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Is there a low-back cost to hip-centric exercise? Quantifying the lumbar spine joint compression and shear forces during movements used to overload the hips

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Abstract

The aim of this study was to quantify joint compression and shear forces at L4/L5 during exercises used to overload the hips. Nine men performed 36 "walking" trials using two modalities: (1) sled towing and (2) exercise bands placed around the ankles. Participants completed forward, backward, and lateral trials with bent and straight legs at three separate loads. Surface electromyography (EMG) was recorded bilaterally from eight torso and thigh sites, upper body and lumbar spine motion were quantified, and hand forces were measured. An EMG-driven musculoskeletal model was used to estimate the muscular contribution to joint compression and shear. Peak reaction, muscle and joint compression and shear forces, and peak gluteus medius and maximus activity were calculated. Significant differences were noted in each dependent measure; however, they were dependent on direction of travel, leg position, and load. The highest joint compression and shear forces for the sled and band conditions were 4378 N and 626 N, and 3306 N and 713 N, respectively. In general, increasing the band tension had little effect on all dependent measures, although a load-response was found during the sled conditions. Before using any exercise to improve hip function, the potential benefits should be weighed against "costs" to neighbouring joints.

Keywords: *Back, band, sled, spine biomechanics, towing*

Introduction

Recent evidence suggests that the musculature of the hips, and more specifically the gluteals, may play a critical role in the prevention and rehabilitation of lower extremity injury and the enhancement of athletic performance (Hollman et al., 2009; Robertson, Wilson, & St. Pierre, 2008). For example, increasing gluteus maximus activity may assist in the prevention of ACL injury via a reduction in frontal plane knee motion (Hewett et al., 2005; Hollman et al., 2009), or aid in the development of greater hip power during athletic activities (Robertson et al., 2008). Consequently, clinicians and performance coaches alike have begun experimenting with training methods believed to challenge the hip musculature (DiStefano, Blackburn, Marshall, & Padua, 2009; Pollitt, 2003; Wakeham & Jacobs, 2009). Gluteal (re-)education or integration is emphasized, via the use of specific coaching cues, movement patterns or modalities, although the decision to use one approach over another is typically based on anecdotal evidence alone with minimal support from the scientific community. As a result, the patient/athlete may be forced to deal with an unnecessary "cost", potentially offsetting the perceived benefit of the intervention.

Before choosing a particular intervention, practitioners should seek to understand the potential implications of the training method on joints proximal or distal to the hips. Simply because an exercise is perceived to be hip-centric does not mean that it will have minimal impact on the rest of the body. The body functions as a system of interconnected joints and segments and thus training methods used to challenge the hips may in fact increase one's risk of sustaining an injury to an adjacent joint. For example, consider the following scenario: If challenging the hip musculature requires that a load be placed in the hands or on the shoulders

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(both of which can increase the spine load), it is possible that certain exercises or movement patterns could increase low-back injury risk if used incorrectly or with the wrong demographic. Towing or pushing sleds, for example, may offer tremendous benefit to a coach seeking to improve their athletes' hip power or sprint performance (Keogh, Newlands, Blewett, Payne, & Chun-Er, 2010; Spinks, Murphy, Spinks, & Lockie, 2007); however, this type of training is often accomplished by directing an external load through the hands or trunk, thereby potentially influencing the load on the spine. As a result, coaches must acknowledge this potential trunk challenge and the resulting spine load, since their chosen method of training may not be best suited to elicit the desired hip-centred training adaptations for the athlete in question.

If the training objective were simply to increase gluteal activity, loading the hips via the lower limbs (e.g. elastic exercise bands around the ankles or knees) may provide an equally effective solution with a lower spine load. Athletes or clients could be coached to walk forwards, backwards or laterally while resisting the medially directed force of the bands, thereby theoretically increasing their gluteal activity. Because an externally applied load would not be directed through the trunk, it is also reasonable to assume that the potential "cost" to the low back would be reduced. However, justifying the use of a specific modality based on the magnitude or point of application of the external load alone may not be appropriate. The muscular demands and their contribution to loading could far exceed those due to the external environment. Placing bands around the ankles or knees may not impose an external load on the trunk, but it might elicit a response from the trunk musculature that does cause the spine load to increase. External forces such as the exercise's resistance and body weight can dramatically influence joint compression and shear, but the greatest contribution to loading might come from the muscles (i.e. internal forces) (McGill & Norman, 1986). It is therefore important for the scientific community to investigate the costs and benefits of various exercises and training modalities so coaches and clinicians can make educated decisions regarding best practice. The aim of this study was to quantify the muscular and external load contributions to the L4/L5 joint compression and shear during the performance of two commonly used methods (sled towing and elastic exercise bands) to overload the hips. Gluteal activation was measured and three loads were examined to provide insight into the load–response relationship. It was hypothesized that compared with towing a sled, band walks would offer an equally effective (i.e. comparable gluteal activation) and spine sparing (i.e. lower L4/L5 joint compression and shear) way to challenge the hip musculature.

Methods

Participants

Nine men with no previous history of lower back or lower limb injury or pain volunteered to participate in this study. The participants' mean ($\pm$sd) age, height, and body mass were 25.5 ± 4.1 years, 1.80 ± 0.09 m, and 86.4 ± 11.1 kg, respectively. Each participant was recreationally active with a resistance training background, but had no prior experience with the training modalities tested in this study. Therefore, coaching was provided by an accredited strength and conditioning specialist and technique was monitored throughout the experiment. Before testing, each participant was asked to read and sign an informed consent approved by the Human Ethics Committee of the University.

Task selection

Practitioners often use several variations of band walking and/or sled towing to challenge the hip musculature; therefore, three movement directions (forwards, backwards, and lateral) and two leg positions (bent and straight leg) were included in this study. For all sled trials, rope handles were held in the hands either behind or in front of the participant, depending on the direction of travel (Figure 1). Elastic exercise bands were placed around the ankles, superior to the lateral malleoli. Throughout all forward and backward trials, participants were instructed to maintain a foot separation distance equal to that of hip width. When moving in the lateral direction, participants were cued to push off with their trailing leg (left in all cases) to prevent reaching with their front foot (right) and to reduce the sway of their upper body.

