifact and linear acceleration errors. Heart rate has been used in previous construction studies as a measure of energetic workload (Anton et al., 2005; Van der Molen et al., 2008). It was collected for the same work periods as the VC data using a Polar RS400 or a Polar S610i monitor (Polar, Kempele, Finland). In order to estimate low back compression force each mason was asked to model a typical posture for picking up a block from ground level while a researcher measured the torso angle using a Baseline HiRes plastic 360° ISOM goniometer. The horizontal distance from the mason's hand on the block to his low back was also recorded. Block weight was measured using a Chatillon 300-strength dynamometer (Ametek, Largo, FL, USA), each block was weighed 3 times and results were averaged. Masons were videotaped using a Sony Handycam DVI recorder.

2.4. Procedure

Thirty minutes prior to starting work in the morning or during the lunch break, two volunteer masons were taken aside and equipped with a VC on each arm and a heart rate monitor. A seated resting heart rate was recorded for 5 min while participants sat quietly, completing paperwork. The VC was then calibrated, triggered, and masons began their work as usual. The research protocol was designed to minimize disruption of the mason's typical workday and aimed to evaluate the entire 'job' and not individual job 'tasks.' The researcher observed each mason for 50 min in 10-min increments over the 3–4 h of data collection. The duration of the time masons spent holding each block during these 10 min increments was recorded by clicking a stopwatch each time the mason's hand grasped and released a block. This established 'block holding time', an indication of exposure. When possible, observations were accompanied by videotaping though on some sites videotaping was not possible. The observation period start point was chosen to minimize the inclusion of activities not directly related to laying block such as rebar work, grout detailing, or setting lines. Following data collection each mason completed a short post-work survey about equipment comfort and whether the mason's workday included non-typical duties, activities, or work conditions. Data stored on the VC were immediately downloaded to a laptop computer.

Table 1
Age, height and weight (mean and range) of masons completing study.

	AAC Group ($N=22$)	CMU Group ($N=19$)
Age (years)	41.6 (25–68)	37.5 (21–61)
Height (m)	1.74 (1.5–2.0)	1.79 (1.5–2.0)
Weight (kg)	84.8 (59.0–120.2)	89.2 (59.0–158.8)

Table 2
Size and weight of blocks evaluated.

Block type	# of masons tested	Size of block (m)	Mean weight (kg)
AAC	6	0.2 × 0.2 × 0.6	15.9
AAC	5	0.2 × 0.25 × 0.6	15.7
AAC	4	0.2 × 0.3 × 0.6	25.7
AAC	7	0.2 × 0.2 × 0.60 and 0.2 × 0.3 × 0.6	15.9 and 25.7
CMU	19	0.2 × 0.2 × 0.4	15.7

2.5. Data analysis

2.5.1. Shoulder and low back pain, discomfort and difficulty working

To use the self-reported responses of the masons on shoulder and low back pain, discomfort and difficulty working, an aggregate score was compiled from questions scored using an 11-point visual analogue scale. The 16 questions for each shoulder and the low back were standardized then averaged, with a higher score indicating more pain and difficulty. The scale had good internal consistency (alpha = 0.84). Additionally, the average time spent holding block was calculated from the observations of masons during the VC data collection to determine a measure of block-handling exposure.

2.5.2. Low back compression

Low back compressive force was calculated using a model developed by Merryweather et al. (in press) (Eq. (1)) which uses body weight in kilograms (BW), torso angle relative to vertical in degrees (θ), the mass of the block used by the mason in kilograms (L) (see Table 2), and the horizontal distance from hands to low back in centimeters (D):

$$\text{Estimated low back compressive force} = \underbrace{3\text{BW}\sin\theta}_{\text{Back Posture}} + \underbrace{0.5(L^*D)}_{\text{Load Moment}} + \underbrace{0.8((\text{BW})/2+L)}_{\text{Direct Compression}} \quad (1)$$

