Electromyography of the thigh muscles during lifting tasks in kneeling and squatting postures

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Underground coal miners who work in low-seam mines frequently handle materials in kneeling or squatting postures. To assess quadriceps and hamstring muscle demands in these postures, nine participants performed lateral load transfers in kneeling and squatting postures, during which electromyographic (EMG) data were collected. EMG activity was obtained at five points throughout the transfer for three quadriceps muscles and two hamstring muscles from each thigh. ANOVA results indicated that EMG data for nine of 10 thigh muscles were affected by an interaction between posture and angular position of the load lifted ($p < 0.001$). Muscles of the right thigh were most active during the lifting portion of the task (lifting a block from the participant's right) and activity decreased as the block was transferred to the left. Left thigh muscles showed the opposite pattern. EMG activity for the majority of thigh muscles was affected by the size of the base of support provided by different postures, with lower EMG activity observed with a larger base of support and increased activity in postures where base of support was reduced ($p < 0.05$). Thigh EMG activity was lowest in postures with fully flexed knees, which may explain worker preference for this posture. However, such postures are also associated with increased risk of meniscal damage.

Statement of Relevance: Kneeling and squatting postures are sometimes used for manual lifting activities, but are associated with increased knee injury risk. This paper examines the EMG responses of knee extensors/flexors to lifting in these postures, discusses the impact of posture and kneepads on muscle recruitment and explores the implications for work in such postures.

Introduction

Workplace characteristics and/or task demands sometimes obligate workers to assume a kneeling or squatting posture in the performance of their work. In some occupational settings, these postures may be transient working positions, interspersed with periods of standing, sitting or other postures. In others, such as working in underground 'low-seam' coal mines (mines with less than 122 cm vertical space), workers may use such postures for almost the entire work shift. Workers who kneel or squat for large portions of the workday have demonstrated increased risk of several types of knee disorders, including osteoarthritis (Anderson and Felson 1988, Felson *et al.* 1991, Cooper *et al.* 1994, Coggon *et al.* 2000), chronic prepatellar bursitis (Sharrard 1964, Tanaka *et al.* 1982, Kivimaki *et al.* 1992, 1994) and meniscal injury (Sharrard and Liddell 1962, Baker *et al.* 2002, 2003). Owing to the increased knee disorder risk associated with prolonged work in these postures, the National Institute for Occupational Safety and Health (NIOSH) is performing research to better understand the demands of work in kneeling and squatting postures, so that better interventions and recommendations may be developed and implemented.

One area of interest is the manner in which the muscles crossing the knee joint are utilised during work in kneeling and squatting postures. It would seem evident that the musculature of both knee flexors and knee extensors would experience different sets of demands in restricted postures compared to work in typical standing or seated postures. In kneeling postures (of which there are several varieties), the leg muscles may generate forces to support activities such as manual materials handling (MMH) and may also be called upon to stabilise the lower limbs and pelvis in what may be relatively unstable positions. The squatting posture is also unstable, but is sometimes used to perform MMH activities as well. Examination of the electromyographic (EMG) activity of the major flexors and extensors of the thigh can provide insight into the physical demands experienced in different postures and the trade-offs that may occur as different postures are adopted.

As vertical work space is reduced, so is the menu of postures available to the worker. In a 1.2 m vertical

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work space, it is possible for most workers to adopt a stooping posture for brief periods of time; however, this posture is uncomfortable and fatiguing and is typically used for locomotion, but not for prolonged work activities (Bedford and Warner 1955). Instead, prolonged work is preferentially done in one of several varieties of kneeling posture. A recent observational study in a low-seam mining operation indicated that kneeling with both knees in full flexion was adopted for over 83% of the observation time for roof bolters and continuous miner operators, 5% in a near 90° included angle kneeling posture and 10% of time kneeling on one knee, with almost no squatting (J. Pollard, personal communication on unpublished data, 2009. Data available upon request from J. Pollard, NIOSH, Pittsburgh Research Laboratory, Pittsburgh, PA. 2009). In slightly higher seam coal mines (approximately 1.5 m), squatting was used approximately 10% of the time (J. Pollard, personal communication 2009).

Space restrictions not only change the postures that can be adopted, but can also change the nature of the work tasks that are being performed. This is evident in terms of MMH activities in vertically restricted space. Due to the geometry of the workspace, lateral load transfers are more prevalent and workers tend to be forced into asymmetric motions when lifting. Furthermore, unlike the standing posture, it is often difficult to reposition the body when lifting in a kneeling posture or a squat. Thus, lifting in these postures is characterised by a twisting motion of the trunk, where the load is shifted from one side of the body to the other.

Previous research on lifting in restricted postures has shown that lifting capacity and muscular strength are reduced in both kneeling and squatting postures compared to a standing position (Ayoub *et al.* 1985a,b, Gibbons 1989, Gallagher and Hamrick 1992, Haslegrave *et al.* 1997). In addition, physiological costs of lifting in a kneeling posture have been shown to be higher than in a stooping posture during lateral transfers of load (Gallagher *et al.* 1988). However, previous research has not examined the role of the knee flexors and extensors during lifting activities in squatting and kneeling postures. Accordingly, the present exploratory investigation was performed to examine the EMG activity of knee flexors and extensors during a lateral lifting task in five kneeling postures and a squatting posture. EMG activity, an indirect measure of muscle activation levels, can help with understanding the physical demands of work in kneeling and squatting postures. In addition, the effect of three kneepad conditions was examined: no kneepads; an articulated kneepad; a non-articulated kneepad. The kneepads chosen for study are commonly used in US low-seam coal mines and were studied to evaluate whether EMG responses may be affected by the potential for increased resistance, changes in patellar motion with vs. without kneepads, possible antalgic posture responses and the potential for the kneepad straps to impact EMG activity, particularly the knee flexors.