Experimental protocol

Each participant attended one familiarization session and one test session separated by a minimum of 48 h. The familiarization session was used to provide preliminary instructions as to the proper execution of each task variation. The session protocol was not standardized with regards to the number of trials or loads; instead, participants were given as much time as was necessary to achieve a level of competency that was considered acceptable by the strength and conditioning specialist. The test session comprised 36 movement trials (one repetition per condition to limit the influence of fatigue), each randomly assigned and separated by a minimum of 1 min.

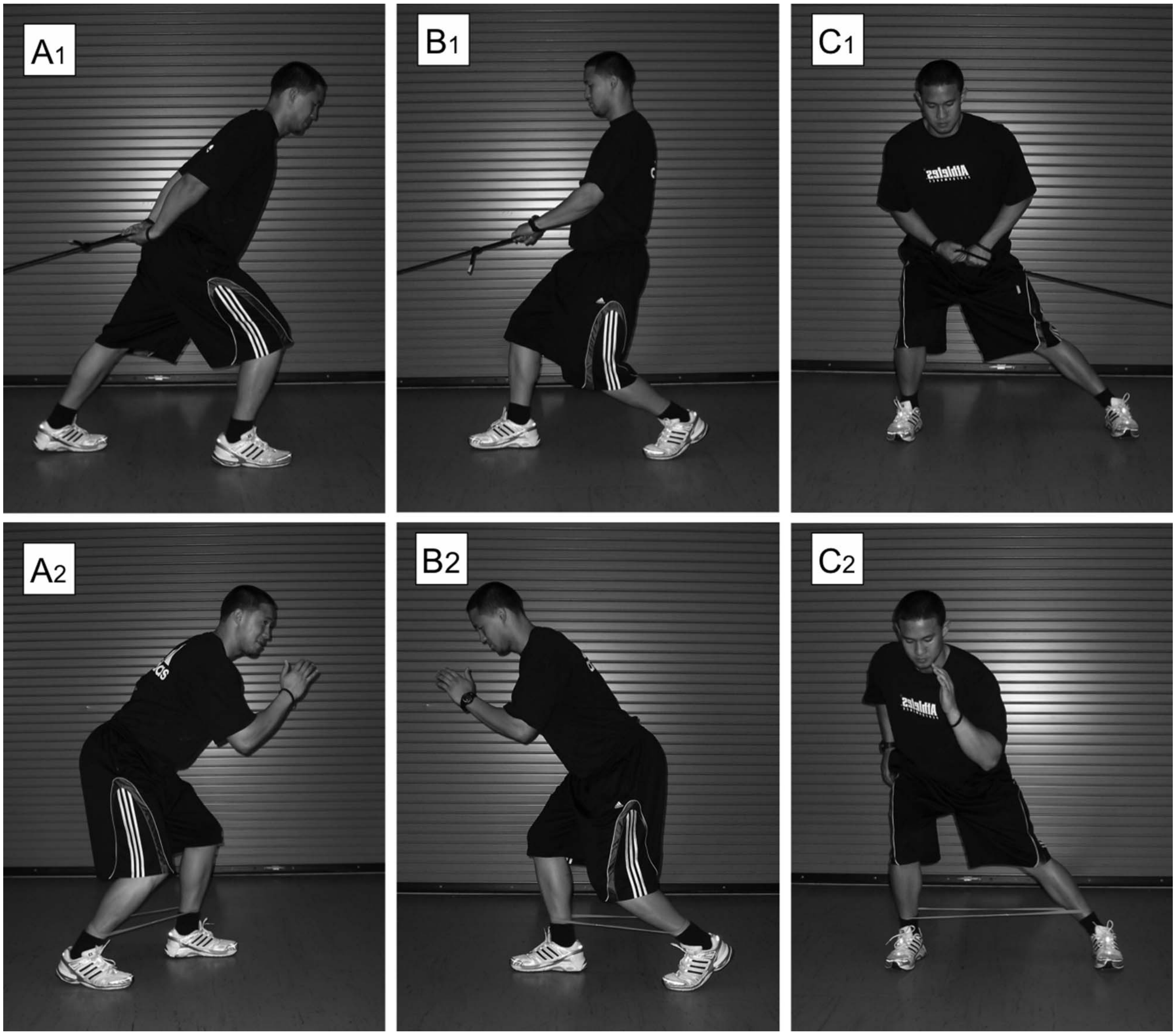

Figure 1. (1) The sled-towing and (2) band walk movements. Participants were asked to perform (A) forward, (B) backward; and (C) lateral walking trials. Although bent leg conditions are shown here, straight leg (knees extended) variations were also performed.

Sled and band trials were performed in the forwards, backwards, and lateral direction, with bent (see Figure 1) and straight legs, using three different loads; the sled was loaded with 20%, 50%, and 80% body weight, and the bands (Perform Better, Cranston, RI, U.SA) had stretch coefficients of approximately 150 (yellow), 200 (green), and 310 (blue) N · m. Multiple variations were investigated to reflect current strength and conditioning and clinical practice. Coaching was provided throughout the test session; however, any repetition not performed appropriately (e.g. knees bent, feet hip width) was repeated after an additional 1 min of rest. Participants were asked to wear a T-shirt, shorts, and a pair of athletic shoes. All trials were performed on a rubberized surface with an approximate coefficient of dynamic friction of 0.32.

Data collection and signal processing

Electromyography. Pairs of Ag/AgCl surface electrodes (Meditrace 200, Mansfield, MA, USA) were placed bilaterally over the following muscles: rectus abdominis, external oblique, internal oblique, latissimus dorsi, erector spinae at the level of L3 and T9, gluteus maximus, gluteus medius, biceps femoris, and rectus femoris. The inter-electrode distance was standardized at 20 mm, electrode orientations were aligned with the muscle fibre directions, and all locations were determined as described by Fenwick and colleagues (Fenwick, Brown, & McGill, 2009). Reference electrodes were placed over the left and right anterior superior iliac spine. Before affixing the electrodes, the skin overlying each muscle was shaved and cleaned with a diluted isopropyl alcohol solution. Raw EMG signals were differentially amplified (CMRR = 115 dB, input impedance = 10 GΩ) and sampled at 2400 Hz using a 16 bit A/D card with a ±2.5 V range. The EMG acquisition hardware (AMT-16, Bortex Biomedical Ltd., Calgary, Alberta, Canada) had a bandwidth of 10–1000 Hz to remove any motion artifact or high-frequency noise. Systematic (DC) bias was removed from the raw signals before full-wave rectification. All signals were then passed through a second-order low-pass Butterworth filter with a cut-off frequency of 2.5 Hz to produce a linear envelope (Brereton & McGill, 1998). The signal amplitude for each respective muscle was represented as a percentage of its maximum activity, recorded during a standardized maximum voluntary isometric contraction (MVC). A detailed description of the procedures is outlined by McGill and colleagues (McGill, McDermott, & Fenwick, 2009). Participants were also asked to complete two resting trials (prone and supine) so that baseline muscle activity could be removed from all signals. The EMG data were synchronized with the kinematic and kinetic data via the collection software (Vicon®, Centennial, CO, USA).