2.5.3. Heart rate

Heart rate data were evaluated by calculating the relative heart rate (RHR) over the course of the data collection period. Relative heart rate has been shown to be a reliable indicator of workload (Shimaoka et al., 1998; Wu and Wang, 2002). The RHR was calculated using Eq. (2) including the heart rate measured during work (HR Work), the heart rate measured while resting (HR Rest) and the maximum heart rate (HR Max). The HR Max for this study was calculated according to the formula $205.8 - (0.685 \times \text{AGE})$ which has been demonstrated to be an accurate method for evaluating maximum heart rate (Robergs and Landwehr, 2002).

$$\text{RHR} = (\text{HR Work} - \text{HR Rest})/(\text{HR Max} - \text{HR Rest})*100 \quad (2)$$

2.5.4. Arm elevation and position

In addition to collecting VC data in the field, in a separate study a motion analysis system was used with masons in a work simulation to estimate the validity of the VC to capture shoulder exposure parameters on masons (Leitz et al., 2008). Kinematic data from 8 masons in that study, laying blocks on courses (rows) 1, 3 and 6, were used in this study to check masons' arm elevation and, motion and that use of the VC was within its operating parameters. To do so, a unit vector was calculated for the arm from the x, y, z coordinates of the acromion process and the lateral epicondyle relative to the lab coordinate system. The dot product of the arm vector and the unit vector representing gravity (0, 0,−1), was then calculated to determine the angle between the vectors which represents arm elevation. The calculated arm elevation angles were then used to calculate the angular velocities and accelerations of the arm.

To predict the elevation angle error as a result of linear acceleration other than gravity a prediction equation was used (Eq. (3)). This equation predicted the error (β) as a function of the angular position (θ), velocity (ω) and acceleration (α) and distance from the virtual corset to the axis of rotation (r).

$$\beta = \sin^{-1}\left(\frac{\alpha r\cos\theta - \omega^2 r\sin\theta}{\sqrt{(\alpha r + g\sin\theta)^2 + (\omega^2 r + g\cos\theta)^2}}\right) \quad (3)$$

The kinematic data were applied to the error calculation with a distance of 10 cm, which was the typical location of the VC on the arm from the axis of rotation of the shoulder. Since the angular velocity and acceleration increased with the course level, the highest course level (6) has the highest predicted error. Based on this data, it was determined that the linear accelerations (radial and tangential accelerations) of masons' arms when laying block resulted in acceptable arm elevation RMS error: between $0.9^\circ \pm 0.5^\circ$ (-5.1° to 5.8°) at course 1 and $2.9^\circ \pm 2.5^\circ$ (-8.2° to 57.6°) at course 6. Therefore, use of the virtual corset to evaluate arm elevation was appropriate in this field evaluation.

For this study, a customized Lab View program was used to analyze the raw linear acceleration data for each mason. The first step was to convert the linear acceleration data to elevation angles using the data from all three accelerometers (x, y, z axes). The elevation angle was defined as the angle between the z axis of the triaxial accelerometer and the resultant gravity vector (Eq. (4)). This calculation was used in a previous validation study (Amasay, et al., 2009).

$$\theta = \tan^{-1}\left(\frac{\sqrt{x^2 + y^2}}{z}\right) \quad (4)$$

The elevation data were then processed for the "jerk" analysis and for the percent time above 30°, 60° and 90° of arm elevation as a measure of exposure. These angles have been used previously to evaluate shoulder exposure (Moller et al., 2004). To calculate "jerk", bins of arm elevation velocities were chosen based on the previously collected kinematic data with masons laying CMU block. The average velocities of arm elevation for each course were: course 1 ($26.8^\circ/\text{s} \pm 10.1^\circ/\text{s}$), course 3 ($30.2^\circ/\text{s} \pm 9.6^\circ/\text{s}$), and course 6 ($40.3^\circ/\text{s} \pm 9.8^\circ/\text{s}$). From this it was determined that a velocity of 40°/s could be used to differentiate between slower motion and faster motion since 40°/s was the mean velocity on the highest course. Thus, the data were divided into three velocity bins for statistical analysis, which represent the percent time spent in these bins during work. Three bins of motion labeled "Static" (<10°/s), "Slow" (between 10°/s and 40°/s) and "Fast" (>40°/s) were used.

