KETTLEBELL SWING, SNATCH, AND BOTTOMS-UP CARRY: BACK AND HIP MUSCLE ACTIVATION, MOTION, AND LOW BACK LOADS

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ABSTRACT

McGill, SM, and Marshall, LW. Kettlebell swing, snatch, and bottoms-up carry: Back and hip muscle activation, motion, and low back loads. *J Strength Cond Res* 26(1): 16–27, 2012—The intent of this study was to quantify spine loading during different kettlebell swings and carries. No previously published studies of tissue loads during kettlebell exercises could be found. Given the popularity of kettlebells, this study was designed to provide an insight into the resulting joint loads. Seven male subjects participated in this investigation. In addition, a single case study of the kettlebell swing was performed on an accomplished kettlebell master. Electromyography, ground reaction forces (GRFs), and 3D kinematic data were recorded during exercises using a 16-kg kettlebell. These variables were input into an anatomically detailed biomechanical model that used normalized muscle activation; GRF; and spine, hip, and knee motion to calculate spine compression and shear loads. It was found that kettlebell swings create a hip-hinge squat pattern characterized by rapid muscle activation-relaxation cycles of substantial magnitudes (~50% of a maximal voluntary contraction [MVC] for the low back extensors and 80% MVC for the gluteal muscles with a 16-kg kettlebell) resulting in about 3,200 N of low back compression. Abdominal muscular pulses together with the muscle bracing associated with carries create kettlebell-specific training opportunities. Some unique loading patterns discovered during the kettlebell swing included the posterior shear of the L4 vertebra on L5, which is opposite in polarity to a traditional lift. Thus, quantitative analysis provides an insight into why many individuals credit kettlebell swings with restoring and enhancing back health and function, although a few find that they irritate tissues.

KEY WORDS kettlebells, stability, muscle activation, core exercises, lumbar spine, snatch, swing, load carry

INTRODUCTION

Kettlebells have become a popular tool for resistance training. As far as we are aware, there are no studies that have quantified the mechanics and back loading during kettlebell exercises. Anecdotal remarks and perceptions from some very accomplished weightlifters, powerlifters, and other types of athletes range from that “kettlebell swings and snatches are therapeutic and enhance athleticism” to “I have no pain while lifting a bar but kettlebell swings are one thing that causes back discomfort.” Clearly, several patients with back pain attribute a component of their success to Kettlebell swings. For example, Brad Gillingham (World IPF Deadlift Champion) stated (personal communication, 2011): “I started incorporating Kettlebell swings into my training after suffering a back injury 2 years ago… After several frustrating rehabilitation attempts I incorporated kettlebell swings and was able to compete within a couple of months… Further I have found this movement to be beneficial in increasing my hip extension strength.” Currently, there is no quantitative data to help give context to such anecdotal remarks. This curiosity motivated this study to better understand the mechanics of kettlebell exercises, specifically the swing and swing to snatch, together with bottoms-up and racked-style carries, with the hope of assisting exercise prescription.

Only a few studies exist that have quantified the effects of kettlebell usage, and these have assessed physiological variables. For example Jay et al. (9) conducted a clinical trial on workers susceptible to pain and noted less pain after a kettlebell-based training regimen together with a higher torso extensor strength, although their aerobic fitness remained unchanged. In contrast, Farrar et al. (5) suggested that the metabolic challenges of kettlebell exercise could be sufficient to stimulate cardiovascular change. Obviously, the intensity and workload would matter greatly in this regard. Nonetheless, the dearth of studies on the biomechanical aspects of kettlebell usage and technique hinder the design of evidence-informed training programs in which kettlebells may be considered.

Occasionally, scientific hypotheses are generated to assess the scientific veracity and applied usefulness of “street wisdom” and urban myth. A popular kettlebell exercise is the

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swing, characterized by rapid acceleration of the kettlebell and what appears to be substantial knee and hip extension with full extensor muscle chain challenge. A progressive version is the swing performed with "kime." This form of the exercise is attributed to the martial artist Bruce Lee. This involves a brief muscular "pulsing" at the top of the swing in an attempt to train rapid muscle contraction-relaxation, which was the foundation for his "1 in. punch." Lee stated,

> "I relax until I bring every muscle of my body into play, and then concentrate all the force in my fist. To generate great power you must first totally relax and gather your strength, and then concentrate your mind and all your strength on hitting the target." (Lee as quoted in Lee and Little [10]).

More perspective on the unique technique is obtained from the martial artist and actor John Saxon, Lee's costar in the film "Enter the Dragon." Upon meeting Bruce Lee for the first time in Hong Kong and visiting the gymnasium, Saxon described the setup Lee had at his home:

> "… He had a whole gym setup… including kettlebells… One of the exercises he used them for was like a swing with a punch at the end of it. He'd hold the punch out for a few moments with the arm and the bell motionless before he lowered it." (as quoted in Hardstyle Magazine [8]).

Saxon himself is another athlete who credits kettlebells in restoring his strength and athleticism at age 71, in particular his lumbar spine and hips after hip replacement surgery (8).

Such anecdotes and subsequent propositions are interesting given the recent findings of McGill. (15) that documented the "double pulse" of muscle activity associated with the elite striking of accomplished Ultimate Fighting Championship (UFC) mixed martial arts athletes. Rapid contraction followed with equally rapid relaxation enhanced the closing velocity of the fist or foot to the target, followed by a final pulse to enhance "effective mass" upon the strike. Lee's much earlier qualitative insight into this later quantified mechanism, and the fact that he used a kettlebell, suggests that a better understanding of the mechanism of kettlebell usage may enhance athletic development.

Recent work by McGill et al. (12) reported the unique ability of asymmetric carries to train the quadratus lumborum and abdominal obliques that are essential for athletic challenge while being supported on 1 leg–the act of running and cutting is such an example. This ability is not trained by conventional lifting and pulling exercises performed in the weight room with both feet planted on the ground. This perspective motivated the quantification of some of the subjects performing bottoms-up and racked kettlebell carries in this study.

Given the several rationales, obtained from both quantitative study and qualitative observation, developed in the previous paragraphs, the intent of this study was to quantify spine loading during kettlebell swings, swings with Kime, swing to a snatch position, and bottoms-up and racked kettlebell carries. This information will help guide exercise program design. Specific questions investigated in this study were (a) "Is there a unique feature of the kettlebell swing low back loading that may be perceived as therapeutic by some yet causing discomfort in others?" (b) "What effects does the "Kime" performed at the top of the swing have on muscle activation and joint loading?" (c) "Do the bottoms-up or racked styles of kettlebell carries create a unique muscle activation profile for training?". It was hypothesized that there will be differences in muscle activity between the different forms of kettlebell exercise; that low back loading will be different between different forms of the kettlebell swing exercises; and finally that the bottoms-up carry will create different muscle activation profiles than the carry of the kettlebell in the racked position.

