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Effect of concrete block weight and wall height on electromyographic activity and heart rate of masons

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Work-related musculoskeletal disorders (MSDs) are common among construction workers, such as masons. Few interventions are available to reduce masons' exposure to heavy lifting, a risk factor for MSDs. The purpose of this study was to determine whether one such intervention, the use of light-weight concrete blocks (LWBs), reduces physiological loads compared to standard-weight blocks (SWBs).

Using a repeated measures design, 21 masons each constructed two 32-block walls, seven courses (rows) high, entirely of either SWBs or LWBs. Surface electromyography (EMG), from arm and back muscles, and heart rate was sampled.

For certain muscles, EMG amplitudes were slightly lower when masons were laying LWBs compared to SWBs. Upper back and forearm extensor EMG amplitudes were greater for the higher wall courses for both block weights. There were no significant differences in heart rate between the two blocks. Interventions that address block weight and course height may be effective for masons.

Keywords: Musculoskeletal disorders; Construction; Intervention effectiveness; Masonry; Electromyography

1. Introduction

Work-related musculoskeletal pain and disorders (MSDs) are common among construction trade workers (Schneider 2001). These workers experience the second highest rate of sprains and strains of all occupational groups. Additionally, construction workers retire early due to MSDs more often than other occupational groups

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(Holmström *et al*. 1995). Of all construction workers, masons are among the most affected by MSDs.

In the USA, masonry had the second highest incidence rate of all construction trades for injuries with lost workdays due to overexertion involving lifting (Bureau of Labor Statistics 2002b). In Canada, masonry ranked sixth among all construction types in lost-time-injuries, with overexertion the most frequent cause (Construction Safety Association of Ontario 2003). The majority of overexertion injuries among masons involve the low back, and the associated costs of medical care for masons are the highest of all construction occupations (Holmström *et al*. 1995, Cook *et al*. 1996, Stürmer *et al*. 1997, Bureau of Labor Statistics 2002a, Construction Safety Association of Ontario 2003). Awkward postures and heavy lifting have been suggested as risk factors that may contribute to these low back disorders (Bernard 1997).

Complaints of pain and MSDs affecting the upper extremity are also common among masons (Stenlund *et al*. 1993, Cook *et al*. 1996, Bureau of Labor Statistics 2002a, Construction Safety Association of Ontario 2003). These conditions may be due to the frequent manual material handling, as well as to regular lifting of concrete blocks at or above shoulder level. Among other construction trade workers, a positive dose-response relationship between work with the hands above shoulder level and discomfort in the shoulders has been reported (Holmström *et al*. 1992).

The physical nature of masonry work has limited the types of administrative and engineering interventions that are possible to reduce musculoskeletal stress. Indeed, masonry work has been performed much the same way for hundreds of years. Administrative interventions, such as teaching masons to 'lift with the legs', may be effective only for workers who have previously injured their back. Despite the intuitive benefit of reducing work pace or decreasing the number of blocks that are laid (placed on a wall) per day, these practices are not widely accepted or practical among masonry contractors. In lieu of administrative controls, engineering controls, such as reducing the weight of materials or handling blocks primarily between waist and chest height, may be more effective for masons.

Use of light-weight concrete blocks (LWBs) may represent such an engineering control for masons. Standard-weight concrete blocks (SWBs), measuring $0.2 \times 0.2 \times 0.4$ m ($8 \times 8 \times 16$ in.), weigh approximately 16.3 kg. In contrast, a LWB of the same size weighs approximately 4.5 kg less than a SWB, yet complies with building code weight-bearing standards (ASTM 2003). Although masons and contractors widely seem to prefer LWBs, the use of LWBs seems arbitrary in the USA. Little quantitative information exists about the effect of LWB use on either the activity of specific muscles or on an overall measure of physical effort. This information will add to the knowledge base used by ergonomists and safety specialists when selecting interventions to control MSDs among masons.

The purpose of this study was to compare the effect of LWBs to that of SWBs on specific muscle activity as measured with surface electromyography (EMG) as well as on energy expenditure as measured by heart rate. A secondary purpose was to evaluate EMG activity associated with laying LWBs as a function of course (row) height.

2. Methods

2.1. *Subjects*

Twenty-one male, journey-level or fourth year apprentice-level, masons participated in this task simulation study. The mean age of the masons was 33.5 (SD 10.4) years, their

mean height was 1.8 (SD 0.1) m and their mean weight was 88.0 (SD 13.9) kg. The participants volunteered through a local masonry union training centre. Exclusion criteria included self-reported history of lumbar disc disease or lumbosacral surgery, cardiovascular disease or any musculoskeletal disorder during the 2 months prior to participation. The Institutional Review Board at the University of Iowa approved the study and participants provided written consent. Participants were compensated monetarily for participating in the study.