Methods

Participants

Nine participants (6 male, 3 female) took part in this study. The average age was 35 ± 17 years (mean ± SD), while the average body mass and height were 69.7 ± 10.6 kg (mean ± SD) and 168.0 ± 7.6 cm (mean ± SD), respectively. Prior to enrolling in the study, each participant read and signed an informed consent form, which was approved by the NIOSH Human Subjects Review Board. Since participants were required to repeatedly adopt kneeling postures, each participant was asked a series of questions to determine if they had ever had any significant injury to the knee. None of the participants had ever had knee surgery. One subject had been diagnosed with bursitis, which did not require any intervention and a second participant had slight nerve damage due to a motorcycle accident. However, neither participant was symptomatic at the time of testing.

Experimental design

Independent variables in this study consisted of kneepad condition (three levels), posture (six levels) and angular block position (ABP; five levels). The block lifted was the size and mass of a cinderblock commonly used in US underground coal mines (dimensions: 19 cm (height) × 39 cm (width) × 15 cm (depth); mass: 11.3 kg). Kneepad states included no kneepad, an articulated kneepad with a hard contoured outer shell (AIS Knee Armor; American Industrial Supply, Inc., Knoxville, TN, USA) and a non-articulated kneepad with a soft outer shell (Barwalt Ultralight^{TM} Knee Pad: KN-1; Barwalt Tool Co., Post Falls, ID, USA). Figure 1 illustrates the kneepads used in this study.

Postures included lifting on both knees with the knees in full flexion (with vertical space restrictions of 97 cm and 122 cm), lifting on one knee (right knee down) with the left knee up and left leg supported by the foot (with vertical space restrictions of 97 cm and 122 cm), lifting on both knees with knees near a 90° angle (122 cm vertical space restriction only) and a squat (122 cm vertical space restriction only). Prior to the start of the load transfer, the subject was shown a graphic depicting the posture to be adopted during the trial and was asked to adhere as closely as possible to

Figure 1. Kneepads used in the study: (a) articulated kneepad with hard contoured outer shell; (b) non-articulated kneepad with soft outer shell.

the posture depicted in the graphic. Figure 2 provides examples of lifting tasks in each of the main postures examined. It should be noted that task performance required some deviation from the idealised postures depicted in the graphics. For example, to accomplish the load transfer while kneeling in full flexion, some knee extension was required to both reach and place the load; however, subjects were asked to minimise the degree to which the buttocks came off the heels. Similarly, subjects in the 'near 90' posture needed to flex the knees to maintain balance during the load transfer, but were asked to keep the buttocks as high as possible during the transfer process.

ABPs were derived from motion analysis markers placed on the block and were defined in relation to the initial block position. Specifically, an ABP of 0° represented the position of the block at the start of the lift (23 cm directly lateral to the participant's right knee), an ABP of 90° was the position of the block when it was directly in front of the participant and an ABP of 180° represented the position of the block at the end of the lift (23 cm directly lateral to the participant's left knee). Data were also obtained at ABPs of 45 and 135° (intermediate between the positions described above).

Vertical space restrictions were achieved using an adjustable ceiling raised and lowered via a system of pulleys. The adjustable ceiling was not rigid in nature but was suspended by ropes from the ceiling and consisted of a frame constructed of polyvinyl chloride pipe, to which wide-mesh netting was affixed. The netting allowed motion analysis cameras to be deployed above the level of the ceiling and still obtain data on marker positions. The levels of vertical space restriction (97 and 122 cm) were selected to represent examples of working heights present in low-seam coal mines, which would limit working postures to varying degrees.

Dependent variables consisted of normalised EMG data of ten thigh muscles. These muscles were the left and right pairs of the vastus lateralis, rectus femoris, vastus medialis, biceps femoris and semitendinosis.

The presentation orders for the three kneepad states were randomised. Within each kneepad state, a restricted randomisation determined the order of the six postures (i.e. a separate random order for postures was generated within each kneepad state) and the effect of block position was evaluated within each lifting trial. Based on this randomisation scheme, a split-split-split plot design (with no whole-plot factor) was employed to evaluate EMG responses. As an exploratory analysis, a comparison-wise type I error rate alpha level of 0.05 was employed (Bender and Lange 2001). The statistical model used is presented in Equation (1) below:

$$Y_{ijkl} = \mu + \pi + \alpha_j + (\alpha\pi)_{i(j)} + \beta_k + (\alpha\beta)_{jk} + (\beta\pi)_{ki(j)} + \gamma_l + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + (\gamma\pi)_{il(jk)} + \varepsilon_{ijkl} \quad (1)$$