METHODS

Experimental Approach to the Problem

Seven participants practiced and then performed one armed swings, swings with Kime, and snatches with a 16-kg kettlebell (RCK model, Dragon Door Inc., Minneapolis, MN, USA). Torso muscle activation was recorded together with 3D body segment kinematics, and ground reaction forces, which were input to an anatomically detailed biomechanical model of the torso that determined spine loading. Five participants also carried the kettlebell racked on the backside of the forearm and in the bottoms-up style. The form of the exercise (swing, swing with kime, kettlebell carry racked, carry bottoms-up) formed the independent variables, whereas muscle activity, lower extremity joint angles, and spine load formed the dependent variables.

Subjects

For the swing and snatch portion of the study, 7 healthy male participants with an average age 25.6 years (*SD* 3.4), height 1.76 m (*SD* 0.06), and weight 82.8 kg (*SD* 12.1) were recruited from the University population forming a convenience sample. The participants were excluded from the study if they reported any previous or current low back pain or injury. They were found to be fit, and most had experience in training with a kettlebell. All the participants read and signed a consent form before data collection. This study was reviewed by, and received ethics clearance through, the University Office of Research Ethics.

Five healthy male participants with an average age 26 years (*SD* 3.8), height 1.75 m (*SD* 0.05), and weight 83.6 kg (*SD* 11.9) were assessed from the original pool of 7 subjects for the portion of the study that evaluated kettlebell carries.

A single case study was also performed on a recognized and accomplished kettlebell master, Russian Master of Sport: Pavel Tsatsouline (permission was obtained from Mr. Tsatsouline to mention his name and include a scientific description of his kettlebell use in this publication).

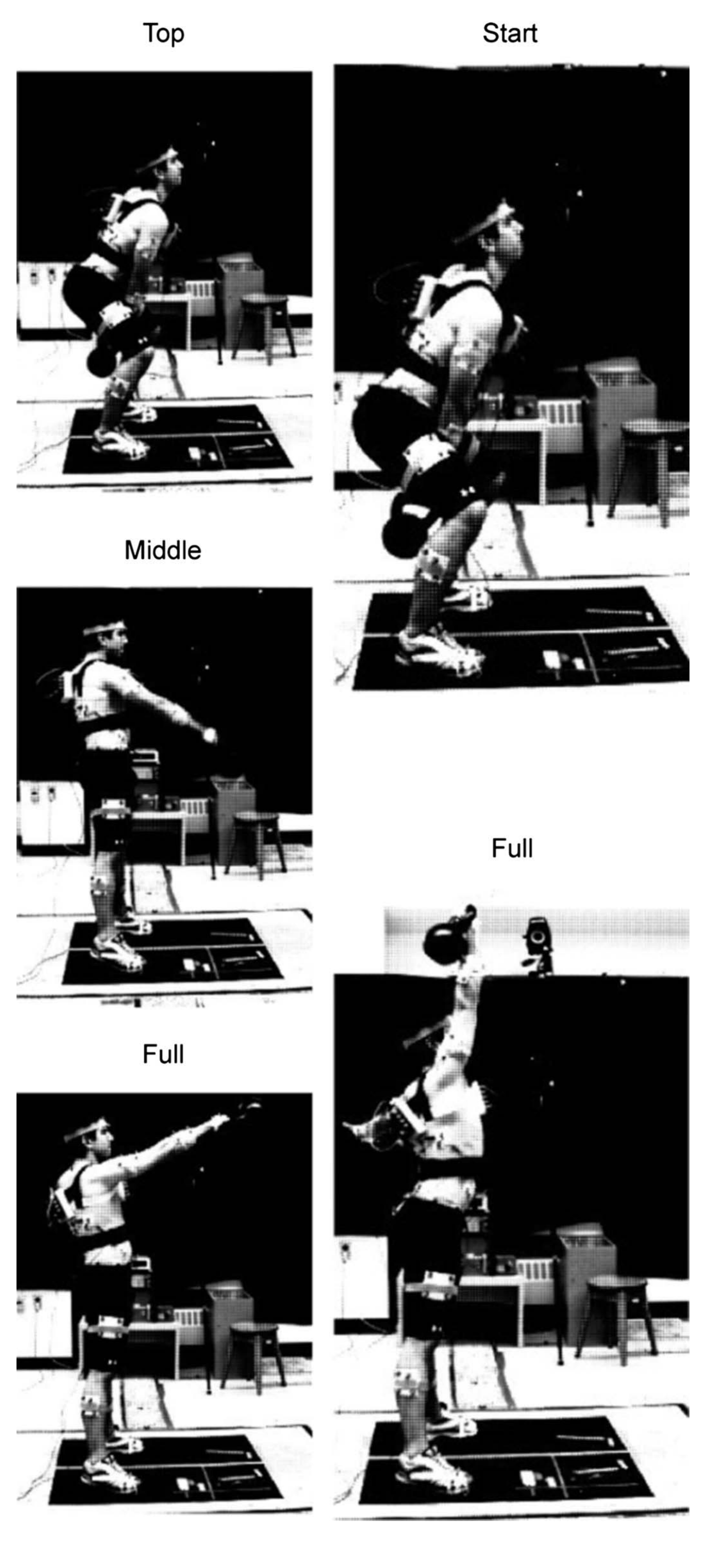


Figure 1. The swing (left) begins with the kettlebell in the right hand and with hip and knee extension is swung to a standing posture with the arm outstretched. ''Kime'' is added with a muscular pulse at the top of the swing with the intent of training rapid muscle activation and relaxation. The swing to snatch (right) begins in the same fashion as does the swing, but it finishes with the kettlebell snatched overhead.

Procedures

Exercise Description. Each participant was provided coaching from research personnel regarding the proper technique before collecting any of the kettlebell trials. Data were not collected until the participant had sufficient practice and felt comfortable performing the exercise and were able to complete the exercise using the proper technique. Each participant performed a kettlebell swing, kettlebell swing with Kime (abdominal pulse at the top of the swing), and kettlebell swing to snatch, and 5 of the 7 participants performed the kettlebell carrying trials (racked on the back of the arm and in the bottoms-up style). (Note: the 16-kg kettlebell [Dragon Door model] was chosen for its "heavy horn," which results in the thick handle and a balance point higher in the ball part of the bell.) The participants also walked without any weight in their hands for comparison purposes.

The kettlebell swing was initiated with the participant in a squat position with a neutral spine and the kettlebell in the right hand. The participant was cued to initiate the swing through the sagittal plane by simultaneously extending their hips, knees, and ankles and to use the momentum to swing the kettlebell to chest level and return to their initial starting position. The right elbow and wrist was to be kept straight during the entire swing. The kettlebell swing with Kime was performed in the same way as the kettlebell swing was with the addition of a "pulse-like" contraction of the abdominals when the kettlebell reached chest height (Figure 1). The kettlebell swing to snatch was initiated with the participant in a squat position with a neutral spine. The participants were cued to initiate the swing by simultaneously extending their hips, knees, and ankles and to use the momentum to swing the kettlebell into the snatch position with the right arm straight while supporting the kettlebell overhead. The snatch was held for approximately 2 seconds (Figure 1).