Kinematics and kinetics. Two high-speed Basler cameras were used to capture sagittal and frontal plane motion during the performance of each task (30 Hz). Video was down-sampled to 4 Hz and the upper body (segment endpoints of the neck, torso, upper arms, and forearms) and rope (sled trials only) were digitized in each frame using 3DMatch software (University of Waterloo, Waterloo, Ontario, Canada). Hand forces (sled only) were estimated via a load cell placed in series with the sled's rope handle (2400 Hz) and synchronized with the video (Vicon®, Centennial, CO, USA).

Lumbar spine motion (flexion/extension, lateral bend, axial twist) was also collected (30 Hz) using a 3-Space IsoTRAK, electromagnetic tracking device (Polhemus Inc., Colchester, VT, USA). A transmitter and receiver were strapped to the pelvis over the sacrum and across the rib cage over the T12 spinous process, respectively, to provide an estimation of the position of the rib cage with respect to the pelvis (lumbar motion). A second computer was used to capture these data; however, both collection stations were synchronized with an external trigger. Spine motion was normalized to upright standing (i.e. upright standing posture was considered to represent zero degrees about each anatomical axis of rotation).

Data analyses

Processed EMG and lumbar spine motion data were entered into an anatomically detailed musculoskeletal model of the lumbar spine (Cholewicki & McGill, 1996) to provide an estimate of the internal (muscle) moments about the L4/L5 joint as well as the muscular contribution to joint compression and joint anterior-posterior shear. External moments about L4/L5 and the joint reaction compression and anterior-posterior shear were calculated using 3DMatch (University of Waterloo), a software program that uses digitized segment endpoints (from video files) and measures hand forces to perform quasi-static inverse dynamics computations (Callaghan, Jackson, Andrews, Albert, & Potvin, 2003). The EMG–muscle force relationship was "tuned" for each participant by computing the least squared error between the internal and external resultant moments computed for each frame of every trial collected. This protocol was used to compute a participant-specific gain that could be used to balance the moments and adjust the muscle compression and shear (Cholewicki, McGill, & Norman, 1995). The L4/L5 joint compression and shear were calculated by subtracting the gained muscle forces (muscular contribution) from the joint reaction forces (Figure 2). One stride, defined as right toe-off to right toe-off with video, was analysed for each trial.

Statistical analyses

Peak reaction, muscle and joint compression and shear forces, and peak left and right gluteus medius and maximus activity were calculated for each condition. A four-factor repeated-measures analysis of variance (ANOVA) was used to examine the independent effects of exercise (sled and band), load (low, moderate, high), direction (forward, backward, lateral), and leg position (bent and straight) on each dependent measure. For all significant interactions, Holm-Sidak *post hoc* comparisons were used to examine the differences. Statistical significance was set at $P < 0.05$ and adjustments were made when applicable to account for multiple comparisons.

Results

Significant main effects were noted between leg positions and directions, thus the effects of exercise and load are presented separately for each condition.

Bent leg

With the exception of joint shear and reaction shear for the sled condition, increasing the sled load/band resistance from light to heavy did not elicit a significant change in any dependent measure when participants moved in a forward direction (Figures 3A and 4A); the sled joint shear and reaction shear decreased (72% lower with load 3 than load 1; $P = 0.002$) and increased (80% higher with load 3