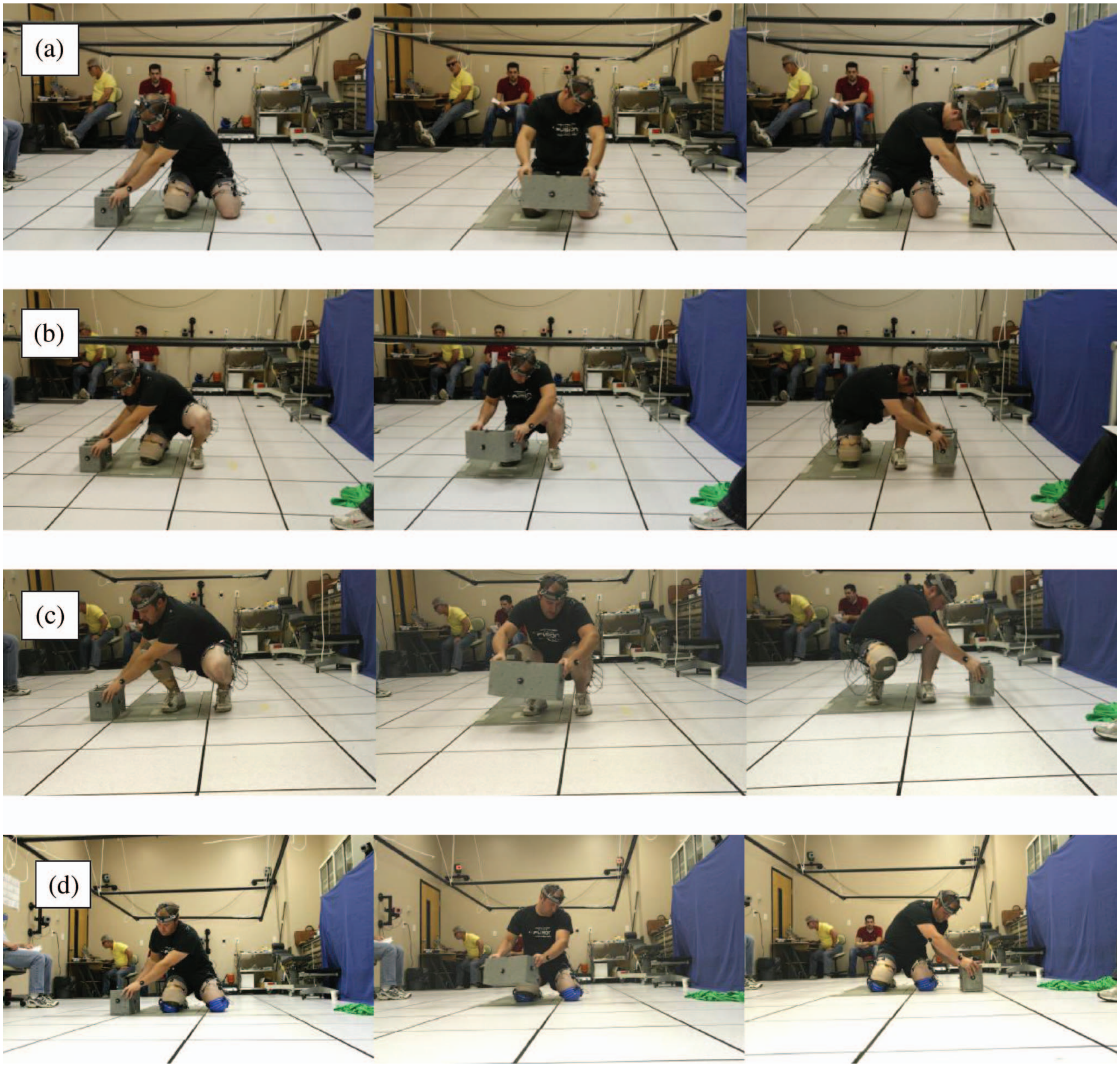

Figure 2. Examples of the postures and lifting tasks used in this study: (a) kneeling in full flexion; (b) kneeling on one knee; (c) squat; (d) kneeling with both knees near 90°.

Electromyographic preparation

The longer of the two kneepads was the articulated pair and they were placed on the right and left knees of the participant to mark the superior-most aspect of the kneepad. Preferred locations of the electrodes for each of the thigh muscles were derived from Ericson *et al.* (1985) and are provided in Table 1. The location of the placement for each EMG electrode was marked on the participant's thigh using an ink pen. Disposable self-adhesive Ag/AgCl dual snap surface electrodes (Noraxon USA Inc., Scottsdale, AZ, USA) with electrode spacing of 2 cm centre to centre were employed. Each electrode site was shaved (if necessary) and cleaned using a skin preparation pad consisting of 70% isopropyl alcohol and pumice (Dynarex Corp., Rochester, NY, USA). Electrodes were placed over the bellies of the muscles, distal to the motor point regions (Ericson *et al.* 1985). In some cases, it was not possible to place the electrodes in the ideal location due to the length of the articulated kneepad. In such cases, the

Table 1. Preferred electrode positions for thigh muscles (from Ericson *et al.* 1985).