For the carrying portion of the study, the participants were instructed to walk carrying a kettlebell with their right hand in both the bottoms-up or racked position. When carrying the kettlebell in the bottoms-up position, the kettlebell was held vertically at approximately shoulder height with the elbow flexed and the wrist neutral (Figure 2). When carrying the kettlebell in the racked position, the kettlebell was positioned with the wrist neutral, the "horn" in the hand, and the "bell" resting on the forearm at approximately shoulder height with the fist close to the chin (Figure 3).

Instrumentation. Sixteen channels of electromyography (EMG) (AMT-8, Bortec Biomedical Ltd., Calgary, Alberta, Canada, with a common-mode rejection ratio of 115 dB at 60 Hz, and input impedance of 10 GΩ) were collected by placing electrode pairs over the following muscles: right and left rectus abdominis (RRA and LRA) lateral to the navel, right and left external obliques (REO and LEO) approximately 3 cm lateral to the linea semilunaris but at the same levels as the RRA and LRA electrodes, right and left internal oblique (RIO and RIO) medial to the linea semi lunaris and caudal to the REO and LEO electrodes and the anterior iliac spine but still cranial to the inguinal ligament, right and left latissimus dorsi (RLD and LLD) over the muscle belly when the arm was positioned in the shoulder midrange, right and left upper (thoracic) erector spinae (RUES and LUES) approximately 5 cm lateral to the T9 spinous process, right and left lumbar erector spinae (RLES and LLES) approximately 3 cm lateral to the L3 spinous process, right gluteus medius (RGMED) on the muscle belly found by placing the thumb on the anterior superior iliac spine and reaching with the fingertips around to the gluteus medius, right gluteus maximus (RGMAX) in the middle of the muscle belly approximately 6 cm lateral to the gluteal fold, right rectus femoris (RRF) approximately 15 cm caudal to the inguinal ligament, and right biceps femoris (RBF) over the muscle belly midway between the knee and hip. Before the electrodes were adhered to, the skin was shaved and cleansed with an abrasive skin prepping gel. Ag-AgCl surface electrode pairs (Blue Sensor, Ambu A/S, Denmark) were positioned with an interelectrode distance of approximately 2.5 cm and were oriented parallel to the muscle fibers. The EMG signal was amplified and converted from analog to digital with a 16-bit converter at a sample rate of 2,160 Hz.

Figure 2. Bottoms-up kettlebell carry.

Figure 3. Racked kettlebell carry.

Each participant performed a maximal contraction of each muscle for normalization. For the abdominal muscles (RRA, LRA, REO, LEO, RIO, and LIO), each participant adopted a sit-up posture at approximately 45° of hip flexion and was manually braced by a research assistant. The participant was instructed to produce a maximal isometric flexion moment followed sequentially by a right and left lateral bending moment and a right and left twisting moment. For the spine extensors (RLES, LLES, RUES, and LUES) and latissimus dorsi, a resisted maximal extension in the Biering-Sorensen position was performed for normalization. The latissimus dorsi was cued by instructing the participants to pull their shoulder blades back and down during extension. The RGMED normalizing contraction was performed with resisted side lying hip abduction combined with external rotation. The participants were instructed to lie on their left side with their knees and hips extended. The research assistant abducted the right hip approximately 45° with slight external rotation and restricted further movement as the participants performed isometric hip abduction. The RGMAX normalizing contraction was the higher activation from either the Biering-Sorensen position or during resisted hip extension. For resisted hip extension, the participants adopted a prone lying position with their right knee flexed to approximately 90°. The participant was instructed to extend at their hip while a research assistant restricted further movement. For the RRF normalizing contraction, each participant was in a seated position with the knee flexed to approximately 45° The research personnel restricted further movement while the participants performed an isometric knee extension. Normalizing contraction for the RBF was performed with the participants lying prone with their right knee flexed to approximately 45°. The participant was instructed to flex the knee while the researcher manually resisted the movement. The maximal amplitude observed during the normalizing contraction for a specific muscle was taken as the maximal muscle activation for that particular muscle.

The average normalized EMG for the walking trials from right toe off to just before right foot contact with the floor for the following muscles: RRA, LRA, REO, LEO, RIO, LIO, RGMED, RGMAX, RBF, RRF, RUES, LUES, RLES, LLES, RLD, and LLD were analyzed while the left foot was in contact with the force plate.

A 9-camera Vicon (v1.52) motion capture system (Vicon®, Centennial, CO, USA) tracked the 3-dimensional coordinates of reflective markers, adhered to the body, during the various trials at a sample rate of 60 Hz. Twenty-eight reflective markers were adhered to the skin with hypoallergenic tape over the following anatomical features to generate a full-body representation: right and left lateral ankle malleolus, right and left medial malleolus, right and left calcaneus, right and left medial femoral condyle, right and left lateral femoral condyle, right and left greater trochanter, right and left lateral iliac crests, right and left shoulder acromion, right and left medial elbow epicondyle, right and left lateral epicondyle, right and left radius styloid process, right and left ulnar styloid process, right and left ear lobe, C7 vertebra and sternum. Fifteen rigid bodies molded from splinting materials were adhered to the skin with hypoallergenic tape over the following segments: right and left feet, right and left shin, right and left thigh, sacrum, T12, head, right and left upper arm, right and left forearm and right and left hand. Four reflective markers were adhered with tape to each rigid body.

Two force plates (single element multicomponent dynamometer [MC3A-6-500], Advanced Mechanical Technology, Inc., Watertown, MA, USA), one under the right and left feet, collected 6 degrees of freedom of force and moment data that were sampled at a rate of 2,160 Hz. This was recorded and synchronized with the motion data through the Vicon system. For the kettlebell carries, the plates were staggered diagonally from one another such that the right foot landed on the first plate and the left foot landed on the second plate to preserve normal stride length.

Data Processing. The EMG data were band pass filtered between 20 and 500 Hz, full-wave rectified, low pass filtered with a second-order Butterworth filter at a cut-off frequency of 2.5 Hz to mimic the frequency response of torso muscle (2), normalized to the maximal voluntary contraction (MVC) of each muscle, and downsampled to 60 Hz using custom Labview software.