2.5.5. Statistical analysis

This study was a quasi-experimental, one panel non-equivalent group design. The independent variable was the type of block each group used, CMU or AAC, while dependant variables included relative heart rate, percent time of arm elevation over 30°, 60° and 90° for each arm, percent time spent in "Static" (<10°/s), "Slow" (between 10°/s and 40°/s) and "Fast" (>40°/s) motion for each arm, average duration block was held (min), and low back compression force (N).

Prior to the main statistical analysis, all measures were checked for out-of-range values, assumptions of normality, and outliers. Results indicated six variables had substantial skew and/or kurtosis; percent of time above 60° for the right and the left arm, percent of time above 90° for the right and the left arm, and lower back compression force. In addition, three of the measures with substantial skew and/or kurtosis each had at least one outlier; percent of time above 60° for the right and left arm, and percent of time above 90° for the right arm. These variables were normalized by applying log to base 10 transformations. Re-examination of the distributional properties and outliers indicated that the transformations were effective in normalizing the data. The transformed variables were used in all subsequent analysis.

To bolster the internal validity of this design between group characteristics were examined to help identify confounding variables as possible covariates. Reports of past surgery, handedness, and the back and shoulder composite pain scores were examined using grouped t-tests for continuous measures and chi-square models for categorical measures. Point-biserial correlations between handedness and the study outcome measures were non-significant (at $p < 0.01$) suggesting that both right and left handed masons were similar in their methods of work. This was confirmed with observation data indicating that all masons used their right hand for troweling regardless of handedness. Therefore handedness was not controlled for in the statistical modeling. Each masonry group was examined separately with a paired t-test to compare right versus left side measures collected with the virtual corset.

The AAC and CMU groups had significantly different total low back pain/difficulty scores ($p = 0.037$) and a trend toward significant total shoulder pain/difficulty scores ($p = 0.098$), so these two variables were added to the model as covariates. Also, due to significant relationships between outcome measures and block size within the AAC group, and to control for other potential site differences between groups (e.g., weather conditions) a categorical variable accounting for each of the nine study sites was treated as a covariate in the analysis of covariance models (ANCOVA) used to examine group differences (CMU versus AAC) in the study outcome measures.

3. Results

Forty-one masons (19 with CMU block and 22 with AAC block) were evaluated. Three masons had a history of shoulder surgery; two participants were in the CMU group and one in the AAC group. There were no significant differences between the AAC and CMU groups for age, weight, height, past surgery or handedness.

3.1. Shoulder and low back pain, discomfort and difficulty working

Masons were asked whether they had shoulder or low back pain associated with work activities in the 12 months prior to the study. The groups differed on their composite back and shoulder pain scores ($t[39] = 2.75$, $p = 0.009$) with the CMU group ($M = 1.47 \pm 0.82$) showing significantly higher rates compared to the AAC group ($M = 0.74 \pm 0.86$). Substantially more AAC masons reported having no job-related shoulder discomfort in either shoulder, than CMU masons (16 versus 7, respectively). Additionally, substantially more CMU masons reported having low back discomfort related to the job than did AAC masons, 15 versus 8, respectively. Both AAC and CMU masons rated their shoulder and back pain less than 3.0 (0 equals "no pain" to 10 equals "worst pain possible"). The largest difference was for back pain, where CMU masons rated their pain as 3.0 while AAC masons rated their pain as 1.5. No mason was being treated for either a shoulder or low back injury when evaluated.

3.2. Arm elevation and position

Table 3 provides the least square means and standard deviations for each outcome measure for the two groups, as well as the test statistics, with the p-value bolded when $p < 0.05$. There were significant differences or trends toward significant differences for arm motion and elevation for the left arm, but not the right. The duration blocks were held was different, with CMU held significantly longer ($p < 0.001$).

CMU masons did not differ statistically between right and left arms ($p < 0.05$). However, in AAC masons left arm motion differed statistically for percent time spent in static, slow and fast motions (Table 4). The left arm measures of percent of time working above 30°, 60°, and 90° were not significantly different ($p < 0.05$) than the right side.