2.2. *Electromyography and heart rate measurement*

Surface EMG and heart rate were sampled while the masons constructed concrete block walls. Electrodes were placed using standard locations for the bilateral flexor digitorum superficialis, upper trapezius and lumbar erector spinae, as well as the dominant-side extensor digitorum (Zipp 1982). The electrodes had dual 8 mm diameter, bipolar, silver–silver chloride surfaces, an inter-electrode distance of 22 mm and on-site pre-amplification with a gain of 35 (E.Q. Inc., Chalfont, PA, USA). The electrodes were attached to a telemetric EMG transceiver placed in a fanny pack. The telemetric receiver was connected to a differential amplifier/processor module (EMG-67, Therapeutics Unlimited, Iowa City, IA, USA) with a bandwidth of 40 Hz to 4 kHz (two-pole Butterworth filter), common-mode rejection of 87 db at 60 Hz and 55 ms time constant. For each subject, the gain was adjusted between 500 and 10 000 to prevent saturation of the signal and the sampling rate was 100 Hz. The amplifier module was connected to an analogue-to-digital data acquisition interface (1401 plus, Spike 2 v. 3.21, Cambridge Electronic Design, Cambridge, UK) affixed to a personal computer.

Surface EMG from all muscles was normalized to percent of root-mean-square (RMS) amplitude during submaximal reference contractions (%RVE) using standard loads. In addition, maximal reference contractions (%MVE) were used for the forearm muscles. Although upper trapezius normalization with maximal contractions has been used by some researchers, it is not known whether true maximal voluntary contractions are attainable (Mathiassen *et al*. 1995). A safe method of maximally contracting the erector spinae does not exist (Ferguson *et al*. 2005).

For normalization of the lumbar erector spinae (%RVE), participants stood with knees extended and held a SWB with their elbows extended and lumbar spine flexed such that the top of the SWB was stationary at knee level. For normalization of the upper trapezius (%RVE), participants abducted their shoulders to 90° in slight horizontal adduction with a 2 kg weight attached to their wrist. For normalization of the forearm flexor and extensor (%RVE), participants gripped a Smedley-type lightweight hand dynamometer (Preston, Jackson, MI, USA) with a force of 9.1 kg (Fess and Moran 1981). Participants held RVEs for 15 s and the middle 10 s was used for analysis.

The forearm muscles were also normalized to %MVE. Using the same arm position, participants gripped the hand dynamometer maximally for 5 s, with the middle 3 s used for analysis. Each RVE and MVE normalizing contraction was repeated three times, with the mean value used for %RVE and the maximal value used for %MVE. Participants rested for 2 min between all normalizing contractions. Resting EMG amplitude was recorded and subtracted from the amplitudes obtained during normalizing contractions and tasks.

Heart rate was telemetrically recorded at 0.2 Hz with a Polar S810 Heart Rate Monitor (Polar Electro Inc., Woodbury, NY, USA). Participants wore the heart rate transmitter around their chest and the monitor on their wrist.

2.3. *Experimental procedure*

After the instrumentation was applied, participants constructed two concrete block walls in a counterbalanced order, one wall with LWBs and one with SWBs, with whole and half blocks, as shown in figure 1. The walls were seven blocks or 'courses' high (1.42 m) and 2.4 m wide. The walls were constructed between two vertical piers, also seven courses high. The piers were constructed by another mason prior to the wall-building tasks and served as boundaries for the wall length and height. The walls were built in a 'running bond' or staggered pattern. The odd courses consisted of five whole blocks and the even courses comprised four whole and two half blocks. Thus, each wall was constructed with 32 whole blocks and six half blocks. A whole block measured $0.2 \times 0.2 \times 0.4$ m and a half block was $0.2 \times 0.2 \times 0.2$ m. Whole SWBs weighed 16.3 kg and whole LWBs weighed 11.8 kg. All of the blocks used in the study were manufactured by one supplier (King's Material, Inc., Cedar Rapids, IA, USA). The aggregate used for the LWB was haydite expanded shale (Buildex, Inc. Ottawa, KS, USA).

In order to simulate actual fieldwork conditions, an instructor of masonry apprentices and a journey-level mason designed the simulated workstation for the wall construction (figure 1). A mortarboard approximately 0.8 m high was placed behind the bricklayer, and a stack of blocks was placed on both sides of the mortarboard. The mortar was made of Spec Mix (Mendota Heights, MN, USA) and dehydrated lime mixed with water. An experienced masonry labourer maintained an adequate supply of mortar and kept the supply stack of blocks at a height of 0.4 m.

All participants were experienced masons familiar with laying LWBs and SWBs. Wall construction consisted of four primary tasks: 1) 'line block' positioning; 2) mortar application; 3) block laying; and 4) finishing. The line block is used to maintain level courses and consists of two wood blocks attached by a length of string. At the beginning of Course 1, the line block was positioned between the two piers. Next, mortar was applied to

Figure 1. Experimental arrangement with mason constructing Course 7 between the two piers. Supply stacks and mortar board are shown in the foreground.

the floor with a trowel. The block-laying task consisted of picking up a block from the supply stack with two hands and positioning it on the course. Blocks were laid from the left pier to the right pier. In order to specifically evaluate the block-laying task, mortar was not placed on the sides of the block. The finishing task consisted of scraping off excess mortar or tapping on a block to maintain a level course/wall. Subsequent courses followed the same pattern of the four primary tasks. Participants were instructed to perform the task at their normal work pace and the time to construct the entire wall was measured. After completing the first wall, participants rested for 20 min before starting the second wall. Surface EMG from all studied muscle groups and heart rate measures were obtained continuously from the beginning until the end of construction of each wall.

