Original Article

Physical Therapy Rehabilitation Science

https://doi.org/10.14474/ptrs.2024.13.1.53
eISSN 2287-7584
pISSN 2287-7576

Phys Ther Rehabil Sci
2024, 13(1), 53-70
www.jptrs.org

Comparison of Kinematics and Myoelectrical Activity during Deadlift, with and without Variable Banded Resistance, in Healthy, Trained Athletes

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Background: The conventional deadlift is a popular exercise for enhancing trunk, core, and lower extremity strength. However, its use in sports medicine is constrained by concerns of lumbar injuries, despite evidence supporting its safety and rehabilitative benefits. To optimize muscle activation using resistive bands in variable resistance therapy, we explored their feasibility in the deadlift.

Design: Comparative experimental design

Methods: Surface electromyography recorded muscle activity in the trunk and lower extremities during lifting, with normalization to the isometric Floor Lift using Maximal Voluntary Contraction. Kinematics were measured using inclinometer sensors to track hip and trunk sagittal plane angles. To prevent fatigue, each subject only used one of the three pairs of bands employed in the study.

Results: Our study involved 45 healthy subjects (mean age: 30.4 ± 6.3 years) with similar baseline characteristics, except for years of lifting and strength-to-years-of-lifting ratio. Various resistance band groups exhibited significantly higher muscle activity than conventional deadlifts during different phases. The minimal resistance band group had notably higher muscle activity in the trunk, core, and lower extremity muscles, particularly in the end phase. The moderate resistance band group showed increased muscle activity in the mid-and end-phases. The maximum resistance band group demonstrated greater muscle activity in specific muscles during the early phase and overall higher activity in all trunk and lower extremity muscles in the mid and end phases of the deadlift ($p < 0.05$).

Conclusion: Our findings provide valuable insights into muscle activation with various resistance bands during deadlift exercise in clinical and gym settings. There appears to be a dose-response relationship between increased resistance bandwidth, external load, myoelectric activation, and range.

Key Words: Deadlift, Resistance, Elastic, Variable, Myoelectrical, Muscle, Kinematics

Introduction

Lifting objects from the floor is essential for daily functionality [1]. The deadlift is a compound exercise that involves extending the hips to lift an object from the ground to a standing position [2, 3]. It recruits the entire posterior chain musculature, benefiting strength, endurance, power, and various muscle groups [4-6]. The deadlift is a closed-chain, multi-joint exercise that enhances functional fitness and targets muscles from the head to the feet [1, 5, 7].

The deadlift, originally known as the "health lift",

Received: Jan 30, 2024 **Revised:** Jan 12, 2024 **Accepted:** Mar 13, 2024
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offers numerous health benefits across all twelve body systems (e.g., skeletal, muscular, endocrine, circulatory, respiratory, etc.) [8-15]. It increases bone density, preventing skeletal frailty. Concerns regarding spinal injuries during the conventional deadlift are primarily focused on lumbar shear and tensile forces, particularly in the bottom third of the lift [1, 16-19].

Trunk inclination or hip hinge during deadlift can occur within a range of lumbar spine positions, rather than a singular neutral posture [13, 20, 21]. Despite the emphasis on maintaining a neutral spine, athletes often experience spinal flexion during the deadlift without injury [13, 20, 22-24]. While moderate spinal flexion may offer performance benefits, the risks should be considered [20]. There is currently no prospective evidence linking spinal flexion during lifting to disabling low back pain [25, 26].

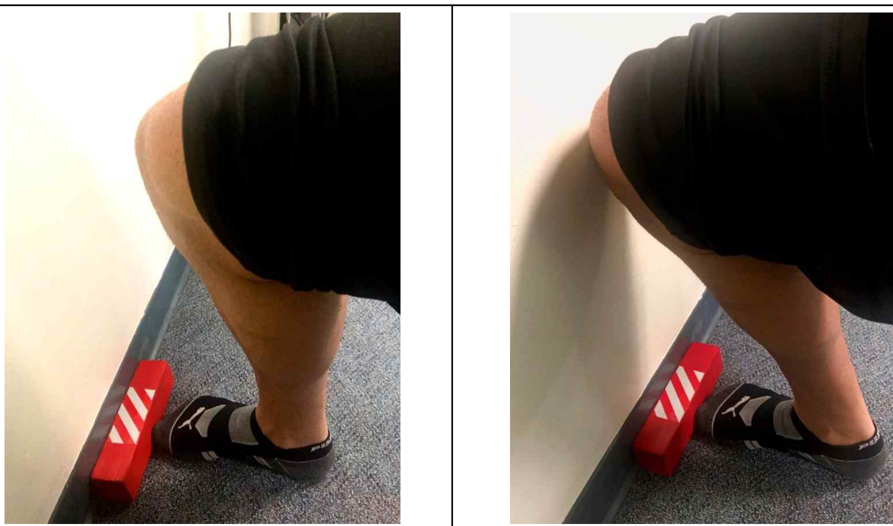
Anecdotal concerns exist regarding lifting heavy loads with potentially faulty techniques and a large range of motion. However, the evidence linking powerlifting (including deadlifts, squats, and bench press) to specific injuries is limited, based on single subject or case reports [27]. A systematic review found that the risk of injury in powerlifting and Olympic weightlifting was similar to other non-contact sports [23]. In summary, no exercise, including deadlifts, is inherently dangerous, but incorrect execution, inappropriate loading, or end-range postures may lead to harm or injury.

Deadlifts and their variations are gaining popularity for injury prevention and strengthening of the posterior chain, lower extremity, spinal, and core muscles [7, 28]. They have shown effectiveness in rehabilitating individuals with low back pain and post-operative rehabilitation [10, 29, 30]. An 8-week individualized barbell deadlift training demonstrated reductions in low back pain and improved strength [29]. Deadlifts provide an overtraining challenge for core musculature, unlike low-load core stabilization exercises [25]. Deadlifts have been effective in rehabilitating athletes with low back pain, particularly those with low pain and greater muscle strength [10].

Allowing lifting athletes to continue lifting, with modifications, during recovery from low back pain is appropriate based on recent findings. Critics argue against replacing functional whole-body lifting activities with isolated single-muscle exercises in the rehabilitation [25]. Best practice now favors functional, whole-body exercises that involve multi-joint movement patterns over isolated exercises. Some even discourage the use of complex abdominal hollowing and bracing maneuvers during lifting [25].

Barbell exercises are essential for strengthening, providing a constant external load [31]. Elastic bands or chains can be added to barbell exercises to provide a variable resistance [15, 31, 32]. Elastic bands offer two primary methods of generating variable resistance during barbell deadlifts: resistive (anchored to the floor) or assistive (attached to the lifting rack) [32-34]. Elastic bands challenge the strength curve, enhancing force capacity throughout the range of motion. Banded resistance in the deadlift creates an ascending strength curve, increasing resistance as the barbell is lifted [34]. Heavy elastic bands have the potential to increase muscular strength and power [35]. While there is knowledge about muscle recruitment during the deadlift, less is known about muscle activation patterns during different ranges of motion and phases, as well as the effects of different band thicknesses or resistances [36].