Muscle	Location
Rectus femoris	Midpoint of the distance between the anterior superior iliac spine (ASIS) and patellar apex
Vastus lateralis	80% of the distance from the ASIS to the medial knee joint space
Vastus medialis	75% of the distance from the ASIS to the lateral knee joint space
Semitendinosis	Midpoint of the distance from the ischial tuberosity to the medial knee joint space
Biceps femoris	Midpoint of the distance from the ischial tuberosity to the lateral knee joint space

electrode was placed as closely as possible to its ideal location, but always distal to the motor point. Two reference electrodes were required (one for each wireless transmitter) and these were placed at remote sites.

Isometric maximum voluntary contractions (MVCs) were obtained for the thigh muscles of both right and left legs (LeVeau and Andersson 1992). The participant was instructed to lie in a supine position in a Biodex System 2 accessory chair (Biodex Medical Systems, Inc.; Shirley, NY, USA) with the knee angle at approximately 90° with the hips (also at approximately 90°) and ankle secured via Velcro straps. The participant was then instructed to attempt knee extension with maximal effort for at least 5 s while a researcher provided verbal encouragement. The participant was then instructed to flex the knee with maximal effort for at least 5 s, again while being verbally encouraged by a researcher. Each leg was tested separately. The number of MVCs performed by the participants ranged from 1 to 4 and was based on assessment of effort and inspection of the EMG signal. EMG activity normalised to single-angle MVCs in the lower extremity have been found to provide similar results to angle-specific normalisation techniques in dynamic lower extremity activities (Yang and Winter 1984, Knudson and Johnson 1993, Burden *et al.* 2003). Furthermore, single-angle MVCs have been recommended as the most appropriate normalisation technique for patterns of EMG activity in dynamic lower extremity tasks (Knudson and Johnson 1993).

All EMG measurements were made using a Noraxon Telemyo 2400R – World Wide Telemetry system with 16 channels (Noraxon USA Inc.). The gain was set to 10 for all channels. Several hardware filters were in place: first order high-pass filters set to 10 Hz $\pm 10\%$ cut-off; eighth order Butterworth/Bessels low pass anti-alias filters set to 500 Hz $\pm$ 2% cut-off. The common mode rejection was >100 dB. The sampling rate for all EMG data was set at 1020 Hz.

Motion analysis

A motion capture system (Eagle; Motion Analysis Corporation, Santa Rosa, CA, USA) was utilised to determine the base of support of the participants in the postures studied. Retro-reflective markers placed on the foot (heel and toe) and the shank (used to calculate position of the knees) were used to estimate the base of support. Specifically, the base of support was estimated by quantifying the surface area bounded by the parts of the body making contact with the ground when kneeling and squatting. Different methodologies were used for the differing postures. For the bilateral kneeling postures (near full and near 90°), this area was assumed to be the region bounded by the knees (represented by anterior thigh markers) and toes (represented by the lateral toe markers). For one knee, this area was assumed to be the region bounded by the left foot (represented by the left lateral toe and left heel markers) and the right lower leg from right knee (represented by the anterior thigh marker) to right toe (represented by the lateral toe marker). For squat, this area was assumed to be the region bounded by the left and right feet with only the balls of the feet making contact with the ground. Therefore, the horizontal distance between the left and right feet was determined from the ankle markers and the length of the ball of the foot was determined from the literature using the subject's anthropometry. In addition, markers located at several locations on the box allowed researchers to track the movement of the box throughout the lifting task.

Procedure for lifting trials

Calibration of the motion analysis system was performed prior to the initiation of the lifting trials. The participant donned the randomly assigned kneepad (if necessary) and then performed the lifting tasks in the six postures described earlier (randomly assigned within each kneepad state). For each lifting task, the participant adopted the posture of interest and the EMG data collection system was activated. The participant was given a verbal cue to begin the lifting task. Participants accomplished the load transfer using their own natural lifting style and pace and the lift was performed using both hands. When the lift was completed the participant returned to a neutral position, facing straight ahead in the posture of interest. A brief period of rest (but at least 1 min) was provided between trials. During rest periods, participants were free to get up out of the kneeling/squatting positions.

Data conditioning and analysis

EMG data were low-pass filtered to 500 Hz and high-pass filtered to 20 Hz using a fourth order Butterworth filter (MATLAB®; The MathWorks, Inc., Natick, MA, USA). The signal was then rectified by taking the absolute value. Data from all tests were normalised by dividing by the MVC for each muscle. Mean amplitude values of the normalised values were then calculated by determining the running mean of every 102 samples or 10% of the sampling rate (LeVeau and Andersson 1992). Trials containing evidence of artefacts (brief spikes of activity with magnitude greater than 150% MVC and uncharacteristic of surrounding EMG activity) were eliminated from the analysis.

Data were analysed using the Statistix software package (Analytical Software, Tallahassee, FL, USA). Residual analysis of the non-transformed EMG data indicated a fan-shaped pattern of residuals in all 10 muscles. Thus, the EMG data were transformed by taking the natural log, which resulted in a near normal distribution of residuals for all muscles, based on visual inspection of the residual plots. All ANOVA results reported below are based on the log transformed data. As repeated measures were obtained for ABP, lower bound adjustments were computed to check for violations of compound symmetry. Linear regression was used to evaluate the relationship between the base of support provided by a posture to the magnitude of normalised EMG activity of the knee flexors and extensors.