The modeling process to obtain estimates of muscle force and low back compression and shear forces was performed in 4 stages: (a) The 3-dimensional coordinates of the joint markers were input into a linked segment model of the arms, legs, and torso constructed with Visual3D (Standard v4.75.13). This software package output the body segment 3D kinematics together with the lumbar spine postures described as 3 angles (flexion/extension, lateral bend, and twist), bilateral hip angles and bilateral knee angles together with the reaction moments and forces about the L4–L5 joint. (b) The reaction forces from the link segment model described above were input into a second model, a "Lumbar Spine model" that consists of an anatomically detailed, 3-dimensional ribcage, pelvis/sacrum, and 5 intervening vertebrae (4). Over 100 laminae of muscle, together with passive tissues represented as a torsional lumped parameter stiffness element, were modeled about each axis. This model uses the measured 3D spine motion data and assigns the appropriate rotation to each of the lumbar vertebral segments (from values obtained by White and Panjabi [19]). Muscle lengths and velocities were determined from their motions and attachment points on the dynamic skeleton of which the motion is driven from the directly measured lumbar kinematics obtained from the subject. As well, the orientation of the vertebral segments along with stress-strain relationships of the passive tissues was used to calculate the restorative moment created by the spinal ligaments and discs. Some recent updates to the model include a much improved representation of the transverse abdominis, as documented by Grenier and McGill (6). Four fascicles of quadratus lumborum were added, which originated on the transverse processes of L5 to L2 and attached to the ribs (from Bogduk et al. [1]). The cross-sectional areas of multifidus and pars lumborum were adjusted so that the physiological area at each level closely approximated the previous findings from magnetic resonance imaging scans (from McGill et al. [16]). (c) The third model, termed the "distribution-moment model" (7,11), was used to calculate the muscle force and stiffness profiles for each of the muscles. The model uses the normalized EMG profile of each muscle along with the calculated values of muscle length and velocity of contraction to calculate the active muscle force and any passive contribution from the parallel elastic components. (d) When input to the spine model, these muscle forces are used to calculate a moment for each of the 18 degrees of freedom of the 6 lumbar intervertebral joints. The optimization routine assigns an individual gain value to each muscle force to create a moment about the intervertebral joint that matches those calculated by the link segment model to achieve mathematical validity (from Cholewicki and McGill [3]). The objective function for the optimization routine is to match the moments with a minimal amount of change to the EMG driven force profiles. The optimization routine has a dynamic lower limit based on current activation, set on the optimized force output of the muscle to prevent any muscle from completely turning off. The adjusted muscle force and stiffness profiles are then used in the calculations of L4–L5 compression and shear forces.

In addition to the modeling described above, the normalized EMG amplitude at the start, middle, and end points of the kettlebell swing and kettlebell swing with kime trials, and at the start and finish of the snatch, was reported for the following muscles: RRA, LRA, REO, LEO, RIO, LIO, RGMED, RGMAX, RBF, RRF, RUES, LUES, RLES, LLES, RLD, and LLD. Peak amplitudes were also tabulated together with when they occurred within the swing cycle as a percentage of the swing. Average activation for the same muscles was reported for the carrying tasks as the participant's left foot was in contact with the force plate.

Modeled muscle, joint and reaction compression, and shear forces about the L4–L5 joint and spine and bilateral hip and knee angles about the 3 axes of motion were also reported at the start, middle, and full swing of the kettlebell swing and kettlebell swing with kimi, and at the start and finish of the snatch of the kettlebell swing to snatch trials.

Statistical Analyses

The dependent variables of peak muscle activation, expressed as a percent of the MVC of each muscle and the average shear load of L4 on L5 and compressive spine loads at L4/L5 were calculated for the independent variables of kettlebell swing, swing with Kime, and swing to snatch exercises. Analyses of variance with repeated measures and *t*-test post hoc analysis with Bonferroni corrections were used to assess the hypotheses dealing with the effects of and differences between the different types of kettlebell exercises (swing, swing with Kime, and swing to snatch) on muscle activation and spine compression and shear loads at the L4/L5 level.

Paired *t*-tests assessed the differences in compression and shear loads between walking with a kettlebell in the racked and bottoms-up positions. Additional *t*-tests evaluated the differences in abdominal muscle activation between these 2 walking trials as well (note: $N = 3$; 2 subjects had difficulty hitting the force plates cleanly with their feet, and their data were not included. Only clean footfalls were included in the analysis).

RESULTS

Swings

Description. Of all the participants, lumbar spine motion (specifically L1 to the sacrum) ranged from 26° in flexion at

TABLE 1. Peak muscle activation of the back muscles, abdominal wall muscles, and right side gluteal and rectus femoris muscles together with the percentage of movement cycle where they occurred during kettlebell swings.*

	Swing				Swing with kime				Swing to snatch			
	Average peak muscle activation (%MVC)	*SD*	Percentage of peak movement	*SD* (%)	Average peak muscle activation (%MVC)	*SD*	Percentage of peak movement	*SD* (%)	Average peak muscle activation (%MVC)	*SD*	Percentage of peak movement	*SD* (%)
RLD	17.3	10.5	17	19	20.3	9.9	48	42	25.4	16.5	46	33
RUES	44.1	10.2	33	24	47.2	13.2	41	28	49.3	15.2	41	24
RLES	45.7	14.2	33	29	57.3	25.1	40	31	54.2	18.3	35	21
RGMAX	76.1	36.6	57	21	82.8	44.2	63	21	58.1	48.9	31	26
RBF	32.6	24.1	52	31	39.7	30.0	61	23	29.8	26.6	46	38
LLD	56.2	29.2	30	16	65.8	40.1	34	28	72.4	29.9	29	31
LUES	55.4	10.9	26	17	67.2	24.9	22	18	68.4	13.9	35	19
LLES	52.0	11.7	28	22	64.3	21.5	32	16	61.3	16.3	30	26
RRA	6.9	6.5	43	22	10.9	7.7	71	21	10.4	9.6	43	29
REO	16.5	12.9	53	20	32.3	18.7	83	16	24.7	13.6	38	19
RIO	42.4	42.5	59	16	49.3	30.3	75	21	53.6	41.2	40	26
RGMED	70.1	23.6	56	16	70.7	34.1	54	21	42.7	24.8	35	25
RRF	33.5	22.1	52	24	49.4	23.9	62	19	53.4	22.2	66	23
LRA	6.7	5.9	49	17	9.9	6.1	73	19	11.4	11.3	47	26
LEO	13.7	8.2	55	16	33.9	31.9	78	17	33.8	23.4	54	29
LIO	30.2	20.9	55	23	80.8	43.7	77	17	53.2	57.0	49	25