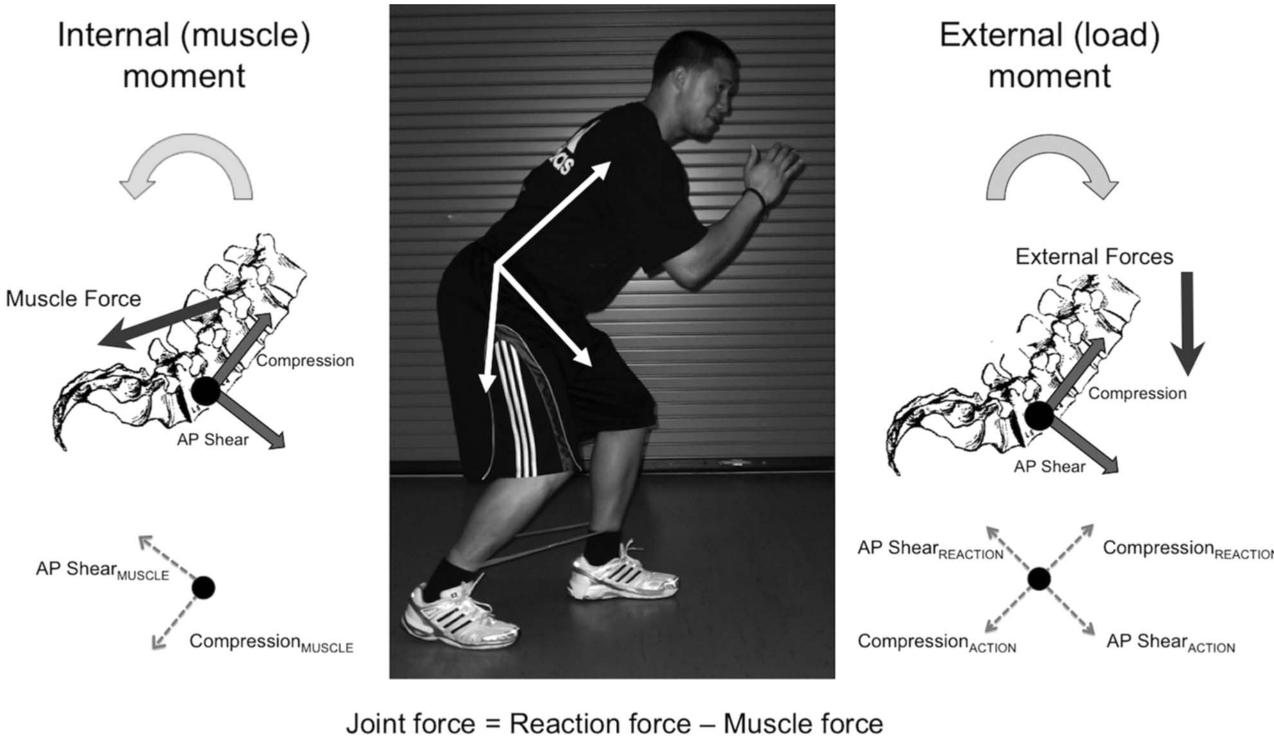

Figure 2. The internal (muscle) and external (load) moment were computed with the processed EMG and lumbar spine motion, and video and hand forces, respectively. The L4/L5 joint (i.e. bone on bone) force (compression and shear) was calculated by subtracting the muscle force from the reaction force.

than 1; $P < 0.001$), respectively, with each subsequent load. A significant difference was also noted in joint compression between the light and intermediate sled loads; however, it was the light load joint compression that was higher (29%; $P = 0.003$). Significant main effects were observed between the sled and band conditions for joint and muscle compression, joint, reaction and muscle shear, and left gluteus medius activity (Figures 3A and 4A), although only the reaction shear was higher during the sled trials. Table I reports the left and right gluteus maximus and medius activity for each sled and band condition in further detail.

Walking backwards was found to alter the load-response compared with the forward conditions. Increasing the sled/band resistance did not affect the joint, reaction and muscle shear (Figure 4B), but significant differences were observed in joint, reaction and muscle compression between the light and heavy sled loads (+20%, $P = 0.002$; +19%, $P < 0.001$; +20%, $P = 0.009$, respectively), and in joint and muscle compression between the low and high band tensions (+13%, $P = 0.010$; +16%, $P = 0.007$, respectively) (Figure 3B). Significant increases were also noted in left gluteus medius and right gluteus maximus activity (49%, $P = 0.016$; 82%, $P = 0.002$, respectively) during the sled trials; however, consistent with observations in the forward conditions, there were no statistically significant relationships between gluteal activity and band tension. Significant main effects were noted between the sled and band conditions for joint, reaction and muscle compression and left gluteus medius activity (Figure 3B), and in contrast to the forward trials the sled was higher for each compression-related variable.

When participants were asked to move laterally with the bands, the only significant load-response was in right gluteus maximus activity (Figure 3C); compared with the lowest tension, activity was 52% higher ($P = 0.002$) when the stiffest band was used. In contrast, between the light and heavy sled loads there were significant differences in joint compression (+32%, $P < 0.001$), muscle compression (+36%, $P < 0.001$), reaction shear (+63%, $P = 0.010$), muscle shear (+41%, $P < 0.001$), and left gluteus maximus activity (+31%, $P = 0.007$) (Figures 3C and 4C). Significant main effects were also found between the sled and band conditions for joint, reaction and muscle compression, reaction and muscle shear, and right gluteus medius and maximus activity; the band trials were associated with a higher shear and muscle activity.

Straight leg

Significant differences were observed in reaction and muscle shear (+60%, $P = 0.018$; +27%, $P = 0.013$,