3.3. Heart rate and low back compression

The relative heart rate and low back compression force are shown in Table 3. There were no significant differences in heart rate across groups. When controlling for low back pain, there was significantly more low back compressive force in the AAC group compared to the CMU masons.

Table 3
Descriptive and test statistics for outcome variables.

	CMU ($N = 19$)	AAC ($N = 22$)	Test statistics	
	LS (mean ± SD)	LS (mean ± SD)	f-Value	p-Value
Right arm motion (% time)				
Static (%)	27.91 ± 9.26	31.59 ± 8.76	1.31	0.260
Slow	53.92 ± 5.65	51.63 ± 5.16	1.40	0.245
Fast	18.18 ± 4.09	16.78 ± 4.36	0.87	0.357
Left arm motion (% time)				
Static	31.13 ± 8.24	38.19 ± 8.44	5.69	**0.022**
Slow	52.20 ± 5.26	48.17 ± 5.00	4.90	**0.033**
Fast	16.67 ± 3.73	13.64 ± 4.06	4.82	**0.035**
Right arm elevation (% time)				
30°	44.10 ± 7.98	40.10 ± 8.61	1.89	0.178
60°	10.38 ± 4.42	9.14 ± 5.95	0.77	0.385
90°	2.32 ± 1.56	1.97 ± 2.02	0.84	0.366
Left arm elevation (% time)				
30°	47.12 ± 7.12	40.23 ± 11.81	4.03	0.052
60°	11.68 ± 5.16	10.14 ± 6.16	1.52	0.226
90°	2.90 ± 2.07	2.35 ± 2.07	1.16	0.288
Average hold time (s)	6.71 ± 1.26	4.97 ± 0.94	23.81	**<0.001**
Low back compression force (kN)	4.31 ± 0.77	4.90 ± 0.91	4.61	**0.038**
Relative heart rate (%)	16.50 ± 8.52	14.37 ± 7.74	0.41	0.524

Descriptive statistics reflect raw scores and test statistics reflect transformed scores. LS = least squares, SD = standard deviation.

Table 4
Adjusted mean ± SD for percent time in different arm motions for the AAC group ($N = 20$).

% time	Left arm (mean ± SD)	Right arm (mean ± SD)	t-Statistic	p-Value
Static	36.82 ± 7.96	31.49 ± 8.76	5.52	0.001
Slow	48.91 ± 4.67	51.82 ± 5.16	−4.41	0.001
Fast	14.27 ± 3.93	16.69 ± 4.36	−5.42	0.001

3.4. Block handling

The observational data indicated that the average block holding time, that is, the time the mason held the block from the time they lifted it from the supply stack until it was released on the wall, was significantly less ($p < 0.001$) for the AAC masons: 4.97 s for AAC masons compared to the 6.71 s for the CMU masons.

4. Discussion

4.1. Mason job experience and self-reported pain, discomfort and difficulty working

Even though AAC is a newer masonry material in the United States we were able to recruit participants for both groups who had a minimum of one year of experience with the material tested. The determination that a year of experience was sufficient time for becoming familiar with the use of either material was made after consultation with an instructor at the International Masonry Institute (Hays, 2008) and several masonry contractors.

Overall, CMU and AAC masons were similar in levels of pain; shoulder discomfort, and difficulty doing their work as well as they wanted. CMU masons reported that they had more left shoulder discomfort, and pain when the left arm was near the side of the body, and with strenuous activity, which comports with the VC data results that CMU masons had greater slow and fast motions in the left arm and a greater percent time above 30° of elevation on the left.

4.2. Arm elevation and position

The use of the VC as a measure of arm motion and elevation worked well. The device was easy to affix to workers on the construction site, was proven accurate for the motions of masons laying block, and did not interfere with the masons' use of their upper extremities while working. There were no reported problems with the device slipping or moving during the 4-h data collection. Testing the error by taking into account typical arm motions (velocity and acceleration) while laying block indicated that using the VC accelerometers to measure arm motion and elevation was acceptable.