2.4. *Data processing*

To determine the effect of block weight across the entire wall-building task, EMG of the flexor and extensor forearm muscles was summarized separately for each block weight with clustered exposure variation analysis (CEVA) (Anton *et al.* 2003), a modification of exposure variation analysis (Mathiassen and Winkel 1991). CEVA is a summary measure of percentage of work time spent in combinations of low, moderate and high amplitude of EMG, with short and prolonged duration of muscle contraction (as can be seen in the results presented in figure 2). These six amplitude-duration clusters have been found to contrast effectively between worker groups (Anton *et al.* 2003), and the boundaries used for designating exertion level are comparable to those used by other investigators (Moore and Garg 1995, Fallentin *et al.* 2001). The EMG amplitudes used in CEVA are scaled using maximal normalizing contractions. Since maximal normalizing contractions were used only for the flexor and extensor forearm muscles, CEVA was limited to these muscles. Although factors for converting RVE to MVE have been reported for the upper trapezius (Bao *et al.* 1995, Hägg *et al.* 1997), these factors are not age- and gender-specific, and no such conversion factor exists for the lumbar erector spinae.

Mean and maximum heart rate in beats per min (bpm) was also calculated for data collected across the entire wall construction task. Data used for the CEVA and heart rate analyses were restricted to those collected during the interval beginning when the first block of Course 1 was picked up from the supply stack and ending when the last block of Course 7 was placed on the wall. Thus, aspects of all four primary tasks, positioning of the line block, mortar application, block laying and finishing, were evaluated with CEVA and heart rate.

In addition to evaluation of the effect of the entire wall-building task, the block-laying task was evaluated to examine the effects of block weight and wall height on muscle activity. Mean RMS amplitude of EMG was calculated separately for each muscle group during Courses 1, 3 and 7. These courses were chosen to indicate workload at approximately floor, knee and shoulder level. Data used to calculate the mean RMS amplitude were restricted to those collected during the interval beginning when the third block was picked up from the supply stack and ending when the fourth block was picked up from the supply stack, for the respective course. Since only Courses 1, 3 and 7 were evaluated, only whole blocks were compared for these analyses.

2.5. *Statistical analysis*

Univariate analyses and tests of assumptions of normality were conducted for the EMG and heart rate data. It was decided *a priori* to consider normalized EMG and heart rate