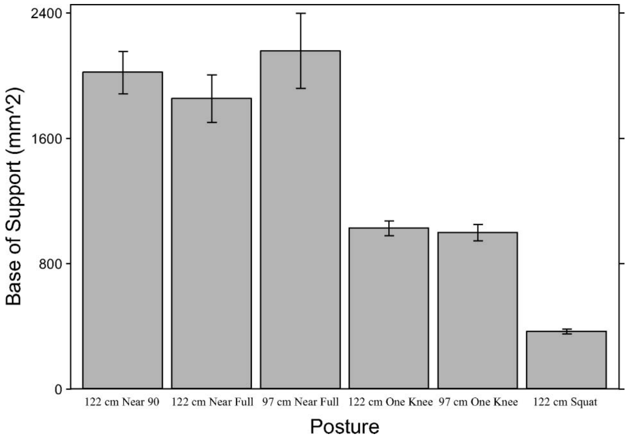

Figure 3. Estimated base of support for each posture ($n = 9$). Error bars represent the standard deviation.

Results

Estimates of the base of support for each posture are provided in Figure 3. A summary of the split-split-split plot ANOVA for EMG activity of each muscle is provided in Table 2. As can be seen in this table, nine out of the 10 muscles investigated were affected by an interaction between the posture adopted and the location of the block throughout the lift. The sole exception was the left vastus lateralis, which was affected by the main effects of posture and block location, but not their interaction. The kneepad main effect was not found to significantly influence EMG activity for any of the muscles studied. However, a significant interaction between kneepad condition and block location was found to affect activity of the left biceps femoris ($p < 0.05$). Results of lower-bound adjustments for ABP indicated no violations of the assumption of compound symmetry involving this factor.

Figure 4 provides a summary of EMG activity at different time points during the lift in each posture and is thus an overall representation of the interaction of posture and block location. This figure provides summaries of EMG data at the start and end positions (as the block was picked up and set down, respectively)

Table 2. Summary of significant main effects and interactions for normalised activity of all muscles

	Kneepad (A)	Posture (B)	A × B	Block location (C)	A × C	B × C	A × B × C
Left vastus lateralis		***		***			
Left rectus femoris		***		***		***	
Left vastus medialis		***		***		***	
Left biceps femoris				***	*	**	
Left semitendinosis		**		***		***	
Right vastus lateralis		***		***		***	
Right rectus femoris		***		***		***	
Right vastus medialis		***		***		***	
Right biceps femoris		***		***		***	
Right semitendinosis		***		***		***	