In this study population, regardless of hand dominance, most masons used their left hand to lift and place the CMU, while the right hand held the trowel and buttered the block. Right arm motion, in terms of bins of percentage of time in static, slow and fast motions, did not differ significantly between the ACC and CMU groups. The AAC masons did spend a slightly higher percentage of time in static ranges with the right arm and a slightly lower percentage of time in slow and fast motion ranges. The trend was the same for the left arm however, AAC masons demonstrated a significantly ($p < 0.05$) higher percentage of time in the static range and a significantly ($p < 0.05$) lower percentage of time in slow and fast motion ranges. From these results it seems that when using AAC block, masons spend more time in slower motions with both arms but, the effect is more apparent in the left arm. The AAC group also had significant differences between the right and left arm for the motion variables (Table 4), which may be related to troweling differences.

Neither the right nor left arm spent a significant percent of time above 90° of elevation (the range was 2.0–2.9% of the time) and above 60° of elevation (the range was 9.1–11.7% of the time) for both groups. A greater percentage of time was spent above 30° of elevation for both groups with the range being between 31.1% and 47.1% of the time, though percent time above 30° approached significance in the left arm ($p = 0.052$). While awkward postures are usually considered to be those above 60° of elevation, there is evidence that exposure severity increases from 30° of arm elevation (NIOSH, 1997). The duration masons held their arms above 30° averaged more than 1.5 h during the 3–4 h of data collection. Hence arm postures above 30° could be important contributors to shoulder injury when coupled with long durations.

While arm motions in masons are typically dynamic, i.e. they do not hold their arms without any motion, these findings could represent prolonged postures over the course of an 8-h workday, possibly resulting in arm fatigue and potentially, shoulder injury. Since this data were collected over 3–4 h it is expected that the masons' did raise their arms to lift and place blocks but, they might also spend time in preparation of other activities, perhaps with their arms at their side hence, minimal elevation would be recorded. Indeed, studies monitoring the work activities of experienced masons have found that on an average workday masons will only lay block between 30 min and 2.5 h of the day. The rest of the time is spent on work preparation such as scooping up mortar, tapping the block into place, using the level, setting the line, etc. (Marks and Vi, 2000; Van der Molen et al., 2008). Moreover, if masons were working on lower courses or using adjustable scaffolding this would reduce the level of arm elevation.

4.3. Block handling

Differences in block holding time could be due to the different buttering methods used with each type of block. When handling AAC, Thinset Adhesive, which is used instead of mortar, is not applied to the block being placed, but instead is applied to the top of each course after block is in place. In contrast, when laying CMU masons usually pick up the block and hold it in one hand while mortar is applied to head joints. Block holding time is a surrogate measure for the duration of exposure of the shoulder and back to bearing the weight of the block, which indicates that the AAC block, since handled for less time, would result in less cumulative exposure.

4.4. Low back compression force

The mean low back compressive forces recorded were 4.3 kN (970 pounds) for the CMU masons and significantly higher, 4.9 kN (1104 pounds) for the AAC masons. NIOSH guidelines suggest that low back compressive forces should not exceed 3.4 kN (764 pounds) (Waters et al., 1993). Therefore, handling both types of block presents a risk of low back injury. Exposure to lifting these heavy loads might be reduced in masons laying AAC because they would likely handle fewer block per day for the same area of wall, since AAC is 1/3 longer. However, the number of blocks laid was not quantified in this study and wall area varied across study sites. When coupled with holding AAC significantly less time, this might mitigate some of the effect of the larger low back compressive force. Further, CMU is generally handled exclusively with the left hand, while the dominant hand holds the trowel. However, with AAC, because it is solid, it is handled with both hands. We observed that single handling of CMU introduces lateral bending and twisting of the trunk which could result in additional exposure to shearing and moment forces to the low back. Evaluating these effects was beyond the scope of this study but should be investigated.