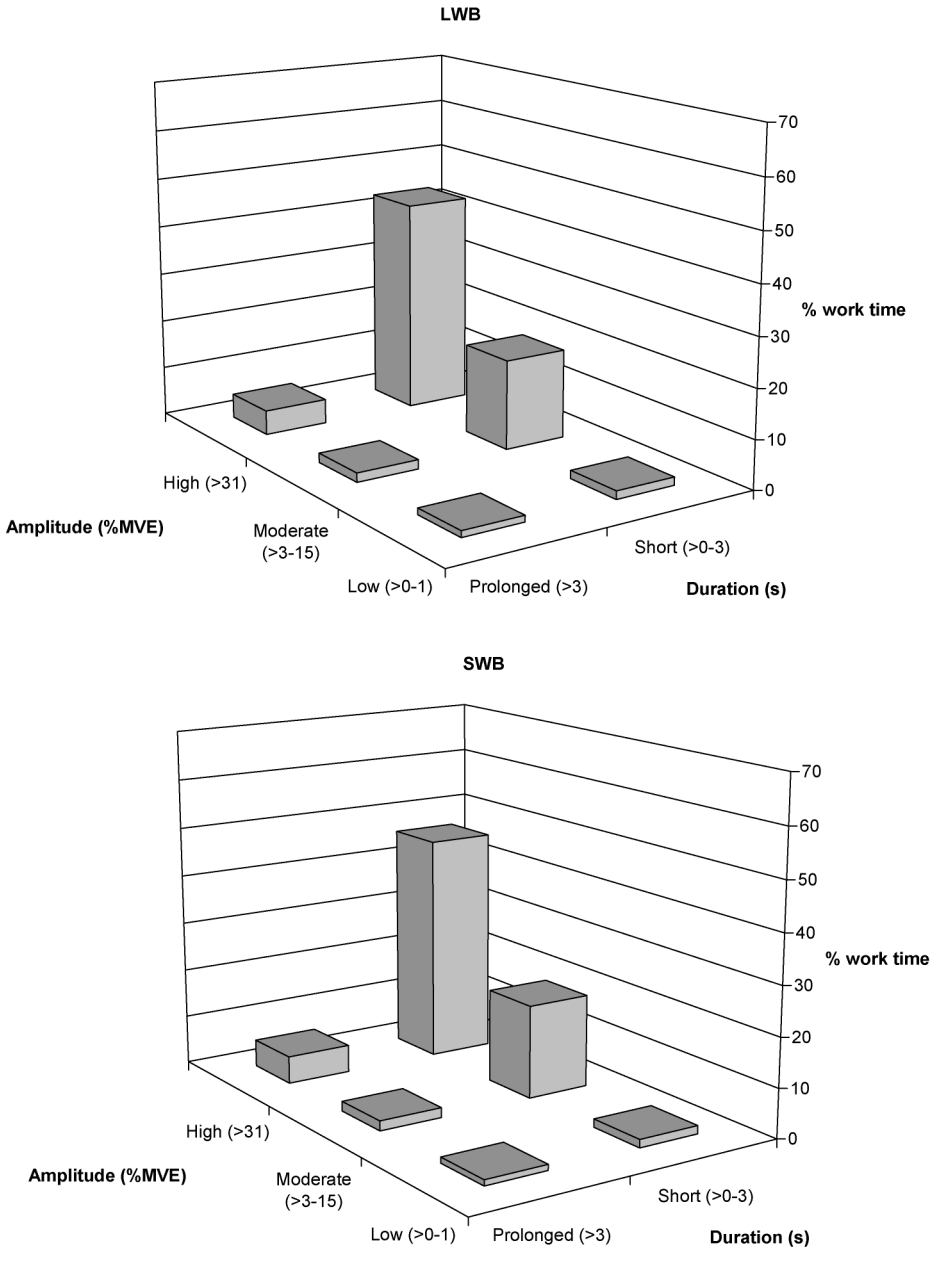

Figure 2. Mean clustered exposure variation analysis values (% work time) for the dominant forearm extensor while laying light-weight blocks (LWBs) and standard-weight blocks (SWBs).

values with z-scores greater than 2.58 ($p < 0.01$, two-tailed) as outliers. Outliers were recoded to a value of one unit greater than (or less than) the next most extreme value (Tabachnick and Fidell 2001). Paired t-tests were used to compare task times and heart rate between the two wall construction jobs.

Differences in CEVA data (% work time) between the two block types during construction of the entire walls were evaluated with two-way mixed repeated measures ANOVA (RANOVA). Separate models were run for each muscle group. The primary analyses were simple effects of the difference in CEVA category across block type. The block-laying task was also evaluated with two-way mixed RANOVA to test for differences in mean EMG amplitude for each muscle group separately, by block weight and course height. For this analysis, course was a within-subjects factor with three fixed levels: 1, 3 and 7. Block type was also a within-subjects factor with two fixed levels: LWB and SWB. The interaction between course and block was a fixed factor and participants were random factors. Although main effects and interaction were evaluated, simple effects were the primary comparisons of interest. A Tukey-Kramer adjustment was used for the simple effects of block type and course height, and a Bonferroni adjustment was used for follow-up pairwise comparisons of course height specific for each block. The appropriate covariance structure of each model was determined for each muscle group separately based on the Akaike's Information Criterion model-fit criteria (Littell *et al.* 1996). The significance level was $p \leqslant 0.05$ for each muscle group separately.

3. Results

3.1. *Effect of block weight across the entire wall building task*

The masons averaged 15.8 (SD 3.6) min to construct the wall with LWB and 16.4 (SD 4.0) min with SWBs ($p = 0.15$). The heart rate averaged across the entire wall construction was 103 (SD 9) bpm for LWBs and 105 (SD 9) bpm for SWBs ($p = 0.003$). The mean maximum heart rate was 117 (SD 11.5) bpm for LWBs and 119 (SD 12.3) bpm for SWBs ($p = 0.58$).

Approximately 7% of the EMG amplitudes were classified as outliers and were recoded accordingly. The mean CEVA results for the dominant forearm extensor muscle obtained while laying SWBs and LWBs are shown in figure 2 and for the dominant forearm flexor in figure 3. For the forearm extensor, more time was spent engaged in high-intensity muscle contractions of short duration than in any other category. Moderate intensity contractions of short duration were also common. The pattern was reversed for the forearm flexor, with more time spent performing moderate levels of contraction than high levels of contraction. Although slightly more time was spent at high and moderate muscular exertion levels while laying SWBs for each muscle group than while laying LWBs, none of these differences was significant.

3.2. *Effect of block weight across specific courses*

The mean EMG amplitudes for Courses 1, 3 and 7 stratified by block weight for the forearm muscles are shown in figure 4 and for the axial skeletal muscles in figure 5. For the forearm extensor muscles, EMG amplitudes were lower when handling the LWBs at all courses. The main effect of block type was statistically significant ($p = 0.01$; table 1), while the interaction between block type and course height was not statistically significant ($p = 0.98$). Mean EMG amplitudes were lower for LWBs at all courses, with a significant simple effect of block at Course 3.

For the dominant forearm flexor, no significant main effect of block was found nor were differences in mean EMG amplitude found between the blocks at any of the courses. For the non-dominant forearm flexor muscle, there was a statistically significant