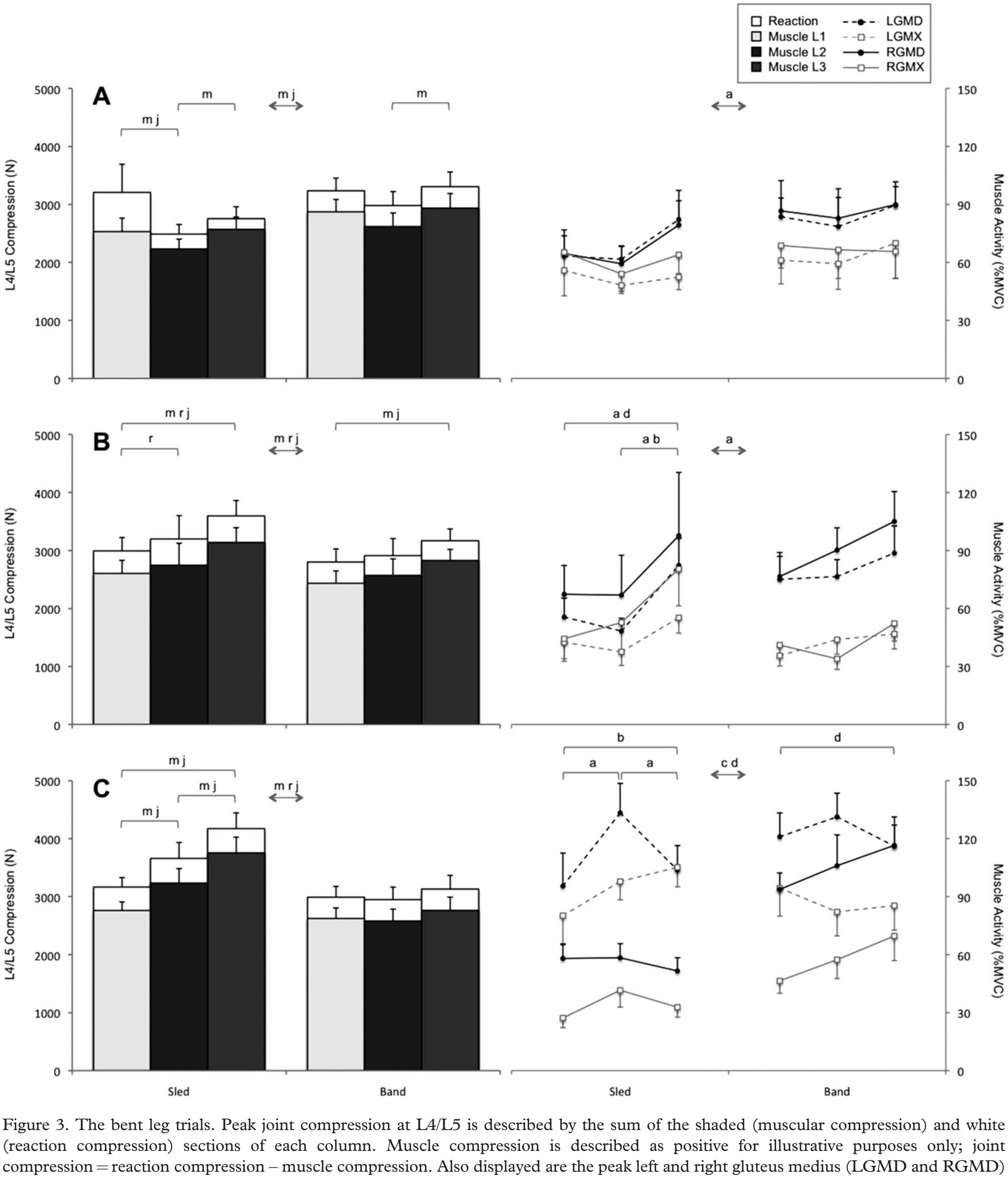

Figure 3. The bent leg trials. Peak joint compression at L4/L5 is described by the sum of the shaded (muscular compression) and white (reaction compression) sections of each column. Muscle compression is described as positive for illustrative purposes only; joint compression = reaction compression – muscle compression. Also displayed are the peak left and right gluteus medius (LGMD and RGMD) and maximus (LGMX and RGMX) for the (A) forward, (B) backward, and (C) lateral conditions. The sled loads and band tensions increase in magnitude from left to right (L1, L2, L3). Error bars represent standard error. Significant differences ($P < 0.05$) in reaction, muscle and joint compression are highlighted with an r, m and j, respectively. Between-load, within-condition differences are described between each condition and load, and main effects between the band and sled for a particular condition are highlighted above the arrow (⇔).

respectively) between the light and heavy sled loads when participants were asked to walk forwards (Figure 4D). No significant load-response was noted for any dependent variable when the bands were used (Figures 4D and 5A). Significant main effects were found between the sled and band conditions for joint, reaction and muscle shear, and like the bent leg trials, joint shear was higher with the bands.

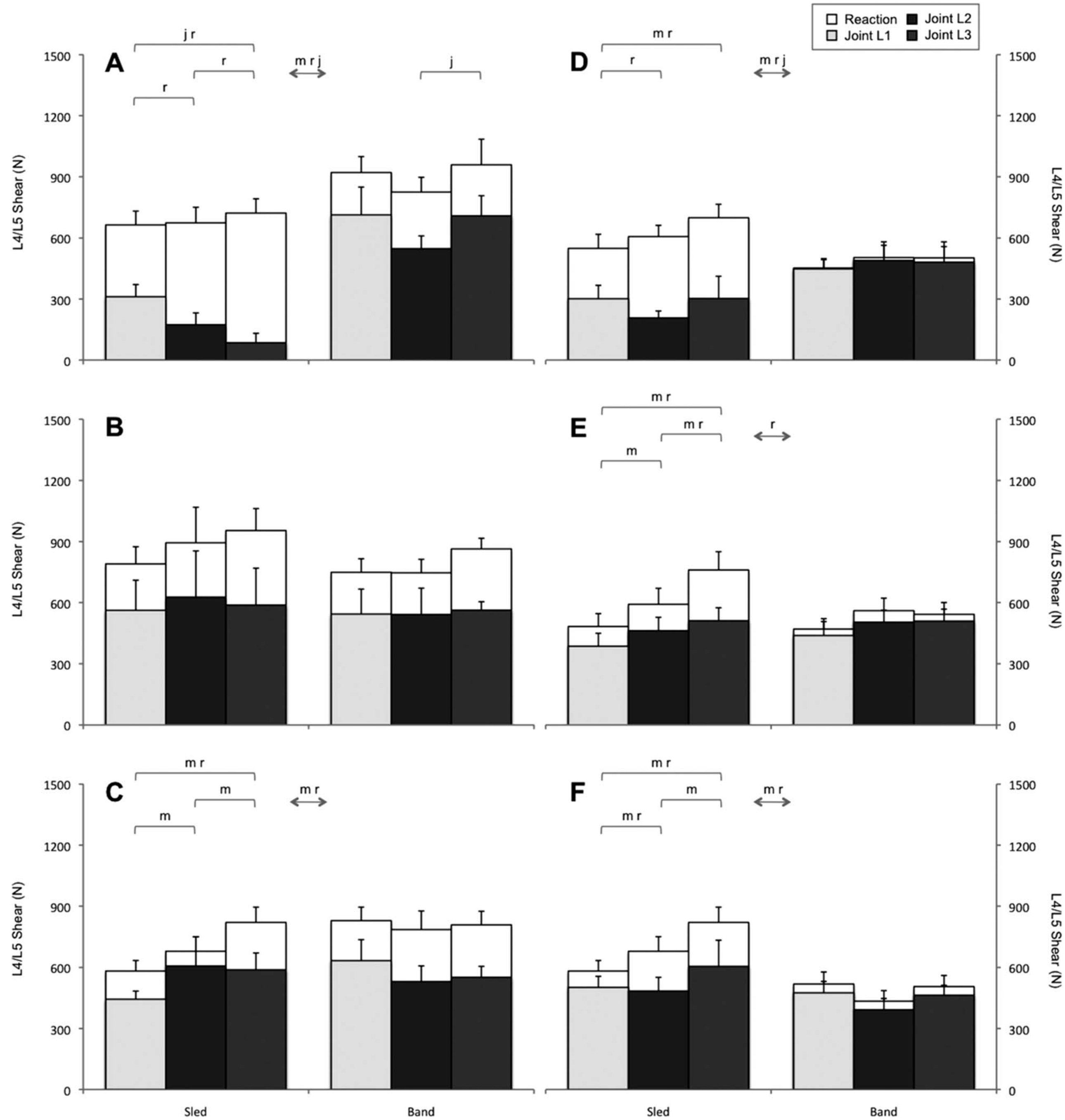

Figure 4. Peak muscle shear at L4/L5 is described by the sum of the shaded (joint shear) and white (reaction shear) sections of each column. Muscle and reaction shear are described as positive for illustrative purposes only: joint shear = reaction shear – muscle shear. Also displayed are the conditions: (A) forward, bent leg; (B) backward, bent leg; (C) lateral, bent leg; (D) forward, straight leg; (E) backward, straight leg; and (F) lateral, straight leg. Positive shear refers to the posterior direction. The sled loads and band tensions increase in magnitude from left to right (L1, L2, L3). Error bars represent standard error. Significant differences ($P < 0.05$) in reaction, muscle and joint shear are highlighted with an r, m and j, respectively. Between-load, within-condition differences are described between each condition and load, and main effects between the band and sled for a particular condition are highlighted above the arrow (⇔).