Taking the above-mentioned findings into account, the primary aim of this study was to determine if the addition of resistive bands could be utilized to allow the load to be lower at the start of the deadlift when the trunk is perhaps more vulnerable to shear forces due in part to the forward trunk inclination while resistance progressively increases throughout the ascent of the deadlift where the spine is more erect. We hypothesized that banded deadlifts will likely progressively and inversely recruit greater myoelectric activation as forward trunk leaning decreases towards erect standing and legs extend (as compared to deadlifts without bands). We also hypothesized that the resistive bandwidth would affect myoelectric activation in different ranges of the deadlift ascent. A secondary aim of this study was to use our findings to make recommendations for injured athletes to utilize a dose-response band selection during variable resistance therapy added to the deadlift exercise in a potentially safer and less vulnerable range of motion.



Start: Toe touching 2“X2” block against wall	End: Patella to wall ≅ 35° of dorsiflexion
Note: This assessment was calibrated using individuals that wear U.S. size 10.0-13.0 shoes NB: The larger the foot size, the greater ankle mobility that is required to touch wall.	

Figure 1. Passive Ankle Dorsiflexion Test: A) start position. B) ending position.

Methods

Participants

Forty-five subjects (age range, 18～60 years) participated in this study, divided equally into three banded deadlift groups: Red (n = 15), Black (n = 15), and Purple (n = 15). Subject demographics by group assignment can be found in Table 1. Inclusion criteria required subjects to be trained weightlifters familiar with the deadlift exercise, able to lift their body weight, and have no history of leg or spine pain or injury within 3 months. Exclusion criteria included inadequate mobility for squat and deadlift positions, individuals weighing over 500 pounds (227 kg), and a known tape allergy. All subjects provided written informed consent approved by the Institutional Review Board of Loma Linda University.

Procedures

Mobility Screening

Functional lower extremity mobility was assessed through two functional movement screens: the Passive Ankle Dorsiflexion Test (Figure 1) and the Simulated Deadlift Test (Figure 2). Adequate ankle dorsiflexion was determined using a single-leg, half-kneeling lunge to ensure subjects had the necessary ankle mobility for lifting activities. Subjects were required to have a minimum of 35 degrees of passive ankle dorsiflexion. Additionally, subjects were screened for functional hip and knee joint mobility to assume the starting position of a standard deadlift. In the simulated deadlift test, subjects needed to reach a specific position with their hands and maintain a neutral lumbar spine.

Bottom of deadlift position

Figure 2. Simulated deadlift test

Functional Strength Screening/Testing Utilizing a Comparative Lifting Tasks

To verify that subjects could deadlift 100% of their body weight, each subject performed isometric testing for the legs and back musculature using a 500-pound (227 kg) rated Hydraulic LCD Push Pull Dynamometer by March 10 linked to a large lifting base designed by Baseline Evaluation Instruments, Fabrication Enterprises Inc. P.O. Box 1500, White Plains, New York 10602, USA. The dynamometer gauge digitally measured isometric leg and trunk strength while performing the Floor Lift with the handle 9-inches (23 cm) from the ground to simulate then starting position/set-up of the deadlift (Figure 3).

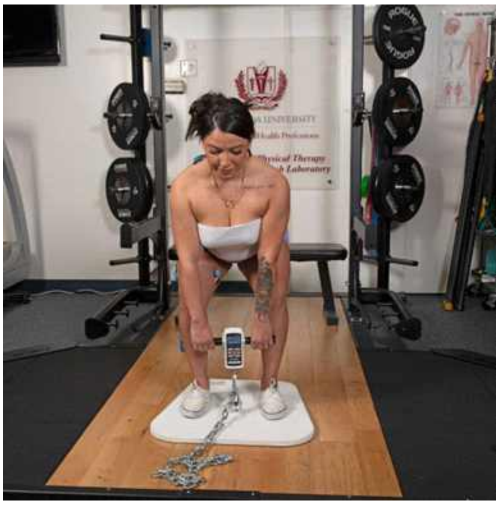


Figure 3. Functional isometric strength test: The Floor Lift

Kinematic Testing

2-Dimensional Inclinometer (2D-Inclinmeter). 2D inclinometer sensors ($4 \times 2.5 \times 1.4$ cm $\times$ 45.5) (Noraxon USA, Inc, Scottsdale, Arizona) were utilized to record hip and trunk angles in the sagittal plane during each deadlifting task. 2D inclinometer is an electromagnetic device, which measures the sensor tilt to the ground in two planes expressed in degrees [37, 38].

Warm-up Exercises

Each subject performed warm up activities, starting on a stationary ergometer for a two-minute warm-up. Next subjects performed 2 sets of 10-12 repetitions of air squats and Goblet squats using a low load (e.g., kettlebells, dumbbells, etc.). Lastly, each subject performed 3 sets of 1 repetition of two squatting activities loaded to body weight (i.e., barbell back squat, safety bar squat) prior to performing the deadlifting tasks.

Placement of the surface Electromyography(sEMG)

The subject’s skin was before electrode placement. A disposal surface electrode (dual, 2 mm diameter, 2 cm apart, Noraxon USA, Inc) was placed parallel to the muscle fibers in accordance with the SENIAM research group recommendations using double-sided tape to minimize movement artifacts during the testing [39]. For each subject, the same researcher placed all electrodes to ensure consistency. Lastly, to minimize the crosstalk effect, electrode placement was visually confirmed by viewing sEMG signals through isometric muscle contractions.

Surface Electromyography(sEMG) Testing

Surface Electromyography (sEMG) and Electrode Placement

An 8-channel MyoMuscle MR3.18 sEMG system (Noraxon USA, Inc, Scottsdale, Arizona) was used to record trunk and lower extremities muscle activity during each deadlifting task. sEMG signals was acquired at a sampling rate of 2000 Hz. The level of EMG activity of the following muscles, (on the dominant side) were recorded:

1. Rectus Abdominis (RA)
   a. 3 cm lateral to midline and 2 cm above the umbilicus [40]
2. External Obliques (EO)
   a. Just below the rib cage and along a line connecting the opposite pubic tubercle and the most inferior point of the costal margin [40, 41]
3. Gluteus Maximus (GMax)
   a. Midway between the S2 and the greater trochanter [42]
4. Lumbar Erector Spinae (LES) at L3 Level
   a. 4 cm lateral to L3 spinous process [42]
5. Lateral Hamstrings (LH)
   a. Mid muscle belly of the lateral hamstrings [43]