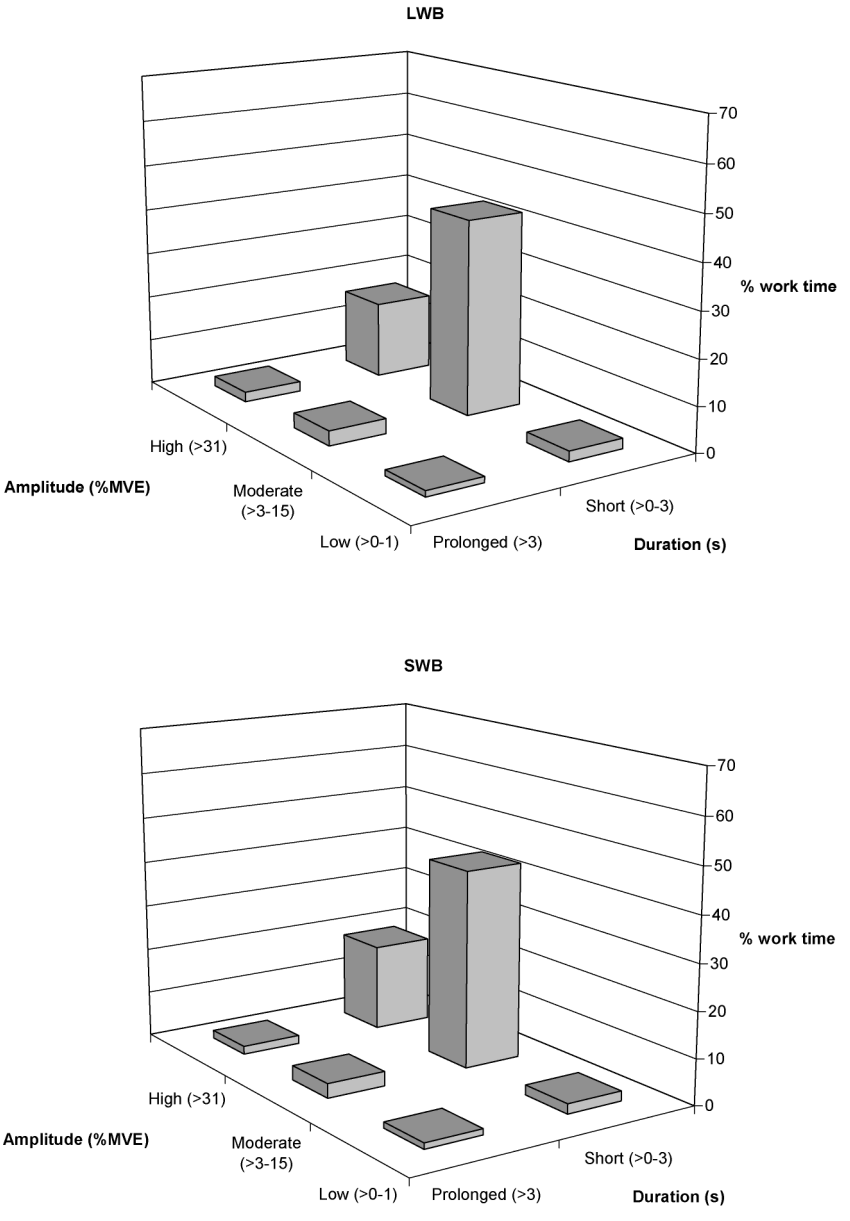

Figure 3. Mean clustered exposure variation analysis values (% work time) for the dominant forearm flexor while laying light-weight blocks (LWBs) and standard-weight blocks (SWBs).

interaction between course and block ($p = 0.02$). Specifically, at Course 1, EMG amplitudes for LWBs were 14% higher than those for SWBs, whereas at Course 7, EMG amplitudes for LWBs were 18% lower than those for SWBs. Although the effects of block type on EMG amplitude were of borderline statistical significance at Course 7 ($p = 0.06$), the effects of block type were not significant at the other courses.

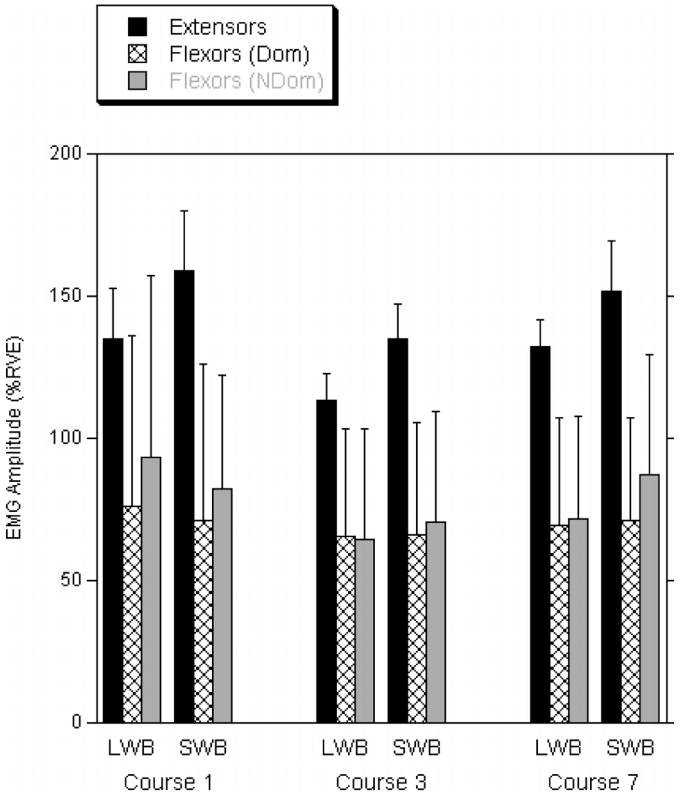

Figure 4. Mean electromyography (EMG) amplitudes (%RVE) for forearm extensor and flexor while laying light-weight blocks (LWBs) and standard-weight blocks (SWBs) at three courses. Dom = dominant side; NDom = non-dominant side.