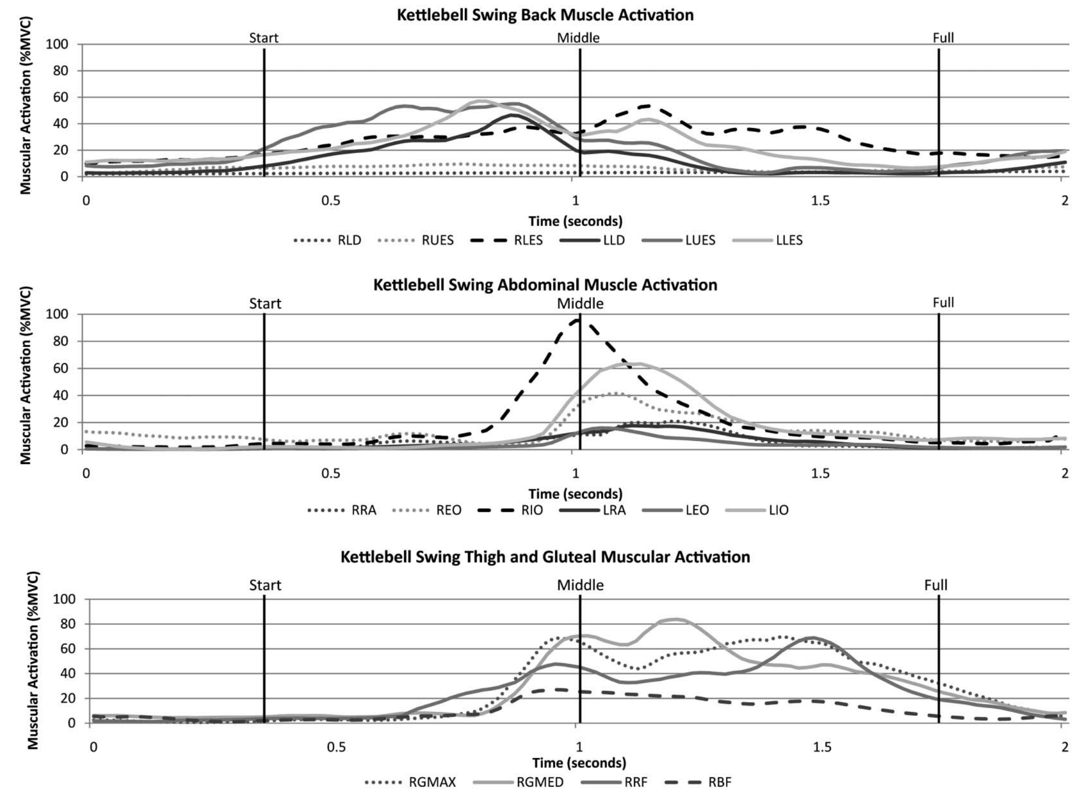
*RLD = right latissimus dorsi; RUES = right upper erector spinae; RLES = right lower erector spinae; RGMAX = right gluteus maximus; RBF = right biceps femoris; LLD = left latissimus dorsi; LUES = left upper erector spinae; LLES = left lower erector spinae; RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique; RGMED = right glutes medius; RRF = right rectus femoris; LRA = left rectus abdominis; LEO = left external oblique; LIO = left internal oblique; MVC = maximal voluntary contraction.

TABLE 2. Average compression and shear loads at the L4/L5 spine joint during kettlebell swings.*

		Compression (N)						Shear (N)					
		Swing		Swing with kime		Swing to snatch		Swing		Swing with kime		Swing to snatch	
		Average	*SD*	Average	*SD*	Average	*SD*	Average	*SD*	Average	*SD*	Average	*SD*
Point in swing	Start	3,195	995	2,983	768	2,992	981	461	172	410	147	404	165
	Middle	2,328	418	2,488	447			326	143	324	106		
	End	1,903	618	2,960	1,153	1,589	601	156	89	267	214	78	124

*The shear force represents the superior vertebra shearing posteriorly on the inferior vertebra.

the beginning of the swing to 6° of extension at the top of the swing. There was $<2°$ of lateral bend and only 4° of spine twist at the beginning of the swing. Hip motion ranged from 75° of flexion at the beginning of the swing to 1° of extension at the top, the knee from 69° of flexion to 2° of extension. The swing began with back muscle activation (just $<50\%$ MVC on the right side and just $>50\%$ on the left side), with peak activation around 30% into the swing. This was followed by abdominal ($<20\%$ MVC in the rectus abdominis and the external oblique and over 30% in the internal oblique) and then gluteal muscle activation peaks


Kettlebell Swing Back Muscle Activation

Kettlebell Swing Abdominal Muscle Activation

Kettlebell Swing Thigh and Gluteal Muscular Activation

Figure 4. A typical time history of muscle activation for the kettlebell swing for the following muscles: right latissimus dorsi (RLD), right upper erector spinae (RUES), right lower erector spinae (RLES), right gluteus maximus (RGMAX), right biceps femoris (RBF), left latissimus dorsi (LLD), left upper erector spinae (LUES), left lower erector spinae (LLES), right rectus abdominis (RRA), right external oblique (REO), right internal oblique (RIO), right glutes medius (RGMED), right rectus femoris (RRF), left rectus abdominis (LRA), left external oblique (LEO), and left internal oblique (LIO).

(Table 1). The leg muscles were primarily associated with knee extension, whereas the gluteal muscle activation later in the swing cycle was more closely associated with the culminating hip joint final extension. The gluteal muscles experienced the greatest activation level (76% of MVC) at 57% of the cycle. Spine loads were partitioned into compression and shear axes (Table 2). Both shear and compressive loads were the highest at the beginning of the swing (461 N of posterior shear of the superior vertebra of L4 on L5 and 3,195 N of compression). Compressive force dropped to 1,903 N at the top of the swing, whereas shear forces dropped to 156 N. A time history of the swing (Figure 4) demonstrates the ballistic nature of muscle activation, in particular the abdominal muscle pulse midway through the swing. Further, the effort is mostly concentric because gravity appears to assist most of the eccentric components of the swing.

The addition of "Kime" to the swing was an "abdominal event" with the largest increases in activation occurring in the external oblique muscles (101% increase in the REO and 140% increase in the left) toward the end of the swing cycle (~80% of the cycle) (Table 1). Spine, hip, and knee kinematics were similar to those of the swing without the Kime. Spine loading was also similar (Table 2), except at the top of the swing (see Statistical Analyses).

The swing to snatch appears to increase the activation of almost all muscles, probably because of the greater effort needed to propel the kettlebell up into the snatch position (Table 1). Spine compression and shear loads were similar at the beginning of the swing to snatch to the other 2 swings (Table 2). A typical time history (Figure 5) shows the sequencing of muscle pulses and the augmented abdominal activation associated with increased acceleration of the kettlebell into the snatch position. Spine, hip, and knee kinematics were also similar to those of the other 2 swings.

Muscle Activation. Swing exercise had a significant effect on only 3 muscles: REO ($F = 4.27, p < 0.05$), RRF ($F = 4.16, p < 0.05$), and LIO ($F = 5.45, p < 0.05$); however, Bonferroni *t*-test post hoc analyses revealed that there were no significant differences in the REO activation between the 3 kettlebell swing exercises. Post hoc *t*-tests with Bonferroni corrections showed that peak RRF and LIO activation was significantly greater during the swing with Kime compared with the swing without Kime ($p < 0.017$).