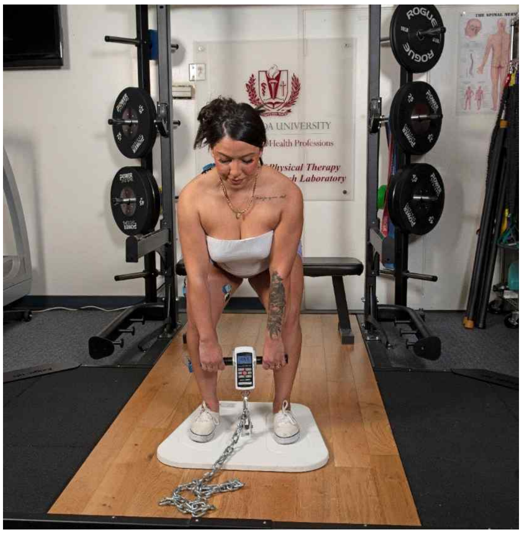


Figure 4. Normalizing lifting task – Floor Lift with sEMG sensors

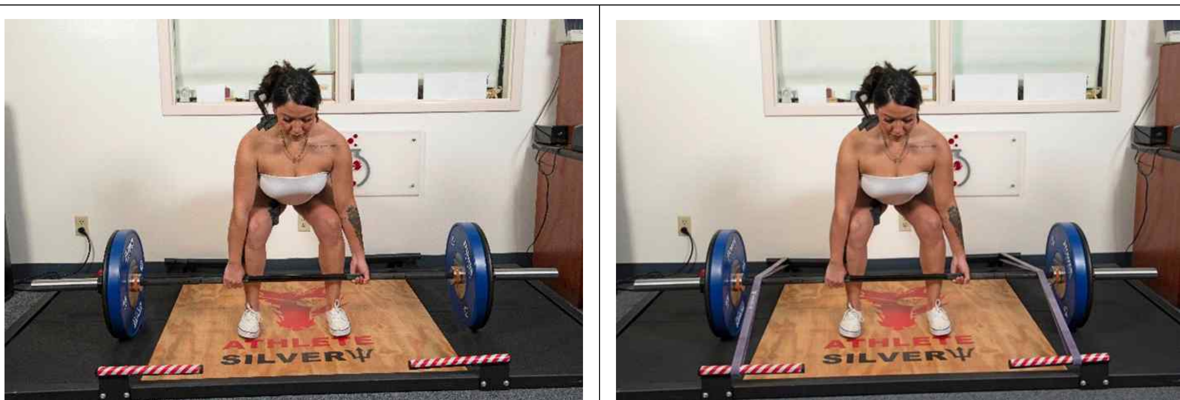
6. Vastus Lateralis (VL)
   a. Mid-muscle belly of vastus lateralis [43]
7. Latissimus Dorsi (LD)
   a. The most lateral portion of the muscle at T9 level [40]

Maximum Volitional Isometric Contraction(MVIC) Testing for EMG Normalization Procedure – Dynamic Lifting Task

We utilized a functional normalizing task, the Floor Lift, which is similar to the actual lifting activity being investigated as recommended by the literature [44]. Subjects were instructed to avoid explosive contraction, but rather to gradually build up their efforts to maximum during testing during the Floor Lift task. Each subject completed one practical MVIC trial to ensure proper performance followed by two 5-second trials for the Floor Lift task (Figure 4) while sEMG data was collected and recorded. A 2-minute rest interval was given between the two sets. The same examiner completed all measurements to ensure consistency. Consistent verbal cueing was given to help assure a 100% maximal effort by the subject for each of the 2 normalization trials [41, 42].

Deadlifting Tasks: Overview, Positioning and Performance Standards

After baseline functional mobility screening, strength testing, and warm up exercises, donning and calibration of sEMG electrodes and angle accelerometers, and normalization, subjects were asked to perform a single repetition of the barbell deadlift at 100% of their body weight (BW), with or without dual resistive bands. The order of the two variations of the deadlift and the level of banded resistance was randomized. Muscle activation and joint positions were monitored and recorded electronically as the subject performed each deadlift task for 3 sets of 1 repetition each. Subjects rested for a minimum of 2 minutes between each lifting set. Following warm up repetitions and



A. Deadlift at the bottom start-position of the deadlift without bands	B. Deadlift at the bottom start-position of the deadlift with bands

Figure 5. Deadlifts – A) Conventional barbell deadlifts without and with banded resistance: B) Deadlift at the bottom start-position of the deadlift with bands

Table 1. Description of the conventional deadlift movement & performance standards for this study

Exercise	Movement & Performance Standard Description
Deadlift	1. Set-up: The medial aspect of the subject's midfoot was positioned at hip width (ASIS distance) in a self-selected, customary leg external rotation position between 0-15 with the barbell over the midfoot (laces), approximately 1-inch (2.54-cm) from the front of the tibia and shoulders positioned just ahead of the barbell (scapula over the barbell). The subject grasped a loaded barbell, 9-inches from the floor, with both hands just outside of the legs. To achieve the bottom position of the deadlift, the movement starts with a hip hinge and enough knee bend (approximately 10-15°) necessary to reach the bar while still creating hamstring tension and maintaining a lumbar curve. To create this hamstring tension, the hips were positioned higher than the knees and the knees "pushed backwards" until the trunk/torso was inclined approximately 30-40° with the platform. This also resulted in the subject's body weight to be shifted into their heels. Throughout the hinge, shoulder and spine were aligned with the hips.
	2. Ascent/Upward Phase - A. Pull, B. Drive, C. Liftoff, and D. Pull Through the Knees. Pull: During the initial pull, the subject pushed their feet into the platform through their heels to initiate back muscles (back set), removing all slack out of the barbell and weight plate interface as well as their arms. Drive: During the initial drive the weights leave the floor (liftoff) while the spine remains long and in relative neutral. During the ascent, the spine retains midline stability with chest up as the bar path moves vertically and close to the body as the legs push the bar upward. NOTE: This relative vertical shin angle (70°-90°) prevented subjects from attempting to utilize the squat lift rather than the desired stoop lift. This 20° variability allows for different body morphologies. After the barbell reaches the knees (Pull Through the Knees), the hips were pushed forward until a full upright standing position was achieved. At all times during the pull, the bar must remain directly above the midfoot.
	3. Lockout at the Top: At the full upright standing position, the subject pushed the front of their hips into the barbell without extending their lumbar spine. At the top lockout position, the lumbar spine curve still maintained in tall standing with the hips slightly extended and knees fully extended.
	4. Descent/Lowering Phase: In this study, subjects were not allowed to drop the weight from the top lock out position but rather lowered the barbell eccentrically as the hips were re-hinged and after the barbell clears the knees (touches the tibial tubercles), the knees then began to re-bend. The subjects were instructed not to allow their tibias to incline forward until after the barbell past their knees to insure a straight bar path on the descent. Essentially, the lowering phase was the reverse of the ascending phase.
	Note: A rigid and upright torso in alignment with the neck and head was maintained with the barbell remaining close to the body throughout all phases or "stroke" of the deadlift [5].
Deadlift with Resistive Bands	Same as the conventional deadlift description above but using a pair of predetermined resistive bands anchored to band loops attached to the lifting platform provided additional progressive resistance through the ascending phase, maximizing at lockout.

barring equipment recording malfunctions, each subject only performed a maximum of 6 repetitions total during this single data collection session.