For both dominant and non-dominant upper trapezius muscles, no significant main or simple effects of block type on EMG amplitudes were observed (table 1). For the dominant lumbar erector spinae, EMG amplitudes were lower for all three courses while laying LWBs than while laying SWBs, and a significant main effect of block type was observed ($p = 0.02$; table 1). Although the difference between block types was greatest for Course 7, the interaction between block type and course was not statistically significant. For the non-dominant lumbar erector spinae, block type was statistically significant only at Course 7 ($p = 0.02$). However, the main effect of block type was not significant ($p = 0.10$). Regardless of statistical significance, averaged across all courses, use of LWBs resulted in 15% less activity for the non-dominant side of the low back.

3.3. *Effect of wall height*

For the forearm extensor, there was a statistically significant main effect of course on EMG amplitude ($p = 0.04$; table 1). The EMG amplitudes were approximately 18% greater at Course 1 than at Course 3 for both block types, and approximately 15% greater at Course 7 than at Course 3. Although, the simple effect of course height on EMG amplitudes was statistically significant only for LWBs ($p = 0.04$), none of the

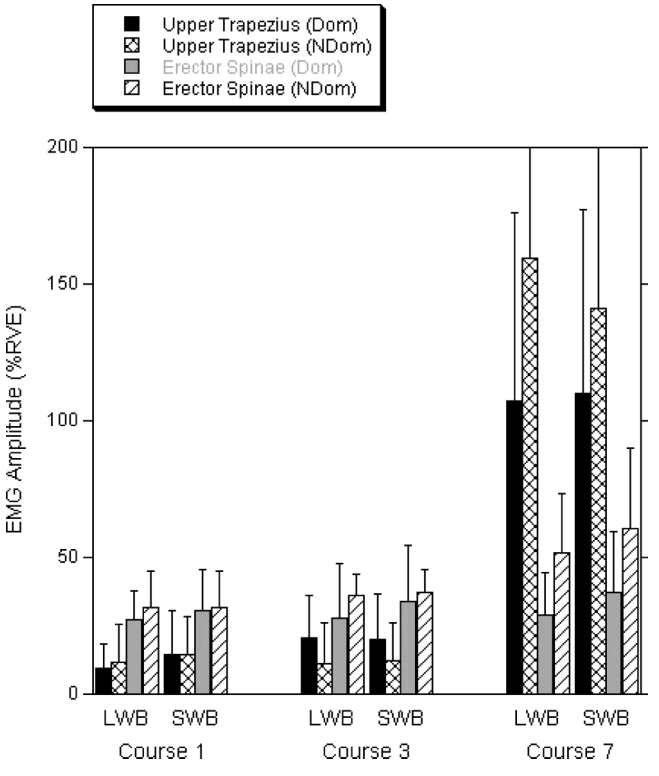

Figure 5. Mean electromyography (EMG) amplitudes (%RVE) for upper trapezius and lumbar erector spinae while laying light-weight blocks (LWBs) and standard-weight blocks (SWBs) at three courses. Dom = dominant side; NDom = non-dominant side.

pairwise comparisons were significant after Bonferroni adjustment of the p-value (values not reported).

For the dominant forearm flexor muscle, no significant differences in mean EMG amplitude were found between the courses for either of the block types. For the non-dominant forearm flexor, the main effect of course height was not statistically significant ($p = 0.12$), whereas the simple effect of course height was statistically significant for LWBs ($p = 0.03$). Similar to the pattern seen with the forearm extensor, the EMG amplitudes were higher on average at Course 1 and Course 7 compared to Course 3 (figure 4).

For both dominant and non-dominant upper trapezius muscles, the main and simple effects of course height on EMG amplitude were statistically significant ($p < 0.01$). Substantially greater muscle activity was found for the bilateral upper trapezius at Course 7 compared to the lower courses. All of the pairwise comparisons between Course 7 and the other courses were significant after Bonferroni adjustment ($p < 0.008$). At Course 7, approximately 40 – 50% more muscle activity was used in the non-dominant than the dominant upper trapezius regardless of block type. Whether laying LWBs or SWBs, the dominant upper trapezius amplitude at Course 7 was over 400% greater than at Course 3 (figure 5). A greater difference in EMG amplitude was observed for the non-dominant upper trapezius with an approximately 1300% increase at Course 7 from the lower courses for LWBs.

Table 1. Main and simple effects of ANOVA for electromyography amplitudes.

		Forearm Extensor (Dom)		Forearm Flexor (Dom)		Forearm Flexor (NDom)		Upper Trapezius (DOM)		Upper Trapezius (NDom)		Lumbar Erector Spinae (DOM)		Lumbar Erector Spinae (NDom)	
		F	*p*	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
Main	Block	6.8	0.01	0.1	0.83	0.3	0.59	0.3	0.61	0.6	0.44	5.5	0.02	3.2	0.10
	Course	3.5	0.04	1.7	0.20	2.3	0.12	24.5	<0.01	22.0	<0.01	1.0	0.37	8.2	<0.01
	Interaction	0.02	0.98	0.4	0.65	4.2	0.02	1.7	0.23	1.2	0.33	0.5	0.63	1.9	0.19
Simple	Course for LWB	3.6	0.04	1.2	0.33	4.0	0.03	18.5	<0.01	20.7	<0.01	0.1	0.88	5.9	0.01
	Course for SWB	1.4	0.26	0.8	0.44	1.4	0.26	17.0	<0.01	26.6	<0.01	1.1	0.35	7.4	<0.01
	Block at Course 1	2.1	0.16	0.6	0.45	1.9	0.18	1.8	0.20	1.3	0.27	0.9	0.34	0.01	0.92
	Block at Course 3	5.5	0.03	0.1	0.83	0.6	0.46	0.04	0.84	0.2	0.70	1.7	0.20	0.2	0.64
	Block at Course 7	2.2	0.15	0.3	0.61	3.7	0.06	0.04	0.85	1.2	0.30	3.3	0.08	6.8	0.02

Dom = dominant side; NDom = non-dominant side; *p* = *p*-value; LWB = light-weight block; SWB = standard-weight block.