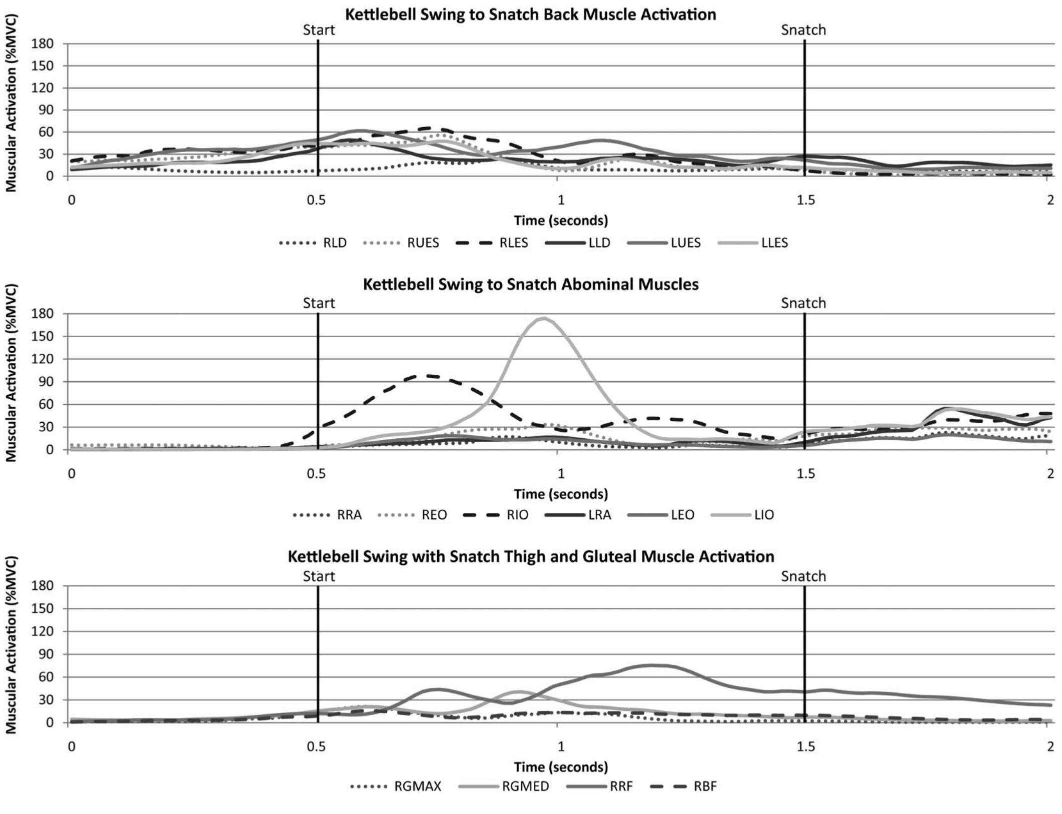


Figure 5. A typical time history of muscle activation for the kettlebell swing to snatch for the following muscles: right latissimus dorsi (RLD), right upper erector spinae (RUES), right lower erector spinae (RLES), right gluteus maximus (RGMAX), right biceps femoris (RBF), left latissimus dorsi (LLD), left upper erector spinae (LUES), left lower erector spinae (LLES), right rectus abdominis (RRA), right external oblique (REO), right internal oblique (RIO), right glutes medius (RGMED), right rectus femoris (RRF), left rectus abdominis (LRA), left external oblique (LEO), and left internal oblique (LIO).

Table 3. Average muscle activation of the back, abdominals, and right side gluteal and rectus femoris muscles while walking normally and with a kettlebell in 2 different positions.*

	Regular walking		Carrying kettlebell racked		Carrying kettlebell bottoms up	
	Average muscle activation (%MVC)	*SD*	Average muscle activation (%MVC)	*SD*	Average muscle activation (%MVC)	*SD*
RLD	1.3	1.1	3.1	2.5	10.0	2.1
RUES	1.5	1.5	7.5	3.7	13.8	11.3
RLES	1.6	1.0	4.5	2.7	9.1	4.1
RGMAX	0.2	0.1	0.3	0.1	0.6	0.3
RBF	0.7	0.3	1.6	0.7	2.3	0.4
LLD	0.3	0.1	7.2	1.4	12.1	2.8
LUES	0.2	0.2	7.9	7.4	10.6	8.9
LLES	1.0	0.5	7.6	1.7	15.2	7.5
RRA	0.3	0.2	1.1	0.9	2.0	1.6
REO	1.9	0.2	3.0	1.0	11.0	7.7
RIO	2.0	1.0	5.1	4.7	7.1	6.1
RGMED	0.5	0.2	1.2	0.7	2.6	1.8
RRF	0.4	0.3	1.3	1.5	2.3	2.7
LRA	0.4	0.1	1.3	0.7	1.8	1.2
LEO	1.1	0.3	5.6	3.3	5.0	2.1
LIO	3.0	0.2	8.4	5.1	13.1	8.0

*RLD = right latissimus dorsi; RUES = right upper erector spinae; RLES = right lower erector spinae; RGMAX = right gluteus maximus; RBF = right biceps femoris; LLD = left latissimus dorsi; LUES = left upper erector spinae; LLES = left lower erector spinae; RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique; RGMED = right glutes medius; RRF = right rectus femoris; LRA = left rectus abdominis; LEO = left external oblique; LIO = left internal oblique; MVC = maximal voluntary contraction.

Spine Loads. Spine compression magnitudes were quite conservative being <3,200 N in all styles. The beginning of the swing created very similar levels of compression regardless of style. There was a significant effect of kettlebell exercise ($F = 5.50, p < 0.01$) on spine compression at the L4/L5 level end of the swing: Spine compression increased from 1,903 N in the swing without Kime to 2,960 N in the swing with the Kime ($p = 0.07$) and was an average of 1,371 N greater in the swing with Kime compared with the swing to snatch ($p = 0.032$); however, these loads are probably not of clinical significance for the spine. The type of swing influenced the magnitude of shear load at L4/L5 ($F = 5.26, p < 0.05$), and in particular, there was a greater shear load in the swing (267 N) with Kime compared with the swing to snatch (78 N) ($p < 0.017$). Note that the shear was of the superior vertebra on the inferior one in the posterior direction. Thus, less shear would be considered better.

Kettlebell Carries

Description. Spine, hip, and knee kinematics were similar for carrying a kettlebell in both the racked and bottoms-up positions as regular walking.

Muscle Activation. Torso and hip muscle activation was very low for all carries (Table 3). There is probably no biological significance of individual muscle activity at these levels. However, the sum of the muscle activities will probably be important in terms of total load on the spine and in terms of spine stiffness (not quantified in this study). Even so, all muscles except the LEO increased their activation with the bottoms-up carry.

Spine Loads. Both carrying methods had greater muscle activation than did normal walking. The magnitude of differences in muscle activation varied from 0.1% MVC (between the racked and normal walking trials) to 14.3% MVC (between the bottoms-up and normal walking trials) (Figure 6A–C). Joint compression and shear load were also significantly greater in the bottoms-up position compared with that in the racked position ($t = 8.7, p < 0.05$; $t = 19.1, p < 0.01$, respectively).

Case Study

The swing of a Russian kettlebell master (Pavel Tsatsouline) was also assessed to form a case study. He swung a 32-kg kettlebell (~70 lb) with one hand (right hand) and then held the bell in 2 hands for the swing. Interestingly, he produced 150% MVC (note that this was a statically determined MVC and dynamic contraction often exceeds static maximal values) in his left erector spine and 100% in his left gluteal muscles. His technique to powerfully stiffen the hip at the top of the swing is evident in the spine motion traces. This is a technique to prepare for additional load and "Superstiffness" (from McGill [15]); however, this technique would not be

