Muscle activation patterns during variable resistance deadlift training with and without elastic bands.

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ABSTRACT

The purpose of this study was to determine the effects of band-assisted variable resistance training on muscular activity in the lower limbs and barbell kinematics during the concentric phase of the deadlift. Fifteen resistance trained men (mean ± SD: 28.7 ± 9.3 y; 1.80 ± 0.90 m; 92.5 ± 15.1 kg) performed six deadlift repetitions during four loading conditions; 100 kg bar (NB), 80 kg bar with 20 kg band tension (B20), 75 kg bar with 25 kg band tension (B25) and 70 kg bar with 30 kg band tension (B30). Muscle activity from the medial gastrocnemius (MG), semitendinosus (ST), vastus medialis (VMO), vastus lateralis (VL), and gluteus maximus (GM) were recorded using surface electromyography (sEMG) during the concentric phase of the lift and expressed as a percentage of each muscle's maximal activity, recorded during a maximal isometric contraction. Barbell power and velocity were recorded using a linear position transducer. Electromyography results showed that muscle activity significantly decreased as band resistance increased in the MG and ST ($p < 0.05$) and progressively decreased in the GM. No changes were observed for the VMO or VL. Peak and mean bar velocity and power significantly increased as band resistance increased. Performing the deadlift with band-assisted variable resistance increases bar power and velocity, whilst concurrently decreasing muscle activation of the posterior chain musculature. Practitioners prescribing this exercise may wish to include additional posterior chain exercises that have been shown to elicit high levels of muscle activation.

Key Words: EMG, deadlift, power, velocity, accommodating resistance

INTRODUCTION

Success in several sports is dependent on an athletes' ability to exert high levels of muscular force and power (1). In sports where there are large volumes of jumping, sprinting and change of direction, peak power production is paramount (2). The use of traditional resistance training to increase muscular power is widely implemented in athletic populations (18). However, due to the length-tension relationship, a constant external load does not allow the muscle to produce high forces through a full range of motion. Instead, a constant load creates biomechanically disadvantageous positions for producing maximal force and acceleration (15). One such position is the start of a deadlift, where the force-producing muscles (quadriceps and gluteal muscles) are in a lengthened position and therefore limited in their ability to produce maximal force to overcome the external resistance (20). During a traditional deadlift exercise, the load on the bar increases as the barbell is moved through the concentric phase of the movement, making it increasingly more difficult to maintain a high velocity and acceleration (4,9). Since power is dependent on both strength and speed, exercises which allow an athlete to maintain force whilst working at high velocities are necessary, especially as traditional resistance exercise encourages athletes to decelerate during the latter stages of the concentric phase which is not necessarily sport specific. It has been advocated that performing traditional resistance exercises, such as deadlift, with submaximal loads, prevents the adequate development of muscular power (16). It has been stated that in order to maximize power in traditional resistance exercises such as the squat and bench press, loads equating to 30-50% 1RM are sufficient (22,9). However, the optimal load for maximizing power development during the deadlift is not clearly defined, especially across a range of athletes with different training backgrounds and strength levels.

When performing a traditional deadlift using constant load, a large force is needed during the initial upward phase, causing a greater generation of momentum throughout the movement. This momentum assists with moving the weight and results in less muscle activity needed towards the top of the lift. As a result, variable resistance training (VRT), has been proposed as an alternative modality to enhance power production, by increasing load throughout the entire concentric phase of a lift (5). In VRT, the resistance generated from elastic bands or chains, negates the use of momentum towards the top of the lift, and creates a greater demand for muscle activity through the full range of motion. At biomechanically disadvantageous positions, resistance is lowered meaning an increase in bar velocity and subsequent stimulation of more fast-twitch fibres. Thus, with VRT, the athlete is able to maintain high force production at high velocities during selected resistance exercises. This type of training has been shown to produce superior strength-power adaptations in comparison to traditional resistance training (e.g. increased 1 repetition maximum bench press, bench press mean velocity and power) (17) by allowing athletes to generate greater bar velocities and power during deadlifts, as a result of decreased initial concentric load (13).