For the dominant lumbar erector spinae, there were no reliable differences in EMG amplitude due to course height (table 1). For the non-dominant lumbar erector spinae, main and simple effects of course on EMG amplitude were significant for both block types. Similar to those observed for the upper trapezius, mean EMG amplitudes were greater at Course 7 than at the other courses. Excluding the comparison of Course 7 to Course 1 for LWBs ($p = 0.019$), all of the pairwise comparisons between Course 7 and the other courses were statistically significant ($p < 0.008$). While handling LWBs at Course 7, there was a 42% gain in amplitude from Course 3 and 66% from Course 1 (figure 5). Greater differences were seen with SWBs.

4. Discussion

4.1. *Effect of block weight across specific courses*

The effect of block weight on mean RMS EMG amplitude was inconsistent across muscles. The largest difference in amplitude between SWBs and LWBs was observed for the extensor muscles of the dominant forearm, where EMG amplitude was always lower for LWBs. Specifically, EMG amplitudes obtained while handling LWBs were 13–16% lower than those obtained with SWBs. This effect of block weight was observed for the dominant forearm extensors regardless of course. If representative of the effect of block weight under actual field conditions, these results suggest that the risk of extensor forearm disorders (e.g. lateral epicondylitis) might be reduced by use of LWBs. However, it is uncertain if this modest level of reduction in muscle activity is meaningful.

The results observed for the extensor forearm muscles in the current study are not consistent with those observed in a similar investigation by Zellers and Simonton (1997). In a study of six masons, they reported that muscle activity of the extensor forearm was lower during use of heavier blocks than during use of lighter blocks. The inconsistent findings between the two studies may be a result of methodological differences. In particular, in the Zellers and Simonton (1997) study, the lighter block was shaped differently than the heavier block, and the participants indicated that the lighter block was more difficult to handle. In the current study, the LWB was identical in size and shape to the SWB. Thus, the difference in muscle activity observed between the studies was likely due to weight of the block alone.

In the current study, there were no consistent differences in forearm flexor activity between the blocks. Although not statistically significant, the activity of the non-dominant flexors was 18% lower at Course 7 while handling LWBs compared to SWBs. This finding was not seen in the dominant flexors, possibly because the majority of the masons held their trowel in the dominant hand while laying the block. Thus, masons may be exposed to static loading of the dominant flexor forearm that is independent of block weight during block-laying tasks. These results are comparable to those observed by Zellers and Simonton (1997).

At the lower courses, low back EMG was similar for the two types of block. However, at Course 7 there was a 17% reduction in muscle activity of the non-dominant low back erector spinae and 22% reduction of the dominant low back erector spinae while laying LWBs compared to SWBs. Kinematic factors not evaluated in the current study may contribute to the similarity in low back muscle activity whilst laying the two block types.

It was somewhat surprising that the bilateral upper trapezius muscle activity was similar for the LWBs and SWBs at all courses, since the investigators anticipated that this muscle group would follow a similar pattern of the forearm extensor. It is possible that LWBs are

not sufficiently light to reduce muscle activity in experienced masons. Alternatively, it is possible that different biomechanics were used with LWBs than with SWBs.

4.2. *Effect of wall height*

The effect of wall height was substantial for both types of blocks for most muscle groups. For example, muscle activity of the non-dominant upper trapezius was ten times greater at Course 7 than it was at Course 3. Muscle activity for the non-dominant low back was greater at Course 7 compared to the lower courses, but was not different across courses for the dominant low back muscle. Luttmann *et al*. (1991) found three to four times greater bilateral low back activity whilst laying bricks at a height of 132 cm from the ground when compared to the same task at 50 cm from ground level, comparable in the current study to Course 7 and Course 3 respectively. However, direct comparisons to the current study are difficult since lighter materials were used.

The observation in the current study that greater muscular activity occurs when the arms are elevated at or above shoulder level is consistent with previous investigations. Örtengren *et al*. (1991) studied the muscular effect of using a powered screwdriver at different work heights. Greater upper trapezius muscle activity was found at 'eye' level compared to 'hip' level. In contrast, Ulin *et al*. (1990) reported lower perceived exertion ratings with the use of a powered screwdriver at shoulder height than at hip level. Although perceived exertion data were not collected in the current study, the masons anecdotally noted that laying blocks at the higher courses was substantially more difficult than at the lower heights. Other laboratory investigations have reported the positive relationship between work with the arm elevated at or above shoulder height and increased muscle activity, greater fatigue and shorter endurance time (Wiker *et al*. 1989, Haslegrave *et al*. 1997, Anton *et al*. 2001, Garg *et al*. 2002). Consistent with the observation of greater muscle effort at higher work heights in experimental investigations, epidemiological studies have shown greater risk of upper extremity MSDs with overhead work (Malmqvist *et al*. 1981, Sakakibara *et al*. 1995, Bernard 1997).