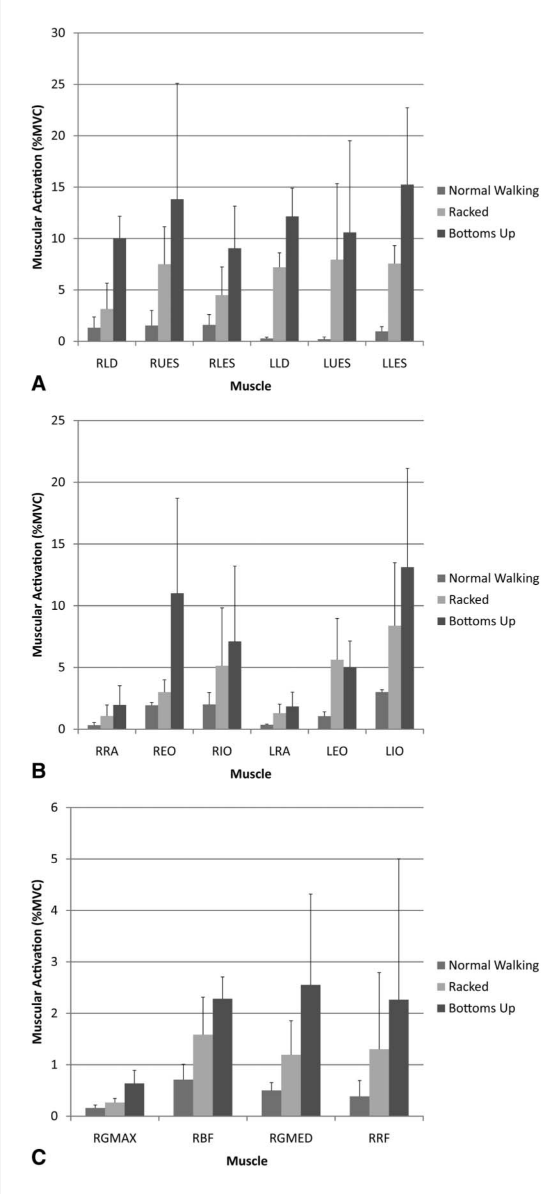


Figure 6. A) Back muscle (right latissimus dorsi [RLD], right upper erector spinae [RUES], right lower erector spinae [RLES], left latissimus dorsi [LLD], left upper erector spinae [LUES], left lower erector spinae [LLES]) activation during normal walking and 2 different types of kettlebell carries. B) Abdominal muscle ([RRA], right external oblique [REO], right internal oblique [RIO], right glutes medius [RGMED], right rectus femoris [RRF], left rectus abdominis [LRA], left external oblique [LEO], left internal oblique [LIO]) activation during normal walking and 2 different types of kettlebell carries. C) Leg muscle (right gluteus maximus [RGMAX], right biceps femoris [RBF], right glutes medius [RGMED], right rectus femoris [RRF]) activation during normal walking and 2 different types of kettlebell carries.

recommended to those with back concerns or have training objectives that do not include superstiffness given the extremely rapid spine motion. The 2 handed swing created more symmetry between sides in back and hip muscle activation together with lower magnitudes than the dominant side during the single arm swing.

Discussion

The intent of this study was to quantify spine loading during kettlebell swings, swings with Kime, swing to a snatch position, and racked and bottoms-up kettlebell carries. It is the first that the authors are aware of that quantified the mechanics in terms of muscle activation magnitude and joint loading. Specific questions investigated in this study were as follows: (a) "Is there a unique feature of the kettlebell swing low back loading that may be perceived as therapeutic by some yet causing discomfort in others?" (b) "What affect does the "Kime" performed at the top of the swing have on muscle activation and joint loading?" (c) "Does the bottoms-up or racked style of kettlebell carries create a unique muscle activation profile for training?". In answering the first question, the most important finding was the interplay between low back compression and shear forces that are not observed during low back extension dominant exercises such as lifting a bar, or squatting. The swing incorporates an inertial component to the kettlebell such that the centrifugal forces and the forces needed to accelerate the bell through its arc-like trajectory cause relatively high posterior shear forces in relation to the compressive forces. Compared with more traditional lifting tasks, such as lifting a bar during a deadlift, the ratio of compression to shear is quite different. Perhaps this is why a few powerlifters have no complaints lifting a bar but experience low-back discomfort during the kettlebell swing. Thus, kettlebell swings would appear to require sufficient spine stability in a shear mode to ensure that it is an exercise that is helpful rather than detrimental. From another perspective, nearly all people who develop painful back conditions have movement flaws. Perhaps the most common is to move the spine when it is under load. Repeated compression of the spine while it is bending is the mechanism that leads to eventual disc bulges although this is modulated by disc size, shape, the magnitude of accompanying compressive load, to name a few variables (a synopsis of this literature is found in McGill [14]). The spine can withstand high loads if it is postured close to its neutral curvature. The "corrected movement pattern" requires "hip hinging" to bend and lift. This is incorporated in kettlebell swings with good form–that being hip motion rather than spine motion. Clinicians and coaches may consider a progression starting with the "short-stop squat" movement pattern and evolving the progression to a kettlebell swing (14). The third question addresses the influence of carrying a kettlebell in the bottoms-up style. The bottoms-up carry appears to pose more challenges to the core musculature. This may be because of several reasons: First, stiffening the core appears to enhance grip strength (15) and grip strength is needed to prevent the bell from sliding in the hand back down to a racked position. Second, more control is needed to carry a bell in the bottoms-up position, and this is probably achieved with core stiffness. However, in the absence of directly measuring stiffness, greater activation in the core was observed and the resultant spine load appears to be quite conservative. Thus, all 3 hypotheses put forward in the Introduction were accepted. Specifically, there were differences in muscle activity between the different forms of kettlebell exercise; low-back loads were different between different forms of the kettlebell swing exercises and different from those of nonkettlebell exercises; and finally, the bottoms-up carry created different muscle activation profiles than did the carry of the kettlebell in the racked position.

There is no literature available on kettlebell use with which to compare the muscle activation and joint load results of this study. Nonetheless, the patterns of muscle activation of the swing must be considered for enhancing some specific training objectives. The rapid acceleration of the bell via the motion of the hips and knees is accompanied by substantial activation of muscles in both the posterior chain and the abdominals. The rapid contraction-relaxation cycles of some muscles occurring over half-second periods, specifically from inactive to 100% activation back to almost complete relaxation, have also been recognized by Jay et al. (9) as a mechanism for flushing muscle of metabolites. Interestingly, Jay et al. (9) also found pain reduction and incorporated kettlebell training 3 times per week over 8 weeks in a group of workers who performed demanding work. They proposed the muscle flushing mechanism as an explanation for the reports of lower pain. Further, studies conducted in elite mixed martial arts fighters showed the importance of rapid muscle activation and relaxation to enhance the speed and force of a strike or kick (15). Perhaps, the incorporation of "Kime" into Bruce Lee's training regimen was, in hindsight, insightful. Context for the spine loads during the swing can be obtained with comparison to a power clean of a bar from the floor. For example, lifting 27 kg on an Olympic bar with maximum speed from the floor created an extensor moment of 450 N·m and a compressive load of 7,000 N (this and loading from other tasks are compiled in McGill [14]). The compressive loads during the swings (16-kg kettlebell), which occurred at the bottom of the swing, were less than one-half of this amount. In terms of relative risk, these compressive loads are below the National Institute for Occupational Safety and Health (NIOSH) action limit (18), suggesting that the compressive load from swings will not be problematic. However, the shear forces on the lumbar joints are opposite in polarity to those created during lifting a bar. This polarity in shear force is rare such that there is no known guideline of risk. This implies that more load is imposed on the disc and the normal support provided by the facet joints in compression would not be available because they would actually be under tension (14). Tolerance of the individual to this, or any, type of loading would depend on injury history, fitness level, applied load, etc. Previously published studies on carrying have not addressed the issue from the perspective of conditioning training, although carrying is a task that uniquely addresses athleticism for walking, running, and carrying. Another study calculated the spine loads while carrying 10 and 20 kg in the way a suitcase is carried to be 1,300 and 1,970 N, respectively (12). It would appear that carrying the kettlebell racked is similar in terms of spine load to carrying a suitcase but clearly the bottoms-up requires more stiffening control to prevent the bell from turning in the hand and falling into the racked position. This extra stiffness and control result in more spine load. Nonetheless, this should be considered a unique training opportunity. Analysis of the "superyoke" strongman event by McGill et al. (13) suggested that lateral spine muscles such as the quadratus lumborum and the lateral abdominal wall play an important role in holding and stiffening the pelvis level to prevent the pelvis from bending toward the side of leg swing. This assists the hip abductors on the stance leg side in their role of creating a stable platform for the spine. In fact, without the assistance of these "core" lateral muscles, the superyoke task was not possible as the hips possessed insufficient strength (13). This critical role of core strength to enhance performance becomes magnified when running and cutting quickly because any spine bending associated with a drop in the pelvis on the swing leg side constitutes an "energy leak" through eccentric contraction of the support hip and torso muscles. In fact, those with a paralyzed quadratus lumborum are not able to walk (17). The bottom-up style appears to enhance this quality, although it is suspected that the benefit obtained using the load magnitude in this study is more in terms of coordination than in strength training, given the quite modest levels of activation magnitude.