Increasing the sled load during the backward trials caused significant changes to joint compression (+37% from the light to heavy condition, $P < 0.001$), reaction compression (+30%, $P < 0.001$), muscle compression (+40%, $P < 0.001$), reaction shear (+157%, $P < 0.001$), and muscle shear (+57%, $P < 0.001$) with each subsequent weight (Figures 4E and 5B). Significant differences were also noted in left gluteus medius activity across the three sled loads; there was an increase of 70% ($P < 0.001$) between the light and heavy conditions. As observed with the

Table I. Peak (standard error) left and right gluteus medius (LGMD and RGMD) and maximus (LGMX and RGMX) for the forward, backward, and lateral conditions, with bent and straight legs.

		Forward				Backward				Lateral			
Muscle group	Load	Sled		Band		Sled		Band		Sled		Band	
Bent leg													
LGMD	1	63.3	(10.5)	83.6	(9.8)	55.6	(9.8)	75.1	(11.8)	95.5	(17.0)	121.0	(12.3)
	2	61.7	(6.6)	78.5	(15.0)	48.3	(6.7)	76.5	(8.8)	133.3	(18.6)[1]	131.3	(12.2)
	3	82.2	(15.0)	89.6	(9.6)	82.3	(14.1)[1,2]	88.7	(14.0)	103.8	(12.6)[2]	116.1	(10.9)
LGMX	1	55.9	(13.2)	61.1	(12.2)	42.5	(9.8)	35.6	(5.4)	80.2	(15.3)	94.4	(14.5)
	2	48.1	(4.3)	59.3	(13.3)	37.6	(7.1)	43.9	(7.5)	97.9	(9.6)	82.1	(12.5)
	3	52.4	(6.5)	70.0	(18.1)	55.3	(8.0)[2]	46.8	(7.7)	105.2	(10.2)[1]	65.3	(12.7)
RGMD	1	64.6	(12.2)	86.6	(15.7)	67.4	(14.9)	76.6	(12.4)	58.0	(7.6)	93.7	(8.5)
	2	59.3	(9.2)	82.8	(15.3)	66.9	(20.6)	90.2	(11.5)	58.4	(7.3)	106.0	(16.0)
	3	79.4	(12.5)	89.9	(11.7)	97.7	(32.7)	105.1	(15.4)	51.6	(6.9)	116.5	(14.7)
RGMX	1	65.2	(10.5)	68.7	(11.7)	44.4	(10.4)	41.1	(5.5)	27.3	(5.1)	46.5	(6.5)
	2	54.0	(9.0)	66.5	(14.8)	52.8	(14.1)	34.0	(5.5)	41.6	(8.7)	57.4	(9.8)
	3	64.0	(9.7)	65.6	(14.0)	80.4	(19.1)[1]	52.3	(9.2)	32.8	(5.2)	69.7	(12.8)[1]
Straight leg													
LGMD	1	55.0	(7.9)	58.6	(8.3)	42.6	(8.8)	39.0	(6.4)	65.2	(11.2)	75.3	(10.4)
	2	54.1	(9.7)	63.3	(11.5)	67.7	(8.9)[1]	53.0	(6.6)	88.2	(14.1)[1]	78.2	(9.7)
	3	74.1	(15.9)	62.3	(7.9)	73.3	(14.6)[1]	46.9	(6.7)	106.5	(19.4)[1,2]	88.8	(8.9)
LGMX	1	49.7	(11.5)	45.3	(11.7)	31.0	(7.4)	44.7	(18.7)	39.3	(6.8)	22.6	(2.5)
	2	47.1	(7.3)	46.2	(12.6)	41.9	(7.9)	43.6	(15.0)	67.6	(10.6)[1]	22.4	(4.0)
	3	51.7	(8.0)	52.0	(14.8)	42.5	(5.2)	47.2	(18.8)	91.1	(15.5)[1,2]	33.8	(4.0)
RGMD	1	56.9	(10.5)	61.6	(12.1)	47.9	(7.9)	44.1	(7.8)	31.3	(2.6)	65.9	(11.4)
	2	67.4	(13.5)	63.4	(12.7)	64.6	(11.7)	53.6	(8.5)	37.8	(4.2)	61.7	(7.1)
	3	79.2	(16.0)	62.9	(9.0)	77.2	(14.9)	54.1	(7.0)	40.6	(5.0)	80.0	(7.4)[2]
RGMX	1	48.3	(10.7)	60.0	(17.6)	50.5	(13.5)	39.6	(15.7)	13.6	(1.4)	20.3	(3.9)
	2	43.5	(5.5)	61.3	(19.9)	46.7	(10.1)	38.9	(11.9)	18.6	(4.7)	17.9	(2.1)
	3	63.2	(9.1)	55.4	(15.2)	63.3	(13.2)	50.5	(14.3)	26.5	(4.8)[1]	26.1	(2.6)

[1]Significantly different from sled load/band tension 1.
[2]Significantly different from sled load/band tension 2.
Note: The three sled loads and band tensions are described Load 1 (low), 2, and 3 (high).

forward trials, there were no significant changes in any dependent measure when the band tension was increased (Figures 4E and 5B). Significant main effects were found between the sled and band conditions for reaction compression and shear only, with the sled values higher.