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

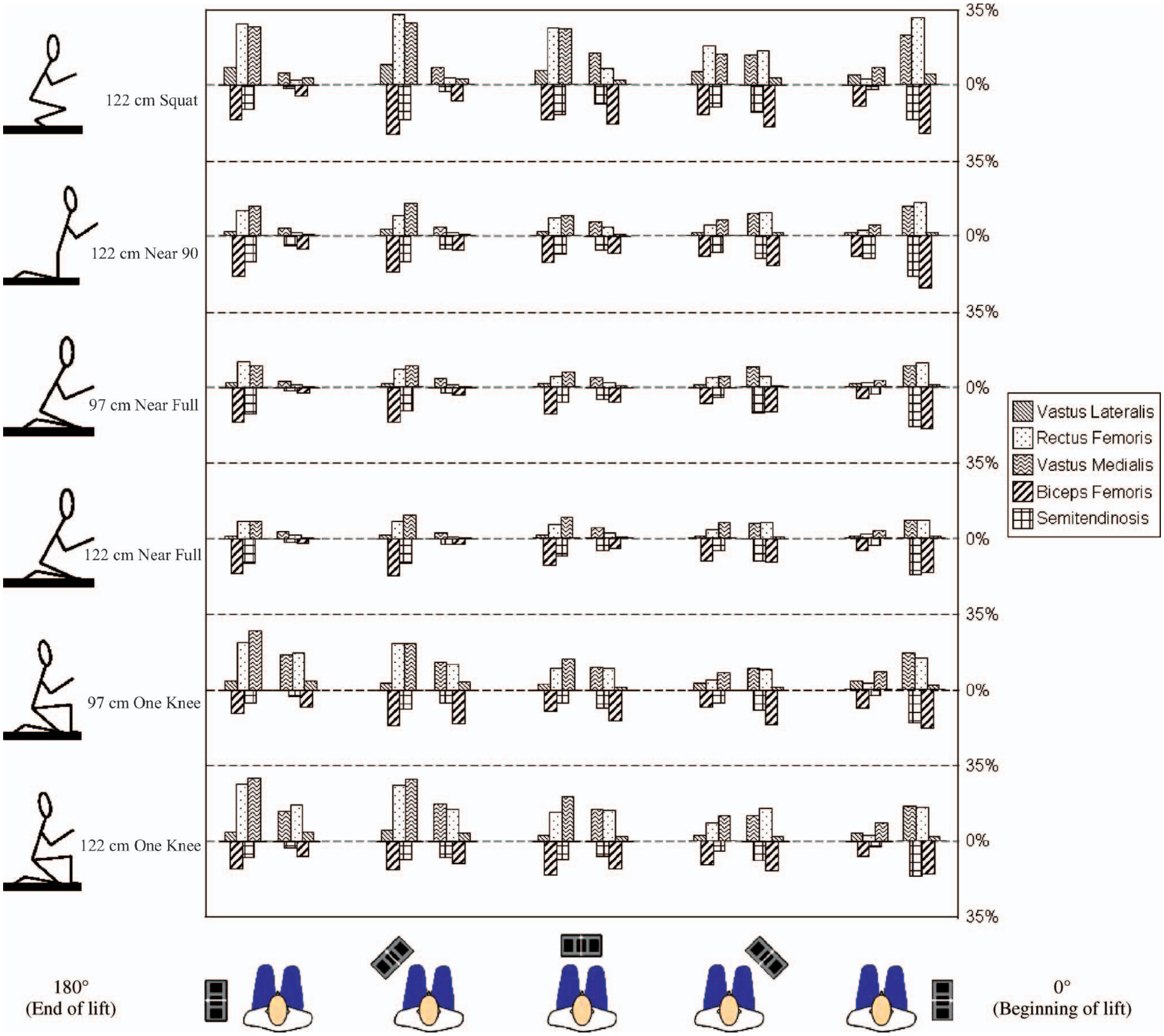

Figure 4. Summary of electromyographic activity by posture and object location. For each posture and object location there are two groups of bars representing the activity of the left and right thigh muscles. Note that the bars representing the left and right thigh muscles mirror their arrangement in the body if looked at from the superior aspect.

and at three intermediate points during the lift (ABPs = 45, 90 and 135°).

Inspection of Figure 4 provides several insights into the activation of the thigh muscles in different postures and at different phases during the lift. One consistent pattern that can be observed with all postures is high activation of the right thigh muscles at the beginning of the lift and the high activation of the left thigh muscles as the load is transferred to the left side. Peak activity of the left thigh muscles tended to occur when the block was at the 135 or 180° positions. In most cases, the lowest overall EMG activity was observed when the block was at the 45 or 90° position.

Several differences in muscle activity can be noted between postures in Figure 4. The squat posture generally exhibited the highest muscle activity levels throughout the entire lift and this was particularly true for the knee extensors. Kneeling in full flexion (in either 97 cm or 122 cm heights) typically exhibited the lowest muscle activity of any posture. Kneeling at 90° exhibited very similar activation patterns to the full flexion posture, but tended to have slightly higher EMG activity. Kneeling on one knee (in both heights), however, resulted in higher activity than the other kneeling postures, with a notable increase in right and left side extensor EMG at the end of the lift compared with the other kneeling postures. The left vastus lateralis was the only muscle not to exhibit a significant interaction between posture and block position, although the *p*-value for this interaction was less than 0.10.

The presence or absence of kneepads had virtually no effect on EMG activity in this study. The one exception is that the left biceps femoris was affected by an interaction of kneepad*block location, shown in Figure 5. Compared with the kneepad states, the no kneepad state resulted in lower EMG activity of the left biceps femoris in all block locations other than the 0° ABP.

Table 3 contains results of regression analyses examining the relationship between the base of support provided in the various postures and the peak normalised EMG observed during the lifting tasks for all muscles. Results of this analysis indicate that the peak EMG activity for the majority of the thigh muscles studied was inversely related to the base of support provided by the posture.

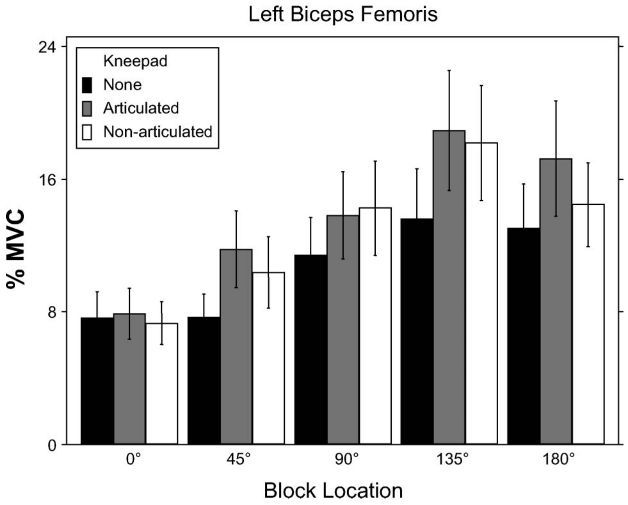

Figure 5. Interaction of kneepad state and block location on electromyographic activity of the left biceps femoris. MVC = maximum voluntary contraction.

Discussion

Restricted vertical workspace not only requires adoption of awkward postures (such as kneeling and squatting), it also encourages asymmetric motions when performing lifting tasks. The present study investigated a lateral load transfer in various kneeling and squatting postures – in this case, the load was transferred from the right side of the body to the left. Not surprisingly, it was found that EMG of the right thigh muscles was greatest at the initiation of the lift and EMG of the left thigh muscles was greatest toward the end of the lift (typically peaking at the 135 or 180° ABPs). This shift in muscle activity clearly reflects the change in force demands on the thigh muscles as the block was lifted from right to the left. Lowest EMG values were typically observed at the 45 and 90° ABPs. The reason for the decrease in muscle activity at this portion of the lift may be due to a decreased load moment as the load is brought closer to the body in this region and/or the fact that the middle of the lift may involve less acceleration/deceleration of the load, which may reduce the forces required of the muscles. Additionally, centring the load distributes the weight of the block between the two legs, thus requiring less muscle activity.