Limitations for the interpretation of the data reported in this study include the uncontrolled variables of fitness that may have influenced the results. For example, the time of day, nutrition, hydration, sleep, etc. were not controlled nor were they surveyed. However, the test session did not induce substantial fatigue nor were the efforts considered to be maximal. For this reason, these factors were assumed to have minimal influence on the results. Interpretation of the data is also limited by the small sample size (even though the variance was small enough to achieve statistically significant results with $N = 3$ in the carrying portion); however, this data collection was difficult precluding a substantial number of subjects. First, it was difficult to get the subjects to achieve complete right foot placement on the force plate when carrying the loads. It was reported by the subjects that this was because of shorter steps that were required when carrying the kettlebell and the need to fixate their gaze ahead and on the level. The instrumentation was involved with many channels of torso, thigh, and hip EMG. Many markers covered to body to facilitate full 3D body kinematics reconstruction. Finally, the spine modeling performed in this study was extremely intensive and complex and is not conducive to assessing a large number of subjects. A large amount of data must be collected from each individual to recognize the many individual differences in the patterns of movement and muscle activation such that a single trial constitutes many hours of processing and analysis.

In summary, the kettlebell swing (regardless of style of swing or snatch) appears to create a hip-hinge squat movement pattern together with patterns of rapid muscle activation-relaxation cycles of quite substantial magnitudes. For this reason, this unique exercise may be very appropriate for some exercise programs emphasizing posterior chain power development about the hip. In contrast, the exercise also appears to result in unique compression and shear load ratios in the lumbar spine that may account for the irritation in some people's backs, who otherwise tolerate very heavy loads. Shear stability and tolerance to posterior shear loading would be a requirement to obtain the other benefits of kettlebell swing exercise painlessly. Thus, quantitative analysis provides an insight into why many individuals credit kettlebell swings with restoring and enhancing back health and function, although a few find that they irritate tissues.

PRACTICAL APPLICATIONS

The message for coaches is that the kettlebell offers several unique training opportunities, for example (a) the opportunity to train rapid muscle contraction-relaxation cycles emphasizing posterior chain power development about the hip. However, the large shear to compression load ratio on the lumbar spine created during swing exercises suggests that this training approach may be contraindicated for some individuals with spine shear load intolerance and (b) enhanced activation of the core musculature during the bottoms-up carry.

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REFERENCES

1. Bogduk, N, Macintosh, JE, and Pearcy, MJ. A universal model of the lumbar back muscles in the upright position. *Spine* 17: 897–913, 1992.
2. Brereton, LC and McGill, SM. Frequency response of spine extensors during rapid isometric contractions: Effects of muscle length and tension. *J Electromyogr Kinesiol* 8: 227–232, 1998.
3. Cholewicki, J and McGill, SM. EMG assisted optimization: A hybrid approach for estimating muscle forces in an indeterminate biomechanical model. *J Biomech* 27: 1287–1289, 1994.
4. Cholewicki, J and McGill, SM. Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. *Clin Biomech* 11: 1–15, 1996.
5. Farrar, RE, Mayhew, JL, and Koch, AJ. Oxygen cost of kettlebell swings. *J Strength Cond Res* 24: 1034–1036, 2010.
6. Grenier, SG and McGill, SM. Quantification of lumbar stability using two different abdominal activation strategies. *Arch Phys Med Rehabil* 88: 54–62, 2007.
7. Guccione, J, Motabarzadeh, I, and Zahalak, G. A distribution-moment model of deactivation in cardiac muscle. *J Biomech* 31: 1069–1073, 1998.
8. HardStyle goes Hollywood. in: *Hardstyle*. St. Paul, MN: Dragon Door Publications, 2008, pp. 40–43.
9. Jay, K, Frisch, D, Hansen, K, Zebis, MK, Andersen, CH, Mortensen, OS, and Andersen, LL. Kettlebell training for musculoskeletal health: A randomized controlled trial. *Scand J Work, Environ Health*, ahead of print, 2010.
10. Lee, B and Little, J. *The Art of Expressing the Human Body*. Boston, MA: Tuttle Publishing, 1998.
11. Ma, S and Zahalak, GI. A distribution-moment model of energetics in skeletal muscle. *J Biomech* 24: 22–35, 1991.
12. McGill, S and Marhsall, L. Low-back loads while walking and carrying, submitted.
13. McGill, S, McDermott, A, and Fenwick, C. Comparison of different strongman events: Trunk muscle activation and lumbar spine motion, load and stiffness. *J Strength Cond Res* 23: 1148–1161, 2008.
14. McGill, SM. *Low Back Disorders: Evidence-Based Prevention and Rehabilitation*. Champaign, IL: Human Kinetics, 2007.
15. McGill, SM. *Ultimate Back Fitness and Performance*. Waterloo, ON: Backfitpro Inc., 2009.
16. McGill, SM, Santaguida, L, and Stevens, J. Measurement of the trunk musculature from T6 to L5 using MRI scans of 15 young males corrected for muscle fibre orientation. *Clin Biomech* 8: 171–178, 1993.
17. Parry, W. Vicarious motions in therapeutic exercise. 4th edition, ed. *J Basmajian*. Baltimore, MD: Williams and Wilkins, 1984. p. 179–191.
18. Waters, TR, Putz-Anderson, V, Garg, A, and Fine, LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics* 36: 749–776, 1993.
19. White, A and Panjabi, M. The basic kinematics of the human spine. A review of past and current knowledge. *Spine* 3: 12–20, 1978.