Deadlifts – Barbell Position and Hand Placement

Despite its simplicity and functionality, the actual deadlift must be performed properly to assure safety and efficiency. Set-up. For the deadlifting tasks, the subjects stood on a lifting platform wearing their typical lifting footwear with their feet directly under their hips. The subject grasped the barbell with their hands just outside of their knees/leg which is standard to conventional deadlifts. Subjects were allowed to self-select their preferred grip position on the barbell. Female subjects used a 35-pound (15-kg) barbell while males subjects used a 45-poundd (20-kg) barbell

Table 2. Mean resistance for each resistance band

	Red	Black	Purple	Red X 2*	Black X 2*	Purple X 2*
23cm	1.50(0.68)	4.14(1.86)	8.60(3.90)	3.00(1.36)	8.20(3.72)	17.21(7.80)
52cm	9.83(4.45)	18.51(8.39)	34.63(15.69)	19.63(8.89)	370.0 (16.78)	69.22(31.39)
80cm	20.23(9.16)	37.10(16.83)	66.29(30.07)	40.41(18.33)	74.20(33.66)	132.63(60.15)

- Units in pounds (kilograms)
- means averaged over 10-trials
- Calculated on a 172.71cm male
- * Values doubled since 2-bands were used

because of bar diameter size (grip size) unless requested otherwise. The deadlift tasks were performed on a 4-foot × 8-foot (122-cm × 244-cm) Titan Fitness Deadlift Platform. The subject was allowed to self-select their leg external rotation position (between 0-15°). Specific deadlift set-up and lifting standards are listed in Table 1.

Deadlifting Task with Resistive Bands

During deadlifting with resistive bands, in addition to the loaded barbell, additional resistive was provided from a pair of commercial stretch bands. The bands are each 41-inches in length made from natural latex rubber (Figure 5). Each color of band varies in thickness and resistance (Red (1.5-10-20 lbs.), 2) Black (4-19-37 lbs.), or 3) Purple (8.5-35-66 lbs.) per each of the dual bands). The three values for each band are representative of resistance, measure in pounds using a pull dynamometer previously described, as: 1) 9-inches from platform (set-up height), 2) mid-ascent pull, and 3) at the lock-out (top position) in a subject 68-inches in height. For each resistance band, we conducted 10-trials each at 23cm, 52cm, and 80cm, then averages were calculated (Table 2). Exact resistances varied by height of each subject. The ends of the two bands were anchored to band pegs located on both sides of the 4-foot × 8-foot Titan Fitness Deadlift Platform. The mid-portion of each band was crossed over the barbell. The band resistance was assigned in blocks (first 15 subjects = Red, next 15 subjects = Black, final 15 subjects = Purple).

Deadlift Movement Execution, Performance Standards & Safety Points

In a randomized order, subjects performed three (3) sets of one (1) repetition for each deadlift task (with and without dual bands) (Table 2). During the deadlift tasks, subjects momentarily paused (approximately 1-second) at the lock out position to assure proper barbell and body alignments were maintained. The deadlift began with a concentric phase (2-second temp ascent), isometric lock-out phase (1-second hold), and an eccentric phase (2-second descent). Subjects rested for a 2-minutes between each of the total of 6 repetitions. Three of the researchers have extensive lifting and movement coaching experience. One of these three examiners monitored and corrected moderate to major movement faults and lifting errors prior to and during the lifting tasks. Excluding warm up repetitions, screening tests, and lifting movement corrections, subjects performed a maximum of 6 repetitions during the single testing session. To assure proper lifting execution and performance standards (Table 1), two examiners observed the subject lift. Verbal cueing related to performance standards, movement errors, bar path, posture, and tempo were given as appropriate.

Data Processing

Kinematics. For the hip, a positive value indicates flexion while a negative value indicates extension. For the trunk angle, a positive value indicates flexion whereas a negative value indicates extension. The peak hip and trunk angles were identified and used for analysis. Hip and trunk angles were used for the purpose of dividing the ascent phase of the deadlift into three equal parts for sEMG analysis as recommended by Hale et al. [45]

sEMG Amplitudes. Before processing sEMG data, visual inspection was utilized to eliminate potential artifacts. Then all data was processed on Noraxon MR13.8 software, in which, the signals were processed at first order high-pass filters set at 10 Hz +/− 10% cutoff in the hardware prior to sampling. Then, a 350 Hz low-pass Butterworth filter was applied to the recorded signals and full-wave rectification [46]. The muscle amplitude values were normalized by using the myoelectric activation created during the maximum effort isometric Floor Lift lifting task to serve as the MVIC, expressed as a percentage (%), and used for the analysis.

Results

Statistical analysis

Data was summarized using mean and standard deviation (SD) for all quantitative variables and counts (%) for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk's test and Q-Q normality plots. A paired t-test was performed to examine the effect of the addition of resistive bands on muscle activity. The least significant difference was used for post-test to see if there would be any differences in the muscle activity between the lifting tasks. The level of significance was set at $p < 0.05$.

Sample size estimate

Power calculations using GPower 3.1 showed that for a power of 80% to detect a medium effect ($F = 0.25$, α-level = 0.05), a total sample of 34 subjects was predicted. For a power of 80% to detect a medium effect (Cohen $d = 0.5$, α-level = 0.05), a total sample of 34 subjects was required.

Data Analyses

Data was analyzed using the Statistical Package of Social Sciences (SPSS) version 28.0. Mean ± standard deviation (SD) was computed for continuous variables and frequency (%) for categorical variables. The normality of the quantitative variables was examined using Shapiro Wilk tests and normality plots. To compare the proportion of males by lifting group, Chi-square of independence was used. The baseline characteristics (age, body mass index (BMI), strength to weight ratio, and years of lifting) among the three study groups were compared using One Way analysis of variance (ANOVA). If the results were statistically significant, post hoc comparisons were done using Bonferroni test to determine which groups were significantly different. Since the distribution of Isometric floor lift and strength to years of lifting were

Table 3. Mean ± SD of baseline characteristics by study group (N = 45)

	Min R (n = 15)	Mod R (n = 15)	Max R (n = 15)	p-value (Effect size)
Male % (n)	40.0 (6)	86.7 (13)	73.3 (11)	0.02^(0.29)
Age, y	27.53 ± 2.47	29.07 ± 4.67	34.53 ±7.31	0.013†(0.23)
BMI (kg/m²)	23.70 ± 3.10	27.00 ± 5.41	25.52 ± 4.08	0.122*(0.09
Isometric Floor Lift (lbs.)	225.70 ± 65.64	290.14 ± 66.44	325.43 ± 78.14	0.002†(0.27)
Strength-to-Weight Ratio	1.53 ± 0.24	1.63 ± 0.23	1.71 ± 0.41	0.140*(0.09)
Years of Lifting	7.20 ± 3.99	7.03 ± 3.64	13.73 ± 8.31	0.004*(0.23)
Strength-to-Years of Lifting Ratio	46.01 ± 33.41	29.24 ± 17.02	63.42 ± 41.13	0.041†(0.16)

Abbreviation: SD, Standard Deviation; Min R, Minimal Resistance Band; Mod R, Moderate Resistance; Max R, Maximum Resistance Band; BMI, Body Mass Index
^Pearson Chi-Square
†Kruskal Wallis analysis of variance
*One way analysis of variance

not approximately normal, the mean of these outcomes was compared by study group using Kruskal Wallis ANOVA. Mean (SD) of muscle activation in RA, EO, LES, BF, VEO, LD, and GMax for each study group was compared to regular deadlift in early, mid, and end phases using Wilcoxon Signed rank test because the distribution of these variables was not normal. One way ANOVA was used to compare mean (SD) of total load (lbs.) by study group. Since the distribution of total load by body weight was not approximately normal, Kruskal Wallis ANOVA was conducted to compare mean of this variably by study group. If the results were statistically significant, the Mann-Whitney U test was used to determine if study groups were significantly different. The level of significance was set at $p \leq 0.05$.