It was apparent that the base of support provided by the different postures had an influence on thigh muscle activity. Three basic postural groups can be identified that had similar bases of support and similar EMG responses to the lifting tasks. Postures in which both knees were on the ground (kneeling near full flexion and the near 90° flexion) had the largest base of support and generally elicited lower magnitudes of EMG activity. In full flexion, both the knees and pelvis were well supported. The resulting postural stability appears to have reduced the force demands of the thigh muscles to stabilise the hip and knee joints, particularly when compared with the other postures studied. Slightly greater EMG activity was observed in the near 90° posture than in full flexion, when both knees were supported by the floor but the pelvis was no longer supported by the lower leg. However, these differences

Table 3. Results of regression analyses examining the relationship between the normalised peak electromyographic activity observed during the lifting tasks for all muscles and the base of support in mm2 ($n = 9$).

	LBF	LST	LVL	LRF	LVM	RBF	RST	RVL	RRF	RVM
Constant	122.56	50.98	68.90	91.95	129.67	100.30	30.68	29.97	96.50	124.44
Base of support	−0.017*	−0.005	−0.027*	−0.019*	−0.026*	−0.006	0.012*	−0.012*	−0.027*	−0.026
R^2	0.73	0.14	0.78	0.69	0.75	0.05	0.82	0.95	0.65	0.31

L = left; BF = biceps femoris; ST = semitendinosis; VL = vastus lateralis; RF = rectus femoris; VM = vastus medialis; R = right.
*Indicates $p < 0.05$.
Note: A negative coefficient for base of support indicates a reduction in peak electromyographic activity with a larger base of support.

were not large and the similarities in muscle activity in these postures were striking.

The second postural grouping was that involving kneeling on the right knee with the left leg supported by the foot. These postures were associated with a base of support almost half that of the two knee postures and demonstrated an increased magnitude of muscle activity compared with postures where both knees were down. This was particularly true of the left thigh at the end of the lift (where significant quadriceps activity was observed). It appears that this configuration of the body required additional muscle activity to maintain postural stability, which previous research has shown to be less than that when kneeling on two knees (Bhattacharya *et al.* 2009). In addition, it should be noted that the raised left knee constituted a barrier, around which the load had to travel. The increased load moment associated with circumvention of this barrier may have also contributed to the higher thigh muscle activity observed in these postures.

The highest EMG activity of the thigh muscles was recorded in the squat posture, which was clearly the most unstable of the postures studied. The base of support in this posture consisted solely of the balls of the feet and was markedly smaller than that in the other postures studied. In this posture, both the knee and pelvis are in an unsupported position, which apparently leads to an increased need to activate the thigh muscles to maintain adequate support and stability throughout the lift.

EMG activity differences in the different postures are a function of the fact that several of the thigh muscles (rectus femoris, biceps femoris and semitendinosis) cross both the knee and hip joints and thus act on both joints. Previous studies have conclusively shown that there is no ability to selectively contract fibres of a particular region of a two-joint muscle so that only one joint is acted upon (Basmajian and de Luca 1985). On the contrary, the entire muscle will contract regardless of the joint (or joints) moved. Which joint is moved depends upon the degree to which each joint is immobilised or supported (Fujiwara and Basmajian 1975).

The results obtained in this study and the interpretation above may help to explain some of the postural preferences demonstrated by miners working in low-seam coal mines. Field observations of postures adopted by roof bolters and continuous miner operators indicate an overwhelming preference for kneeling with both knees in full flexion. As mentioned previously, this posture was used for 86% of the time that these workers were under observation in a low-seam coal mine (J. Pollard, personal communication 2009). One reason that miners may favour this position is due to the postural stability afforded by this body configuration (Bhattacharya *et al.* 2009). Another motivation may be a by-product of the enhanced stability; the fact that, in a stable posture with a large base of support, there is a greatly reduced need for active contraction of the thigh muscles. The lower the force demands on the muscles, the lower the body's requirement for oxygen to replenish adenosine triphosphate stores in the muscle. Therefore, kneeling with both knees in full flexion reduces the need to employ active contraction of the thigh muscles for postural control, reducing energy cost (at least in the lower extremity) and may well spare the cardio-respiratory system. Lower metabolic demands associated with this posture can also be a strong behavioural motivator. Workers like to conserve energy, especially in performance of occupational tasks (Cavanagh and Kram 1985, Trafimow *et al.* 1993, Minetti *et al.* 1995, Straker 2003). The other postures provide less stability and would be expected to increase local metabolic cost and may be less preferred as a result.