The evidence for the use of VRT to change bar velocity and power is promising (19,11) but the neuromuscular mechanisms, by which this occurs has produced mixed findings. It has been demonstrated that vastus lateralis (VL) muscle activity is higher during squats with banded resistance, though only during early stages of the eccentric phase and at the end of the concentric phase, coinciding with maximal resistance (13). This was contradicted by Ebben et al. (7) who showed no changes in muscle activation of the quadriceps and hamstring during a squat using VRT with bands. Only one study to date has investigated the effects of VRT on muscle activity during the deadlift (15). In this study, chains were used to apply accommodating resistance, resulting in decreased gluteus maximus (GM) muscle activity in comparison to a traditional free weight condition. Muscle activation levels for the erector spinae and VL muscles were unaffected by chain use. These results highlight that the modality of accommodating resistance may influence the effects of VRT. This was supported in two further studies on kinetics, which showed that, performing the deadlift decreased bar power and velocity with chains (19) but increased bar power and velocity with bands (11).

No study to date has investigated both lower limb muscle activation and bar velocity and power with banded variable resistance training during the deadlift. Consequently, the neuromuscular mechanisms responsible for a potential observed increase in bar power and velocity during the deadlift exercise remain unclear. Therefore, the purpose of this study was to investigate bar kinematics and muscle activation of the lower limb during a deadlift, performed with and without elastic bands as an accommodating resistance.

METHODS

Experimental Approach to the Problem

The study used a randomized, repeated measures, balanced design to investigate the effects of banded variable resistance on muscle activation, bar velocity and power during the deadlift. Surface electromyography (EMG) recorded muscle activation of the gluteus maximus (GM), vastus lateralis (VL), vastus medialis (VMO), semitendinosus (ST), and medial gastrocnemius (MG) in four deadlift conditions; 100 kg barbell load (NB), 80 kg bar with 20 kg band tension (B20), 75 kg bar with 25 kg band tension (B25) and 70 kg bar with 30 kg band tension (B30) (loads were equated at the top of the lift). The load of 100kg at the top of the lift equated to a mean of 53.6 ± 7.9% of subjects 1RM. Simultaneous measures of bar velocity and power were also recorded using a linear position transducer. For each condition, participants were instructed to lift the barbell by applying maximal effort during the concentric phase, and then lowering the barbell in a controlled manner. Belts and straps were not allowed to be utilised during the trial. Prior to the study, a pilot test was carried out to assess intra and inter-set reliability of banded resistance on kinetic bar variables by calculating intra-class correlation coefficients. The results demonstrated excellent inter-set reliability (peak power = 0.99, peak force = 1.00, peak velocity = 0.98) and good intra-set reliability (peak power = 0.80, peak force = 0.86, peak velocity = 0.82 for intra-set reliability) (14).

Subjects

Fifteen resistance trained men (Mean ± SD: age, 28.7 ± 9.3 y; stature, 1.80 ± 0.9 m; mass, 92.5 ± 15.1 kg) with at least 1 year of deadlifting experience (1RM barbell deadlift, 190 ± 28 kg) volunteered for this study. All participants were free from musculoskeletal injuries and instructed to refrain from resistance training 48 hours before testing. Ethical approval was granted by the institutional ethics committee in accordance with the declaration of Helsinki. All subjects provided written informed consent prior to participating in the study.

Experimental setup

Surface EMG (Biometrics Ltd, MWX8 DataLOG) sampling at 1000 Hz, recorded muscle activation during the concentric phase of the deadlift, in each condition. To avoid confounding the EMG signal, participant's skin was shaved at the electrode placement site and cleaned with isopropyl alcohol to reduce impedance levels (<10 kΩ) (3). Surface electrodes were placed over the GM, VL, VM, ST and MG muscles in the direction of the underlying muscle fibres, with the reference electrode placed over the pisiform bone (www.seniam.org). Electrodes for each muscle group were placed on the participants dominant limb, in the following manner: (i) GM; midway between the sacral vertebrae and the greater trochanter (ii) ST; midway between the ischial tuberosity and the medial epicondyle of the tibia (iii) VM; 80% along the line between the anterior spina iliac superior and the joint space in front of the anterior border of the medial ligament (iv) VL; two thirds on the line from the anterior spina iliac superior to the lateral side of the patella (v) MG; on the most prominent bulge of the muscle. Electrodes were connected to a Datalog device (Biometrics Data Log PC Software Version 8.51), which used both a high-pass third order filter (18dB/octave; 20Hz) to remove DC offsets due to membrane potential, and a lowpass filter for frequencies above 450 Hz.