Results

Forty-five subjects with a mean age of 30.38 ± 6.28 years and mean body mass index (BMI) of 25.41 ± 4.41 (kg/m^2) participated in this study. The baseline characteristics were not significantly different among the three study groups except for years of lifting and strength to years of lifting ($p > 0.05$, Table 3). There was a significant difference in mean number of years lifting among the three study groups ($F_{2,42} = 6.41$, $p = 0.004$; $\eta^2 = 0.23$). Subjects using the maximum resistance band had significantly more years of lifting than those using the moderate resistance and minimal resistance bands (13.73 ± 8.31 versus 7.03 ± 3.64 and 13.73 ± 8.31 versus 7.03 ± 3.99; $p = 0.010$ and $p = 0.012$, respectively). There was a significant difference in mean strength to years of lifting by study group ($H = 6.38$, $p = 0.041$). The mean strength to years of lifting was significantly higher in the maximum resistance band group than that in the moderate resistance group (63.42 ± 41.13 versus 29.24 ± 17.02, $p = 0.007$; Table 3).

Changes in mean ± standard deviation (SD) of muscle activation for each group compared to conventional deadlifts are displayed in Table 4. During the early phase, subjects in the minimal resistance band had significantly higher mean EO and LD activity (179.59 ± 119.20 versus 158.25 ± 91.41, $p = 0.047$; and 158.49 ± 113.72 versus 139.45 ± 95.90, $p = 0.006$). Those in the moderate resistance band had significantly higher mean VLO and LD activity (153.28 ± 36.54 versus 128.44 ± 40.51, $p = 0.020$; and 119.35 ± 40.61 versus 112.39 ± 44.89, $p = 0.012$). Those in the maximum resistance band had significantly higher mean EO, BF, VLO, LD, and Gmax activity (145.95 ± 82.99 versus 115.93 ± 108.97, $p = 0.023$; 216.36 ± 113.59 versus 191.22 ± 125.99, $p = 0.023$; 199.03 ± 25.67 versus 168.16 ± 45.64, $p = 0.041$; 163.28 ± 61.82 versus 135.56 ± 78.85, $p = 0.012$; and 201.84 ± 112.86 versus 151.65 ± 84.71, $p < 0.001$ respectively). During mid-phase, subjects in the minimal resistance band had significantly higher mean EO, LES, and BF activity (112.94 ± 84.60 versus 81.68 ± 47.10, $p = 0.006$; 154.94 ± 97.30 versus 125.74 ± 109.63, $p = 0.012$, and 215.74 ± 128.42 versus 179.92 ± 105.51, $p < 0.001$ respectively). Those in the moderate resistance band had significantly higher mean RA, BF, VLO, LD, and Gmax activity (132.13 ± 100.26 versus 112.10 ± 88.77, $p = 0.027$; 234.60 ± 61.28 versus 197.53 ± 75.87, $p = 0.006$, 95.52 ± 64.51 versus 73.34 ± 56.54, $p = 0.023$; 93.28 ± 61.65 versus 63.96 ± 49.93, $p = 0.009$, and 252.99 ± 192.37 versus 186.81 ± 134.46, $p = 0.017$; respectively). Subjects in the maximum resistance band had significantly higher mean in all trunk and lower extremity muscle activity (RA:115.10 ± 85.39 versus 86.01 ± 65.89, $p = 0.011$; EO:95.88 ± 55.50 versus 60.35 ± 58.89, $p = 0.006$; LES:148.52 ± 70.77 versus 115.26 ± 52.05, $p = 0.031$; BF:225.20 ± 116.49 versus 185.66 ± 140.17, $p = 0.008$; VLO: 124.13 ± 50.69 versus 92.28 ± 46.45, $p < 0.001$; LD: 168.12 ± 92.46 versus 74.71 ± 33.47, $p < 0.001$; and Gmax: 215.97 ± 144.40 versus 143.96 ± 11.82, $p < 0.001$ respectively).

During the end phase, subjects in the minimal resistance band had significantly higher mean RA, EO, BF, LD, and Gmax activity (123.76 ± 67.73 versus 116.44 ± 83.82, $p = 0.012$; 119.01 ± 88.40 versus 87.44 ± 49.00, $p = 0.009$, 167.46 ± 109.15 versus 141.22 ± 112.95, $p = 0.001$; 93.27 ± 86.67 versus 84.57 ± 110.35, $p = 0.020$, and 195.80 ± 106.76 versus 158.07 ± 120.45, $p = 0.006$, respectively; Table 4). Those in the moderate resistance band had significantly higher mean LES, BF, VLO, and Gmax activity (142.65 ± 89.35 versus 112.52 ± 97.79, $p = 0.011$, 206.54 ± 100.75 versus

Table 4. Mean ± SD of muscle activation for each group compared to conventional deadlift (N = 45)