Like the forward and backward trials, there were no significant differences between the three band tensions for any dependent measure when participants walked laterally (Figures 4F and 5C). In contrast, the heaviest sled load was found to significantly increase joint compression (39%, $P < 0.001$), muscle compression (37%, $P < 0.001$), reaction shear (169%, $P = 0.005$), and muscle shear (41%, $P < 0.001$) compared with the light condition. A significant load-response was also seen in left gluteus medius, left gluteus maximus, and right gluteus maximus (+63%, $P < 0.001$; 133%, $P < 0.001$; 86%, $P = 0.003$, respectively) between the light and heavy loads. Significant main effects were observed between the sled and band conditions for joint and muscle compression, reaction and muscle shear, left gluteus maximus activity and right gluteus medius activity; with the exception of the right gluteus medius activity, each variable was higher during the sled conditions.

Discussion

Before using any novel training modality to challenge the hip musculature, the perceived benefits should be weighed against the potential "costs" to neighbouring segments and joints. Hip muscle function can be improved with a variety of exercises, but each also places demands on the rest of the body that should be acknowledged when deciding on the most appropriate means to elicit a specific training adaptation. It was hypothesized that using exercises that load the lower limbs (i.e. bands were placed around the ankles), rather than the trunk, would provide a spine sparing way to increase gluteal activation. Interestingly, however, the muscular

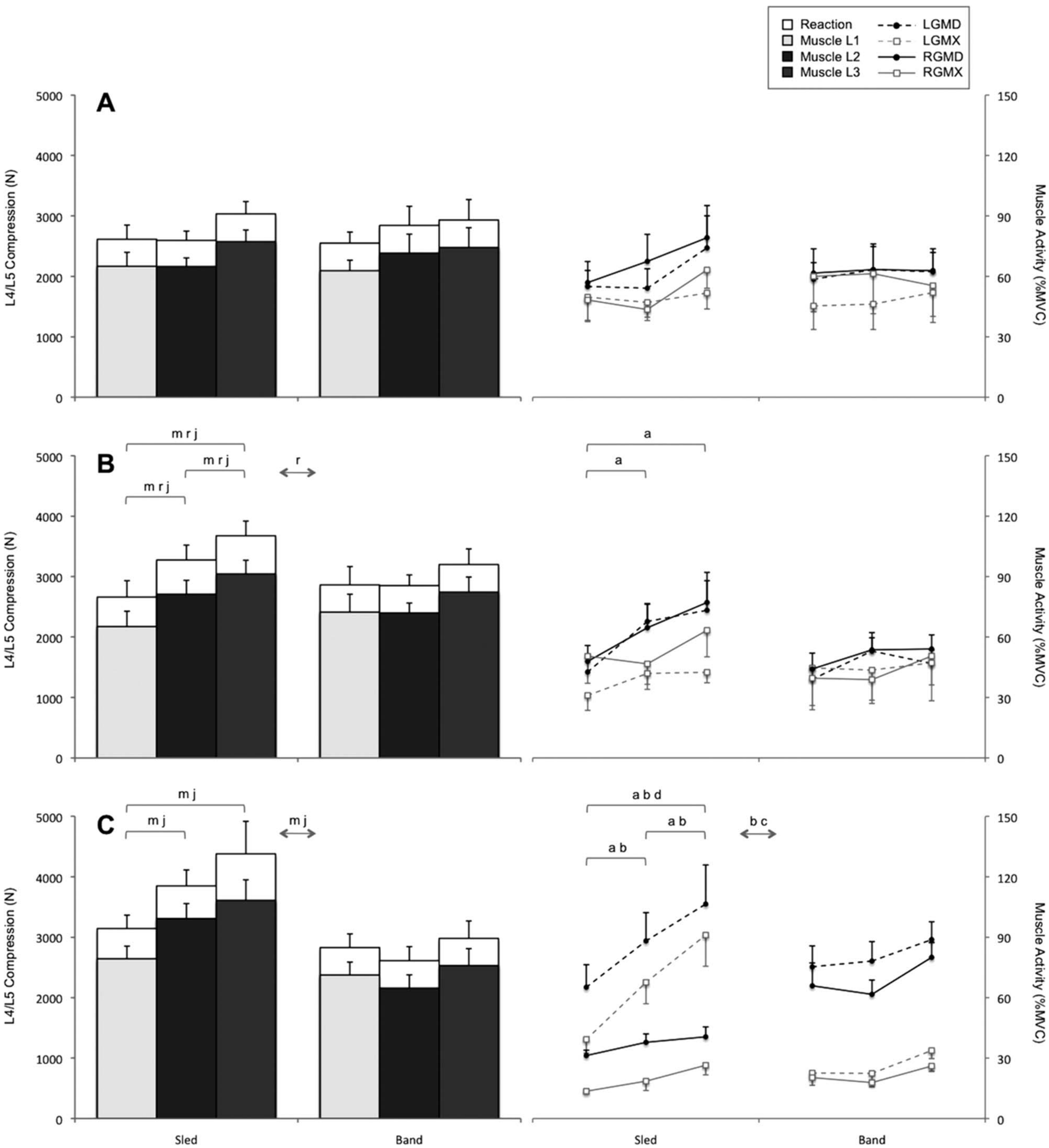

Figure 5. The straight leg trials. Peak joint compression at L4/L5 is described by the sum of the shaded (muscular force) and white (reaction force) sections of each column. Muscle compression is described as positive for illustrative purposes only; joint compression = reaction compression – muscle compression. Also displayed are the peak left and right gluteus medius (LGMD and RGMD) and maximus (LGMX and RGMX) for the (A) forward, (B) backward, and (C) lateral conditions. The sled loads and band tensions increase in magnitude from left to right (L1, L2, L3). Error bars represent standard error. Significant differences ($P < 0.05$) in reaction, muscle and joint shear are highlighted with an r, m and j, respectively. Between-load, within-condition differences are described between each condition and load, and main effects between the band and sled for a particular condition are highlighted above the arrow (⇔).

contribution to the lumbar spine L4/L5 joint compression and shear was much higher than that from the external load and, therefore, fewer differences were found between the two training modalities than originally anticipated.