To record bar velocity and power in each condition, a linear transducer cable, recording at 50 Hz, (GymAware Powertool, Kinetic Performance Technology, Canberra, Australia) was attached to the centre of the barbell. A barbell load of 100 kg was entered onto the GymAware software for each deadlift condition to calculate power, as total load with band tension was approximately the same for each condition. Data for each repetition were collected and stored on an iPad handheld device.

Band tension measurement

Two elastic bands (Perform Better, Warwickshire, UK) were anchored to dumbbells and looped over the sleeves of the barbell (Eleiko, Halmstadt, Sweden). Subjects were stationary in both the lockout and bottom position of the deadlift while standing on a force plate sampling at 1000Hz (type 9287BA, Kistler Instrumente AG, Winterthur, Switzerland) the mass of the individual and barbell were accounted for and the resistance produced by the bands at either position was measured. The band tension was the average over the entire range of motion and represented 14.61 ± 1.02 to 0.00 ± 0.22 % at the top and bottom of the deadlift.

Procedures

Participants began with an exercise-specific warm-up, including five repetitions at 60 kg, five repetitions at 80 kg and three repetitions at 100 kg. To allow normalisation of the sEMG signal during the deadlift conditions, maximal sEMG signals were obtained for each muscle group. To do this, participants performed three, 5 s maximal voluntary isometric contractions (MVIC) of each exercise: bilateral standing calf raise (MG), seated unilateral 45° knee extension (VM and VL), unilateral prone hamstring curl (ST) and standing glute squeeze (GM) (feet slightly wider than shoulder width apart and hips slightly externally rotated).

Following the MVIC testing, participants were given a mandatory 15 min rest period before performing six repetitions of each deadlift condition with a three-minute rest between each condition; the order of which was randomised Participants were instructed to perform "dead stop" repetitions (no rebounding the barbell from the floor) and apply maximal effort during the concentric phase followed by lowering the barbell in a controlled manner during the eccentric phase (Figure 1). For each condition, the start and end of the concentric phase was marked using a manual digital input.

Figure 1. Experimental setup of the banded deadlift condition

Data processing

Raw electromyographic signals were analysed using a root mean square (RMS) filter with a moving window length of 100 ms. For each muscle group and for each condition, mean and peak amplitude over the concentric phase were calculated and expressed relative to each participants' highest recorded sEMG amplitude during the MVIC trials. Rate of activation was also calculated over the concentric phase, as a change in activation over the concentric phase divided by a corresponding change in time.

Vertical displacement of the barbell was measured from the rotational movement of the spool by correcting for any motion in the horizontal plane. Instantaneous velocity was determined as the change in barbell position with respect to time and acceleration data were calculated as the change in barbell velocity over the change in time. Acceleration was multiplied by mass to give force, and power was then subsequently calculated as the product of force and velocity. Power and velocity were expressed as both peak values and averaged over the concentric phase of the deadlift. For all variables and for each condition, two of six repetitions were chosen for further analysis. The two repetitions where peak EMG amplitude was highest and within ± 10%, were averaged and these same trials were used for power and velocity analyses.

Statistical analyses

A series of one-way repeated measures ANOVA's were performed to assess differences in muscle activation between deadlift conditions. Further one-way repeated measures ANOVA's were performed to assess differences in bar velocity and power. In the case of a significant main effect, post-hoc pairwise t-tests with Bonferroni corrections were performed between conditions to control for Type I errors. Statistical significance was set at $p < 0.05$ (version 25, IBM SPSS). Where significant differences were found Cohen's *d* was calculated to determine the magnitude of difference in conditions. Changes were considered trivial <0.2; small 0.2-0.6; moderate 0.6-1.2; and large 1.2-2 (6).

RESULTS

Electromyography

Results of deadlift condition on mean and peak MVIC% are presented in Table 1. There was no significant effect of deadlift condition on mean MVIC%. There was a significant main effect of deadlift condition on peak MVIC% for the MG ($F_{(3,14)} = 3.99$, $p = 0.01$) and ST ($F_{(3,14)} = 3.90$, $p = 0.02$), but no significant main effect of deadlift condition on peak MVIC% for the for the GM ($F_{(3,14)} = 2.52$, $p = 0.07$), VL ($F_{(3,14)} = 0.40$, $p = 0.750$) and VMO ($F_{(3,14)} = 0.44$, $p = 0.720$). *Post hoc* tests showed that peak MVIC% for the MG decreased significantly ($p < 0.05$) between NB and B25 (ES = -0.45; 95% CI [-1.17 - 0.28]); NB and B30 (ES = -0.31; 95% CI [-1.03 – 0.41]) and B20 and B25 (ES = -0.31; 95% CI [-1.03 – 0.41]). Peak MVIC% for the ST decreased significantly ($p < 0.05$) between NB and B20 (ES = -0.44; 95% CI [-1.16 - 0.29]) and NB and B25 (ES = -0.40; 95% CI [-1.13 - 0.32]).