Deadlift Phase	Muscle	RegularDL (n = 15)	Min R (n = 15)	Within Group Difference p-value† (r)	Regular DL (n = 15)	Mod R (n = 15)	Within Group Difference p-value† (r)	Regular DL (n = 15)	Max R (n = 15)	Within Group Difference p-value† (r)
Early Phase	RA	213.31± 182.54	156.00 ± 80.74	0.865 (0.04)	159.76± 118.75	134.24± 69.12	0.733 (0.09)	175.61± 194.30	165.91± 93.99	0.125 (0.40)
	EO	158.25± 91.41	179.59 ± 119.20	0.047 (0.25)	113.43± 63.89	111.09± 62.09	0.865 (0.04)	115.93± 108.97	145.95± 82.99	0.023 (0.59)
	LES	180.79± 124.00	192.60 ± 120.45	0.334 (0.64)	146.95± 79.06	136.87± 35.44	0.394 (0.22)	141.70± 68.74	170.32± 82.75	0.078 (0.45)
	BF	210.61± 118.35	216.73 ± 127.46	0.256 (0.51)	197.07± 57.44	219.17± 46.49	0.061 (0.48)	191.22± 125.99	216.36± 113.95	0.023 (0.59)
	VLO	170.90± 63.73	160.87 ± 58.33	0.100 (0.42)	128.44± 40.51	153.28± 36.54	0.020 (0.60)	168.16± 45.64	199.03± 25.67	0.041 (0.53)
	LD	139.45± 95.90	158.49 ± 113.72	0.006 (0.70)	112.39± 44.89	119.35± 40.61	0.012 (0.60)	135.56± 78.85	163.28± 61.82	0.012 (0.64)
	GMax	193.59± 87.35	194.82 ± 60.26	0.463 (0.19)	192.23± 115.06	204.58± 119.58	0.112 (0.41)	151.65± 84.71	201.84± 112.86	< 0.001 (0.85)
Mid Phase	RA	105.10± 65.17	113.51 ± 56.50	0.363 (0.23)	112.10± 88.77	132.13± 100.26	0.027 (0.57)	86.01 ± 65.89	115.10± 85.39	0.011 (0.66)
	EO	81.68 ± 47.10	112.94 ± 84.60	0.006 (0.70)	78.57± 73.72	90.47± 68.66	0.088 (0.44)	60.35± 58.89	95.88 ± 55.50	0.006 (0.70)
	LES	125.74± 109.63	154.94 ± 97.30	0.012 (0.64)	128.53± 88.26	125.04± 52.44	0.191 (0.34)	115.26± 52.05	148.52± 70.77	0.031 (0.56)
	BF	179.92± 105.51	215.74 ± 128.42	< 0.001 (0.88)	197.53± 75.87	234.60± 61.28	0.006 (0.70)	185.66± 140.17	255.20± 116.49	0.008 (0.69)
	VLO	91.63 ± 59.62	99.72 ± 70.20	0.776 (0.07)	73.34± 56.54	95.52± 64.51	0.023 (0.59)	92.28± 46.45	124.13± 50.69	< 0.001 (0.85)
	LD	111.74± 122.44	121.42± 78.50	0.088 (0.44)	63.96± 49.93	93.28± 61.65	0.009 (0.67)	74.71± 33.47	168.12± 92.46	< 0.001 (0.88)
	GMax	172.67± 60.71	184.24± 62.79	0.233 (0.31)	186.81± 134.46	252.99± 192.37	0.017 (0.61)	143.96± 111.82	215.97± 144.40	< 0.001 (0.88)
End Phase	RA	116.44± 83.82	123.76± 67.73	0.012 (0.65)	114.79± 72.45	120.84± 74.22	0.256 (0.29)	93.62 ± 72.85	125.72± 92.87	0.020 (0.60)
	EO	87.44± 49.00	119.01± 88.40	0.009 (0.67)	82.88± 59.24	95.98± 64.19	0.334 (0.25)	71.05± 73.82	95.08± 76.42	0.005 (0.73)
	LES	154.38± 207.56	146.70 ± 124.56	0.173 (0.35)	112.52± 97.79	142.65± 89.35	0.011 (0.66)	115.09± 85.11	150.17± 69.27	0.027 (0.57)
	BF	141.22± 111.95	167.46 ± 109.15	0.001 (0.83)	158.17± 87.17	206.54± 101.75	< 0.001 (0.87)	130.82± 90.89	219.84± 115.41	< 0.001 (0.88)
	VLO	85.73 ± 62.03	105.99 ± 86.22	0.053 (0.50)	81.33± 85.69	103.85± 85.89	0.005 (0.73)	93.03± 54.10	124.04± 55.08	0.005 (0.72)
	LD	84.57 ± 110.35	93.27 ± 86.67	0.020 (0.60)	44.89± 52.98	55.50± 45.20	0.125 (0.40)	58.42± 69.91	117.12± 60.70	0.001 (0.82)
	GMax	158.07± 120.45	195.80 ± 106.76	0.006 (0.70)	180.92± 119.86	245.71± 168.53	< 0.001 (0.88)	130.10± 143.29	205.15± 156.67	< 0.001 (0.88)

Abbreviation: SD, Standard Deviation; Min R, Minimal Resistance Band; Mod R, Moderate Resistance; Max R, Maximum Resistance Band; Regular DL, Regular Dead Lift
†Wilcoxon Signed Rank test

158.17 ± 87.17, $p < 0.001$; 103.85 ± 85.89 versus 81.33 ± 85.69, $p = 0.005$, and 245.71 ± 168.53 versus 180.92 ± 119.86, $p < 0.001$; respectively). Subjects in the maximum resistance band had significantly higher mean in all trunk and lower extremity muscle activity (RA:125.72 ± 92.87 versus 93.62 ± 72.85, $p = 0.020$; EO:95.08 ± 76.42 versus 71.05 ± 73.82, $p = 0.005$; LES:150.17 ± 69.27 versus 115.09 ± 25.11, $p = 0.027$;

BF:219.84 ± 115.41 versus 130.82 ± 90.89, $p < 0.001$; VLO: 124.04 ± 55.08 versus 93.03 ± 54.10, $p = 0.005$; LD: 117.12 ± 60.70 versus 58.42 ± 69.91, $p < 0.001$; and Gmax: 205.15 ± 156.67 versus 130.10 ± 143.29, $p < 0.001$; respectively) (Table 4).

Mean ± SD of total load (lbs.) by study group for early, mid, and end phases is shown in Table 5. There was a significant difference among the three study groups in the early, mid and end phases ($F_{2,42} = 6.96$, $p = 0.002$;$\eta^2 = 0.25$, $F_{2,42} = 11.45$, $p < 0.001$;$\eta^2 = 0.35$, and $F_{2,42} = 19.45$, $p < 0.001$;$\eta^2 = 0.49$, respectively). In the early phase, Bonferroni post hoc comparisons showed that subjects using the moderate resistance and maximum resistance bands had significantly higher total load than those using the minimal resistance band (186.27 ± 34.94 versus 145.57 ± 22.03 and 190.03 ± 47.14 versus 145.57 ± 22.03, $p = 0.005$ and $p = 0.011$, respectively). In the mid phase, subjects using the moderate resistance and maximum resistance bands had significantly higher total load than those using the minimal resistance band (212.27 ± 34.94 versus 153.87 ± 22.03 and 204.03 ± 47.14 versus 153.87 ± 22.03, $p = 0.001$ and $p < 0.001$, respectively). In the end phase, subjects using the moderate resistance and maximum resistance bands had significantly higher total load than those using the minimal resistance band (243.97 ± 34.94 versus 164.27 ± 22.03 and 222.63 ± 47.14 versus 164.27 ± 22.03, $p < 0.001$ and $p < 0.001$, respectively; Table 5).

There was a significant difference in ratio of total

Table 5. Mean ± SD of total load (lbs.) (body weight barbell + band resistance) by study group (N = 45)

	Min R (n = 15)	**Mod R (n = 15)**	**Max R (n = 15)**	**p-value* (η^2)**
Early Phase	145.57 ± 22.03	186.27 ± 34.94	190.03 ± 47.14	0.002 (0.25)
Mid Phase	153.87 ± 22.03	212.27 ± 34.94	204.03 ± 47.14	< 0.001 (0.35)
End Phase	164.27 ± 22.03	243.97 ± 34.94	222.63 ± 47.14	< 0.001 (0.88)

Abbreviation: SD, Standard Deviation; Min R, Minimal Resistance Band; Mod R, Moderate Resistance; Max R, Maximum Resistance Band; BMI, Body Mass Index
*One way analysis of variance

Table 6. Mean ± SD of total load (lbs.) divided by body weight (lbs.) by study group (N = 45)

	Min R (n = 15)	**Mod R (n = 15)**	**Max R (n = 15)**	**p-value † (r)**
Early Phase	1.01 ± 0.00	1.03 ± 0.01	1.05 ± 0.01	< 0.001 (0.88)
Mid Phase	1.07 ± 0.01	1.10 ± 0.02	1.20 ± 0.04	< 0.001 (0.82)
End Phase	1.14 ± 0.02	1.21 ± 0.05	1.39 ± 0.07	< 0.001 (0.80)