4.5. Energetic workload

The relative heart rate was used to measure the physical workload of the masons working with AAC and CMU. The two groups were not significantly different and at 13.1% for AAC and 17.8% for CMU mason, both groups were below the 33% minimum where fatigue is likely (Eastman Kodak Company, 2004). The rate for the AAC masons was somewhat lower than the rate in the CMU masons indicating a slightly lighter workload when using AAC block. Again, since fewer blocks were laid, this trend is to be expected. Also, the use of Thinset instead of mortar between the blocks may make a difference in workload but our study was not able to differentiate changes in workload due to block handling or buttering, but rather overall workload and exposure for all the masonry work.

4.6. Implications for practice

As new materials and work practices come on the market it is important to evaluate their biomechanical impact prior to recommending them as superior to existing materials and practices. This initial comparison demonstrated that AAC use results in less upper extremity stress than does CMU, while both materials exceed NIOSH standards for low back compression. These findings suggest that AAC may be a beneficial material for reducing upper extremity injury risk. Yet, AAC should be promoted with caution as an ergonomic alternative to medium weight CMU and these findings underscore the need to follow 'best practices' guidelines even when using AAC (Entzel et al., 2007), such as keeping the work between the knees and shoulders, using adjustable tower scaffolding, and lift teams for heavier block, in order to minimize shoulder and low back injury.

Further, the troweling process differs substantially between these materials. An area for future study is the difference in elbow, wrist and hand activity associated with use of Thinset when placing AAC. Thinset adhesive is applied in a very thin layer using a tile trowel, unlike mortar, which is applied about a centimeter thick with a masonry trowel. Buttering with Thinset requires much less forearm and wrist motion, may reduce grip forces, and the risk of injury in the wrist and hand.

Shoulder force should also be specifically evaluated since it may be reduced when laying AAC. It seems likely that lifting AAC block with both hands would effectively half the force to each shoulder. Furthermore, research has shown that adding molded grips to solid block decreases low back load and decreases awkward low back postures, but the effect on the shoulders has not been quantified (Vi, 2000). An evaluation of shoulder and hand force during AAC use with and without grips would be insightful.

4.7. Limitations and future study

In order to simulate a real work environment and determine realistic exposures, data were collected on actual construction sites. One of the limitations of this type of applied research is that many variables were out of the researchers' control. Unlike CMU, AAC is not produced or used in one standard size. This is one of its attributes, it can be ordered in whatever width and height best fits the job. However, this meant that while CMU sites consisted of a single block size, the AAC sites were varied and finding a sufficient number construction sites with a single AAC size was not possible. Therefore, during statistical analysis a 'site variable' was added to control AAC site variability. Use of a static formula for calculating low back compression force has limitations because it does not take into account the dynamic aspect of the work. The complex nature of forces applied to the low back, such as the effect of shear forces on facets during rotational movements (Shirazi-Adl, 1991) and the interaction of force and velocity on injury risk (Marras et al., 1993), contribute to low back stress but are not considered with a static model. However, this model was used solely to provide an indication of low back stress and indeed, it indicated that work using either type of block exceeded NOISH safe lifting limits.

A limitation of this data collection was that neither trunk nor low back motion was measured. Researchers observed that some masons combined trunk lateral flexion with arm elevation as a strategy to elevate the arm rather than use pure arm elevation. The torque at the shoulder joint is relative to gravity therefore, movement of the trunk would not impact the torque on the shoulder, however, the posture of the shoulder would be altered and could benefit healthy shoulder function. The contribution of lateral trunk flexion was not evaluated, though could be interesting since it might be a 'shoulder sparing' motion, to prevent shoulder injury or in response to past shoulder pain.

5. Conclusions

AAC is an emerging masonry material and its use in the US appears to be on the rise. The results of this study indicate that there was greater left arm stress in masons handling CMU compared to those handling AAC but both resulted in excessive low back compression force or energetic workload, and appear to be hazardous for the low back. CMU masons also reported more shoulder and low back pain. These findings suggest that there may be benefit in using AAC over CMU but additional study is needed before AAC can be recommended as being superior to CMU for reducing the risk of injuries in masons. In any case, masonry best practices should be considered whether masons work with AAC or CMU.

Acknowledgements

This project was funded by CPWR, the Center for Construction Research and Training (NIOSH/DHHS Cooperative Agreement 1U54 OH008307-01).

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