However, while the full flexion posture provides a stable and energy efficient posture from which to work in restricted postures, the knee joint itself may incur a significant burden resulting from the choice to use this posture. Specifically, the fully flexed knee is known to be associated with meniscal tears (Baker *et al.* 2002, 2003) and the development of knee osteoarthritis (Cooper *et al.* 1994, Coggon *et al.* 2000, Manninen *et al.* 2002). Previous research has suggested that one possible pathway to cumulative meniscal lesions or tears may be the result when the medial or lateral meniscus is repeatedly (or continually) caught between the condyles of the femur and the tibia during full knee flexion (Sharrard and Liddell 1962). An alternative proposal has suggested that increased laxity of the anterior cruciate ligament due to prolonged or repeated kneeling may lead to instability in the knee and that sudden movement or internal/external rotation of the joint may then result in meniscal damage (Atkins 1957, Sharrard and Liddell 1962). Knee osteoarthritis involves degenerative dissolution of normal cartilage behaviour and function. The breakdown of a joint's cartilage results in a loss of shock absorption in weight bearing and may ultimately result in bone to bone contact during joint movement, leading to severe pain and disability. Miners have been identified specifically as an occupational group associated with development of knee osteoarthritis (Atkins 1957, MacMillan and Nichols 2005).

It is an unfortunate fact (in the current context) that feedback regarding metabolic load is almost immediately perceptible to an individual, while the wear and tear on the tissues of a joint may be the result of a relatively long-term process, in which feedback may be deferred. This is not to suggest that postures requiring additional energy expenditure will necessarily confer immunity from tissue damage. However, if muscle recruitment can be reduced (and energy saved) in the short term by an individual via sinking into deeper knee flexion and the resulting meniscal wear and tear does not become immediately apparent, it would certainly seem a reasonable choice (in the short term) to use the posture that is both more stable and that saves energy. However, the long-term effects of such a choice may ultimately be very detrimental. It may be noted that the reduced energy expenditure of the fully flexed kneeling posture also makes it a challenge to recommend, as an alternative, a posture that increases energy demands. Any such recommendation is likely to be quickly discarded by workers as soon as the increased physical demand becomes evident.

It should be noted that wearing kneepads of the sort used in this study resulted in virtually no influence on thigh muscle activity. Thus, none of the potential influences related to kneepad use detailed in the Introduction appears to have impacted EMG activity required for the task studied. A companion study demonstrated that these kneepads were effective at decreasing peak pressures on the bony structures of the knee by distributing forces across more surface area of the superior portion of the tibia (Porter *et al.* 2010). Results of these two studies suggest a positive benefit regarding the use of such kneepads, without a trade-off in terms of increased muscle activity.

Several limitations of this study should be noted. One limitation is the relatively small sample size. Further, subjects in this study were not underground miners and it is possible that EMG activity may differ between novices and experienced coal miners in performing these load transfers. Some of the postures employed (specifically kneeling in full flexion and squatting) may have introduced the opportunity for EMG artefacts of the hamstrings via tissue compression, although the artefact checking performed during analysis should have helped to minimise this effect. In addition, as subjects used their own natural lifting cadence, it is possible that differences in lifting dynamics might have influenced the results; however, normalisation over the task should have helped to control such an effect. As with any study examining anisometric contractions, the interpretation of the relationship between EMG amplitude and force requires great caution due to the numerous factors that can modify this relationship. While there was not a great deal of dynamic motion of the legs during these lateral load transfers, and while fixed epochs were assessed during the load transfers as recommended during anisometric contractions (de Luca 1997), the differences in knee flexion between certain of the postures studied would likely involve relative movement of the electrodes with regard to active muscle fibres. It should be recognised that the amplitudes of the EMG signals may not provide a straightforward indication of mechanical muscle outputs in such cases (Basmajian and de Luca 1985).

In summary, the results of the present study have several implications worth noting for those interested in reducing knee morbidity due to work in kneeling or squatting postures. One important issue highlighted is that a kneeling posture that would be desirable to workers from an energy conservation standpoint (e.g. kneeling in full flexion) is known to generate damage to the menisci due to pressures generated by the femoral condyles in the flexed knee posture. Researchers wishing to intervene to reduce knee morbidity due to use of full flexion kneeling will need to contend with the powerful motivating influence of the energy conservation associated with this posture, as well as the improved stability afforded in this position. Furthermore, the data suggest that the muscles of the lower extremity have to compensate for smaller bases of support via increased muscle activation during materials handling activities in kneeling and squatting postures. Finally, data from the present study suggest that kneepads (at least those studied here) do not significantly affect EMG activity and, thus, they seem to engender no downside in terms of increased muscle activity and related energy cost.

Conclusions

Based on the results of the present investigation, the following conclusions are drawn:

(1) In a lifting task involving a right to left transfer of a load, the muscles of the right thigh are most active at the initiation of the lift and the muscles of the left thigh are most active near the end of the lift. Lowest overall EMG activity was observed during the middle portion of the lift.
(2) Results of the analysis indicate that the peak EMG activity for the majority of the thigh muscles studied was inversely related to the base of support provided by the posture.
(3) Wearing kneepads was not found to influence EMG activity of the thigh muscles in this study.
(4) Kneeling on both knees was associated with the lowest EMG activity, while kneeling on one knee was associated with increased activity and

squatting resulted in the highest amount of EMG activity of any posture.

(5) The reduced EMG activity observed when kneeling in full flexion suggests lower metabolic demands, which may be a reason that this posture is preferred by miners working in low-seam coal mines.

(6) Despite the reduced thigh muscle EMG activity in the fully flexed kneeling posture, this posture has been associated with development of meniscal tears and development of knee osteoarthritis.

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