Abbreviation: SD, Standard Deviation; Min R, Minimal Resistance Band; Mod R, Moderate Resistance; Max R, Maximum Resistance Band; BMI, Body Mass Index
† Kruskal Wallis analysis of variance

Table 7. Mean ± SD of total load (lbs.) divided by maximum floor lift (lbs.) by study group (N = 45)

	Min R (n = 15)	**Mod R (n = 15)**	**Max R (n = 15)**	**p-value † (r)**
Early Phase	0.67 ± 0.12	0.60 ± 0.13	0.64 ± 0.10	0.221 (0.07)
Mid Phase	0.71 ± 0.13	0.65 ± 0.14	0.74 ± 0.11	0.097 (0.11)
End Phase	0.76 ± 0.14	0.71 ± 0.15	0.86 ± 0.13	0.015 (0.18)

Abbreviation: SD, Standard Deviation; Min R, Minimal Resistance Band; Mod R, Moderate Resistance; Max R, Maximum Resistance Band; BMI, Body Mass Index
† Kruskal Wallis analysis of variance

load by body weight to years of lifting among the three study groups for all phases ($p<0.001$; Table 6). In addition, we found a significant difference in mean total load (lbs.) divided by maximum floor lift (lbs.) by study group in the end phase (0.86 ± 0.13 versus 0.9 ± 0.1 versus 0.71 ± 0.15, $p=0.015$; Table 7). The mean load divided by maximum floor lift in the maximum resistance band was significantly higher than that in the moderate resistance band ($p=0.02$, Table 7).

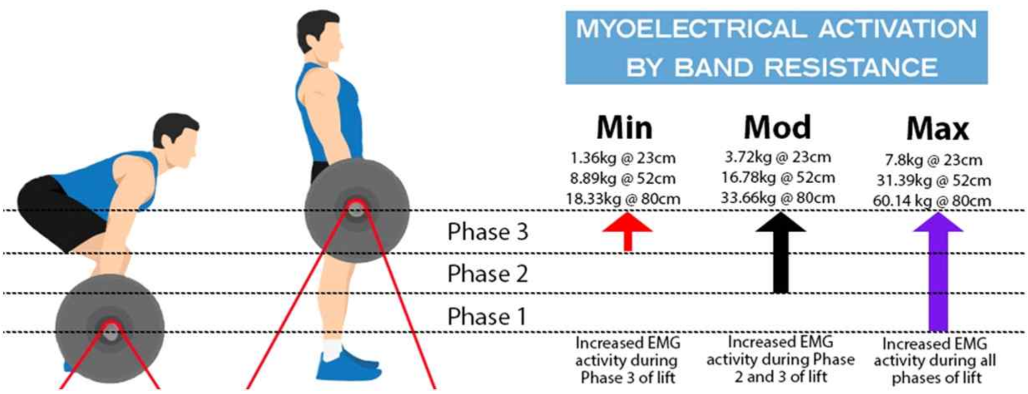
Discussion

The authors determined that the conventional deadlift is more closely aligned with the semi-squat lift than the stoop lift that more resembles the Romanian deadlift or even the stiff leg deadlift. The posture during a semi-squat technique is defined as a posture midway between the stoop and squat lifts which is further quantified as a position of 45° of trunk flexion and approximately 90° of knee flexion. The average knee flexion of the athletes in this study at the start position of the deadlift was 71°. Although the athletes in our study typically did not achieve the 90° of knee flexion, they utilized more knee flexion that commonly used in the more straight-legged stoop lift (<65° of knee flexion) [47]. The majority of physical therapists and other health care providers contend that the squat lift is the safest technique for gym or other functional lifting activities from the ground; however, many competitive or recreational athletes engage in lifts that require both the stoop and semi-squat lift [47]. We agree with the assertion of Washmuth and colleagues [47] that there exists a significant gap between healthcare practitioners' recommendations, athletes' lifting routines, and current scientific findings regarding lifting exercises; particularly, the conventional deadlift [47].

Resistance training is a popular method used to improve strength and power adaptations. Variable, external resistance implemented through the concurrent use of free weights with resistance bands are commonly used by lifting athletes [48] and nullifies the momentum [31]. Literature indicates that variable resistance training (VRT), as provided by resistive bands, is more effective in producing these adaptations compared to standard resistance training [49]. VRT has been proposed as a method to increase load throughout the entire deadlift concentric ascent [31, 33]. Resistive bands are frequently used in rehabilitation and performance settings to alter their kinetics [48].

Three pairs of resistive bands were used in the study, progressively increasing in accent load (Table 2) from pull to lock-out phases, with the highest load at lock-out position (17.2 lbs., 69.2 lbs., and 132.6lbs., respectively) [50]. The study found a dose-response relationship between resistance load and myoelectric activation during the barbell deadlift. In the Minimal Resistance Group (red bands), muscle activation significantly increased in the last third of the deadlift. In the Moderate Resistance Group (black bands), muscle activation significantly increased in the second and last third of the deadlift. In the Maximal Resistance Group (purple bands), muscle activation significantly increased in the first, second, and last third of the deadlift (Table 2) [50]. These findings

Table 8. Infographic. Electromyographical activation by band resistance



demonstrate the dose-response relationship between variable resistance training and different phases of the deadlift, supporting the study's objectives. Despite the non-linear resistance properties of elastic bands, the resistance provided was sufficient to elicit significant myoelectric activation (Table 8) [50].

Andersen et al. [32], reported that variable, external resistance (VER) is purported to increasingly amplify muscular stress throughout the dynamic deadlift movement. VER provided by elastic bands increases myoelectrical activation and neuromuscular stress that progressively intensifies throughout the range of deadlifting. All three resistive bands used in this study significantly increased muscle activation at the last third of the ascending deadlift. Only the Maximal Resistance Group demonstrated significant increases in myoelectric activation during all phases of the ascending deadlift as compared to non-banded barbell deadlift. For most of the muscles study, the greater the band resistance, the greater the range of motion in which myoelectric activity was significantly increased, or a predictable dose-response relationship was established regarding VRT.

In our study, we investigated the effects of resistive bands added to barbell deadlifts in healthy athletes. Although these findings cannot be directly applied to injured athletes or those undergoing rehabilitation, we believe they hold promise for both rehabilitation and return to performance. A previous study by Aasa et al. [29], demonstrated that individualized, progressive deadlift training reduced back pain and improved strength and function over an 8-week period. Our results suggest that the use of resistive bands can further customize barbell deadlifts by allowing resistance to be modified throughout the range of motion, including a lower load on the barbell. This approach may be beneficial for individuals who lack access to expensive equipment or would benefit from varying resistance. Furthermore, using low load barbell lifts with small resistive bands may serve as a useful initial starting dosage that can be progressed as needed.