At the highest course, dominant muscle activity was considerably different than non-dominant muscle activity. If normalizing contractions were higher for the dominant compared to the non-dominant low back or upper trapezius, lower task amplitudes would be noted. However, the mean amplitudes during the normalization were quite similar, and the possibility that there is no difference in the means cannot be ruled out (two-tailed independent t-test, upper trapezius $p = 0.60$, low back $p = 0.53$). Specific block-handling techniques could also account for the higher amplitudes on the non-dominant side. Post-hoc video analysis indicated that over 80% of the masons rotated their trunk to the non-dominant side while placing blocks at Course 7, which has the possibility of increasing muscle activity of the non-dominant erector spinae (Andersson *et al*. 2002). If increased muscle activity corresponds to increased potential for injury, the non-dominant low back and upper trapezius may be more susceptible to injury when laying blocks at higher courses.

4.3. *Effect of block weight across the entire wall building task*

The overall effect of constructing the entire wall on muscle activity of the forearm was remarkably similar for both block types. The mean and variation for the CEVA values between the two block types were comparable (figures 2 and 3). Since the participants were masons experienced with laying both types of blocks, it is possible that the 4.5 kg

difference in block weight was not sufficient to increase the exertion level in these individuals. Nevertheless, the greater time spent performing high amplitude contractions of short duration for the forearm extensor indicates the increased stress on these muscles.

Although there was a statistically significant difference in mean heart rate between laying LWBs and SWBs, the difference would not be considered substantial. The mean heart rate observed in this simulation study was comparable to the mean heart rate observed in field studies of bricklaying (Jørgensen *et al.* 1991, Malchaire and Rezk-Kallah 1991). However, direct comparison between the studies is difficult since the weight of the brick was not reported in these previous studies. Nevertheless, the similarity in heart rates suggests that the wall-building task used in the current study realistically simulated field conditions.

Bulthuis *et al.* (1991) found that masons had higher mean heart rates while laying blocks heavier than those used in the current study. Similarly, although mean values were not reported, Zellers and Simonton (1997) found apparently higher heart rates among masons laying blocks with weights comparable to those used in the current study.

A practical consequence of using LWBs is that masonry contractors may expect an increased handling frequency. Productivity expectations for masons employed by a large US contractor are 165 SWBs or 185 LWBs laid per day. An increased handling frequency could influence energy expenditure and cumulative biomechanical loading. Previous investigators have suggested that handling lighter materials at a faster frequency may increase energy expenditure and spinal compression (Hamilton and Chase 1969, de Looze *et al.* 1996). In the current study, heart rate was used as a proxy measure of energy expenditure, and there was no important difference in mean or maximum heart rate while handling the two block types. Although the masons constructed a wall consisting of approximately one-quarter of the typical number of blocks handled per day, it seems unlikely that energy expenditure would increase in the field by increasing handling frequency of 2 – 3 more blocks per hour (since 20 more LWBs than SWBs over 8 h = 2.5 more blocks per hour). Regardless of a change in energy expenditure, daily masonry work would increase cumulative spinal load by approximately 500 kg when handling SWBs (SWBs 16.3 kg/block × 165 blocks per day = 2690 kg per day; LWBs 11.8 kg/block × 185 blocks per day = 2183 kg per day). Greater cumulative spinal load has been related to increased risk of low back disorders (McGill 1997, Norman *et al.* 1998).

4.4. *Limitations*

The masons who participated in this study performed a masonry task in the laboratory, which may not have been identical to actual fieldwork. However, the experimental task can be considered representative of one aspect of typical wall building with concrete blocks, since seven courses are typically laid before scaffolding is raised. Also, journey-level masonry instructors designed the task to assure a realistic simulation.

An additional limitation is that some masons in the field alternate between using one and two hands when lifting 0.2 × 0.2 × 0.4 m concrete blocks, especially at the lower courses. In the current study, masons were asked to use two hands to lift all of the blocks to remove this source of variability in block-laying method. Although it is possible that masons who lay blocks with one hand in the field may use their muscles differently while using two hands, there would be no differential effect due to block weight. A final limitation was that mortar was not placed on the sides of the block before the block was positioned. Thus, the mean RMS amplitude values may be more representative of a block-handling task than of a true wall-building task.

5. Conclusions

Although a significant effect of block weight on muscle activity was found, muscle activity was not routinely greater when handling SWBs. The current study is the most comprehensive analysis of the muscular effect of concrete block laying, yet biomechanical and physiological differences due to the effect of block weight may be better demonstrated by factors other than muscle activity and heart rate. Despite the minimal effect of block weight, the results of this study clearly demonstrate the adverse effects of work with the arms elevated at or above shoulder level. A substantial increase in upper trapezius muscle activity was noted when handling blocks at higher courses, regardless of the block weight. There is a need to examine this association between the effect of course height and musculoskeletal disorders in future epidemiological studies among masons.

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