Because pulling a sled requires that the external load be applied to the body through the hands, it was hypothesized that all sled conditions would be associated with an elevated trunk challenge, and therefore higher reaction, muscle and joint compression at

L4/L5. Significant differences were found between the band and sled conditions, but they were also direction and leg position specific. For example, reaction compression was higher during the sled versus the band conditions, when participants moved laterally with bent legs, but not straight. And when moving forwards the differences were limited to muscle and joint compression, but interestingly, it was the band conditions that were higher; reaction compression was unaffected by modality or load, suggesting that the weight of the sled had minimal impact on the external moment. In other words, the load must have been applied to the body in close proximity to L4/L5, thus decreasing its moment arm and thereby the challenge to the trunk musculature. Had the sled's handle been held away from the L4/L5 joint's axes, its moment arm would be larger and there would be an increase to the external moment and the trunk demands, which would likely also result in an increase to the muscle, reaction and joint compressive forces. Because the differences in reaction compression between sled trials were not of a magnitude that reflects the changes in sled load, body position (i.e. trunk lean) must have been the most influential factor. Consider the mechanics of pulling a sled forwards. As the weight is increased, participants must adopt a greater trunk lean to generate the horizontal ground reaction force required to move in a forward direction. Although such postural changes may not influence reaction compression, they will cause reaction shear to increase as a function of load. This is precisely what was seen during the forward sled trials (Figures 4A and 4D). A similar load-response in reaction shear was not seen when using the bands because the same postures were not required, but interestingly, joint shear was significantly higher than in the sled conditions, and with a bent leg posture so too was the shear force from muscle. Although not intuitive, these findings are a reflection of smaller differences between the posteriorly directed muscle shear and the anteriorly directed action shear when participants adopt a forward lean (Figure 2); both the highest reaction shear and lowest joint shear (joint = reaction – muscle) were observed during the heavy sled trials. When the bands were used, the action shear created by the upper body was much smaller than the posterior shear generated by the lumbar extensor muscles; hence the reason why performing forward band walks yielded higher joint shear compared with pulling the sled.

Compared with pulling a sled, placing bands around the ankles was hypothesized to offer a spine-sparing means to overload the hip musculature. Although not entirely supported by the findings, the conflicting evidence is primarily a reflection of the fact that the L4/L5 joint loads reported for the sled trials were lower than expected. The highest joint compression and shear forces found in any condition were 4378 N (lateral, straight leg) and 626 N (backwards, bent leg), respectively, which is similar to those of the bands (3306 N and 713 N, for compression and shear, respectively; both forward, bent leg), and within the range of values reported previously for other tasks and exercises, including: sitting, 1500–1800 N (McGill, Kavcic, & Harvey, 2006); walking, 1500–2000 N (Callaghan, Patla, & McGill, 1999); pushing and pulling cable resistance, 2200–3500 N (Lett & McGill, 2006); push-ups, 2500–3000 N (Beach, Howarth, & Callaghan, 2008); rowing movements, 2300–3600 N (Fenwick et al., 2009); and back extension exercise, 3000–4000 N (Callaghan, Gunning, & McGill, 1998). Furthermore, despite the fact that loads of up to 80% body weight were tested, the peak joint forces for the sled trials were below the maximum permissible limits (MPL) for compression (6376 N) established by the National Institute for Occupational Safety and Health (Waters, Putz-Anderson, & Garg, 1994), and shear (1000 N) by the University of Waterloo's Occupational Biomechanics group (McGill, Norman, Yingling, Wells, & Neumann, 1998). In fact, participants were arguably closest to a "worrying" load when walking forwards with bent legs using a band. Provided that the external load's moment arm is small, sled-towing exercises may not be as "costly" to the lower back as was originally thought. That said, the findings may have been different had the initiation of movement been captured (i.e. higher trunk muscle activity may be required to initiate movement) or had multiple sets and repetitions been performed (i.e. fatigue- or learning-induced changes in muscle activation patterns or posture could alter the calculated low-back loading response). There was a load-response for select variables, so careful consideration should be given before deciding on a particular sled-towing variation, but the same can be said for using the bands. The muscular contribution to joint compression and shear was substantially higher than that from the external load and the results were independent of band tension. That is, there was no load-response; similar joint compression and shear were observed across conditions. As a result, it is important for coaches and clinicians to clearly define their training objectives, particularly if working with individuals who have a history of lower back pain or injury, so the demands of the exercises being used do not exceed their clients' capacity to perform safely.

Given that links have been made between hip muscle weakness and frontal plane knee motion (Mascal, Landel, & Powers, 2003) and knee pain (Ireland, Willson, Ballantyne, & Davis, 2003), many practitioners will seek to increase gluteal activation using methods such as those examined here. But, the question of how much muscle activity is needed to control knee motion and alleviate pain needs to be considered. Should the training objective always be to graduate to a higher load or band tension? Although commonly assumed that more difficult equates to more muscle activity, the results from this study provide evidence to the contrary. Gluteal activation was unaffected by band tension and only the lateral, straight leg sled condition showed a consistent load-response; left side gluteus maximus and medius activity increased with each subsequent load. Both modalities challenged the hip musculature, which is evident in the magnitude of activity (up to 120% MVC), and the right side gluteals were more active during the lateral band conditions – which makes sense because they were not loaded when the sled was used – but aside from these observations there were no statistical differences between modalities or across loads. While whole-body movement patterns were not quantified in the present study, it is possible that the findings reflect the fact that participants compensated in response to the increased load/tension by changing the way they moved (perhaps a reflection of the fact that they had little prior experience with each specific training modality). Each participant was coached to limit the potential for movement variation, but they were also encouraged to complete each task. If for any number of reasons the demands of the exercise exceeded their ability to use a particular movement pattern, compensations will have been made. This highlights another important point – simply because an athlete/client performs the exercise does not imply that they will perform in such a manner that elicits the desired training adaptation. Therefore, if gluteal activation is being emphasized in hopes of preventing or rehabilitating injury or improving performance, the coaching provided will be equally or more important than the exercise itself.

Conclusion

The hip musculature has been shown to play a critical role in preventing or rehabilitating injury and improving performance. The results of the present study highlight the fact that the potential ''costs'' to neighbouring joints such as the lumbar spine should be considered before deciding the most appropriate training modality to achieve the desired adaptations. Although it was hypothesized that towing a sled would create a greater trunk challenge and thus higher spine loads, in general they were comparable to those found during the band walks. Interestingly, however, increasing the band tension had limited influence on all dependent measures tested, including gluteal activity. Therefore, before using any training modality or exercise, coaches and clinicians should clearly define their training objectives and seek to understand the benefits and limitations to ensure that their athletes/clients receive the best possible opportunity to improve their performance.

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