Participants rated their perceived exertion when performing deadlifts with added resistive bands on a 7-point Likert scale ranging from 0 (no change in effort) to +3 (considerably harder). Positive scores indicated increased effort, while negative scores indicated decreased effort. The average responses for each group were as follows: 1) Min Resistance Group: mean = 0.87 (slightly harder), Mod Resistance Group: mean = 1.3 (slightly harder), and Max Resistance Group: mean = 1.87 (moderately harder). While there were significant differences in isometric lifting maximums as measured by a pull dynamometer during the floor lift between groups, the subjective ratings of perceived effort cannot be generalized. However, the results suggest that a subjective rating of moderately harder effort is needed to increase myoelectric activation throughout the entire range of motion of the banded deadlift. Specifically, a subjective rating of a slight increase in effort is sufficient to significantly increase activation of all trunk and lower extremity muscles assessed during the top portion of the deadlift, where barbell momentum is nullified.

Previous research on banded barbell deadlifts has employed diverse approaches to determine the comparative load, such as estimating the 1-repetition maximum (1RM) or using a percentage of the 1RM. For instance, Galpin et al. [51] used 90% of the estimated 1RM, Andersen et al. [32] based it on the estimated 2RM, Heelas et al. [52] used either 100 kg at the top or 54% of the 1RM, and Andersen et al. [33] used one repetition of the 2RM. A study by van den Tillaar et al. [53] found that muscle activation during "maximal intended velocity" lifting is similar between 70～90% of the 1RM. To standardize the resistance load in our study, we opted to use each participant's body weight as a constant load on the barbell, instead of relying on 1RM estimation, which enabled us to complete each subject session in a single day.

sEMG, a highly sensitive voltmeter, is commonly used in experimental research in the fields of sport and rehabilitation sciences to detect changes in voltage on the sarcolemma of various muscles during exercise techniques with different loads, indicating depolarization and hyperpolarization, which are precursors to active force generation [54, 55] While sEMG amplitude is indicative of muscle excitation, making assumptions about muscle activation, muscle force production, and mechanisms of force production based on sEMG readings alone is a considerable limitation in the rehabilitation and performance arenas [55].

In our study, we compared sEMG myoelectrical activation during deadlift variations to a normalized maximum voluntary isometric contraction, utilizing a functional task of an isometric deadlift simulation (isometric floor lift test) at the starting position. Skeletal muscle fatigue can lead to an increased perception of effort and reduced force per muscle activation (Force/EMG) due to an impaired muscle excitation-contraction process [56]. These amplitude changes in surface detected myoelectric activation due to fatigue, and failure to maintain the expected or required force, are complicated, can occur from a variety of biochemical, electrophysiological, and neuromuscular mechanisms, and appear to be nonlinear [57, 58]. To minimize the impact of fatigue on our results, all lifts were performed in a single session, following recommendations from previous studies [33, 59, 60]

As highlighted by Lederman (25), isolation of core muscles during non-functional exercises is not necessary or particularly effective. Our study found that the high-load stimulus provided by deadlift exercises was sufficient to engage the core musculature, providing the necessary "overtraining challenge" for strength and endurance gains. Additionally, the addition of VRT to the functional deadlift resulted in increased myoelectric activity in the quadriceps, posterior chain muscles, and most of the core muscles tested. The amount of resistance applied appeared to determine the extent of activation, with minimal resistance leading to activation primarily in the top third of the range, and maximum resistance resulting in activation throughout the entire range of the deadlift. As such, we recommend the use of VRT with the deadlift as a functional movement for training prime mover and core muscles simultaneously.

To mitigate potential fatigue effects, we limited each subject to a total of six deadlifts following warm-up exercises: three at bodyweight and three with the addition of a pair of resistive bands. As a result, each participant was unable to perform lifts with each of the three different resistance levels, resulting in three distinct comparative groups, which represents a limitation of our study. Despite this limitation, we note that the strength-to-weight ratios among the groups were not significantly different, as previously mentioned. Since our study focused solely on trained lifting athletes, our findings may not be generalizable to other populations. While acknowledging the importance of deadlifts in both rehabilitation and return-to-performance settings, the primary focus of this paper is to propose additional strategies to further assure safe and effective lifting.

Conclusion

Clinicians as well as fitness, performance, and strength practitioners are responsible for determining the appropriate level of physical stress needed to promote tissue adaptation and hypertrophy, while also addressing all aspects of the functional movement system and minimizing the risk of injury. Although a consensus on the ideal lifting technique has not yet been reached, modifications, variations, or training aids can be added to the conventional deadlift to optimize movement and achieve tissue adaptation and safety. The deadlift is a functional, dynamic, full-body exercise that can be customized using variable, external resistance provided by elastic bands to increase load and myoelectric activity in certain ranges of motion, as deemed appropriate by rehabilitation workers or performance coaches. Our study found that the addition of lighter resistance bands significantly increased myoelectric activation in the last third of the deadlift ascent, where the spine is more upright and less prone to anterior shear. When using the thickest resistance band, we observed a significant increase in myoelectrical activation throughout the entire ascent of the deadlift. There appears to be a dose-response relationship between increased resistance band width, external load, myoelectric activation, and range of motion.

Abbreviations

2-D:	Two dimension
A:	Alpha
ANOVA :	Analysis of variance
BMI:	Body mass index
e.g.:	Exempli gratia

Cm:	Centimeters
D:	Chone's measurement of effect size
EO:	External obliques
F:	F distribution
GM:	Gluteus maximus
Kg:	Kilograms
Hz:	Hertz
i.e.:	Id est
N:	Subjects
Lbs:	Pounds
L:	Lumbar
LH:	Lateral hamstrings
LD:	Latissimus dorsi
LES:	Lumbar erector spinae
M:	Meters
p:	Probability
U:	Mann-Whiney test
MVIC:	Maximum volitional isometric contraction
Q-Q:	Quantile-quantile
RA:	Rectus abdominis
S :	Sacrum
SD:	Standard deviation
sEMG:	Surface electromyography
T:	Thoracic
VL:	Vastus lateralis
VRT:	Variable resistance therapy

Acknowledgements

The authors would like to thank all study participants.

Funding

Open access funding provided by Loma Linda University, School of Allied Health Professions.

Contributions

EBL and MA contributed to the conception and design of the study. MA and FC performed data processing and analysis. FC organized the database. MA and ND performed statistical analysis. EBL wrote the first draft of the manuscript. MA and ND wrote sections of the manuscript. EBL, FC, CCC, MS, OM, KM, and SJ participated in data collection. GB assisted in the Institutional Review Board submission and approval, subject recruitment, and manuscript editing. MD was involved in the the early pilot and feasibility trials. All authors contributed to manuscript revision, read, and approved the submitted version.

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Ethics Approval and Consent to Participate

Written informed consent, approved by the Institutional Review Board of Loma Linda University (IRB #521088), was obtained for all subjects.

Consent for Publication

The consent of both models in images were obtained.

Competing interests

Currently, we know of no conflicts of interest with this publication. The primary author formally owned an exercise supply company that sold resistive bands. He no longer has any financial, commercial, or other relationships that might be perceived by the academic community as representing a potential conflict of interest to disclose. There has been no significant financial support for this work that could have influenced its outcomes.

Availability of Data and Materials

Data are available upon request from the authors.

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