Table 1. Electromyographic (EMG) results of peak and mean MVIC (%) during no band, B20, B25 and B30 conditions. Values are mean ± SD.

		Muscle group				
Condition		**GM**	**ST**	**VL**	**VMO**	**MG**
NB	**Peak**	124.7 ± 46.4	99.6 ± 28.4	89.6 ± 33.5	101.6 ± 23.3	46.4 ± 17.7
	Mean	78.3 ± 30.1	61.1 ± 18.6	81.7 ± 20.7	69.4 ± 28.3	30.0 ± 11.9
B20	**Peak**	118.7 ± 45.0	88.9 ± 19.6*	86.3 ± 25.3	101.7 ± 27.1	43.5 ± 13.2
	Mean	76.1 ± 31.6	55.9 ± 12.1	81.4 ± 22.3	67.5 ± 21.9	29.3 ± 8.3
B25	**Peak**	116.0 ± 42.9	88.7 ± 25.7*	87.3 ± 25.4	100.7 ± 27.5	39.0 ± 15.4*†
	Mean	76.5 ± 28.9	56.1 ± 15.9	82.2 ± 24.4	69.4 ± 23.3	26.9 ± 9.6
B30	**Peak**	112.5 ± 38.6	92.6 ± 24.6	88.0 ± 29.5	98.3 ± 26.4	41.4 ± 14.5*
	Mean	74.4 ± 24.9	61.3 ± 18.7	81.0 ± 23.5	70.1 ± 25.5	29.9 ± 9.7

** denotes statistically significant different to NB (p < 0.05). † denotes statistically significant different to B20 (p < 0.05).*

Results of deadlift condition on rate of activation are presented in Table 2. No significant effect of deadlift condition on rate of activation was observed for the MG ($F_{(3,14)} = 2.77$, $p = 0.052$), ST ($F_{(3,14)} = 0.65$, $p = 0.580$), VMO ($F_{(3,14)} = 0.28$, $p = 0.830$), VL ($F_{(3,14)} = 0.04$, $p = 0.980$), and GM ($F_{(3,14)} = 1.60$, $p = 0.200$).

Table 2. Results of rate of activation ($mV \cdot s^{-1}$) during no band, B20, B25 and B30 conditions. Values are mean ± SD.

	Rate of Activation ($mV \cdot s^{-1}$)				
	GM	ST	VL	VMO	MG
NB	0.2 ± 0.1	0.4 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
B20	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
B25	0.3 ± 0.1	0.3 ± 0.2	0.3 ± 0.1	0.3 ± 0.2	0.2 ± 0.1
B30	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	0.3 ± 0.2	0.2 ± 0.1

Power

Results of deadlift condition on bar power are presented in Table 3. There was a significant main effect of deadlift condition on concentric peak power ($F_{(3,14)} = 30.33$, $p < 0.01$) and concentric mean power ($F_{(3,14)} = 39.81$, $p < 0.01$). *Post hoc* tests revealed that concentric peak power increased significantly ($p < 0.05$) between NB and B20 (ES = 0.48; 95% CI [-0.25 - 1.20]); NB and B25 (ES = 0.56; 95% CI [-0.17 - 1.29]) NB and B30 (ES = 0.61; 95% CI [-0.12 – 1.34]) and B20 and B30 (ES = 0.17; 95% CI [-0.55 – 0.88]). No significant differences were observed between B20 and B25 and B25 and B30. Additionally, concentric mean power increased significantly ($p < 0.05$) between NB and B20 (ES = 0.78; 95% CI [0.04 - 1.52]); NB and B25 (ES = 0.89; 95% CI [0.14 - 1.64]); NB and B30 (ES = 1.00; 95% CI [0.24 - 1.75]) and B20 and B30 (ES = 0.29; 95% CI [-0.43 - 1.01]). No significant differences were observed between B20 and B25 and B25 and B30.

Table 3. Results of peak and mean power (W) during no band, B20, B25 and B30 conditions. Values are mean ± SD.

Condition	Peak Power (W)	Mean Power (W)
NB	1285.8 ± 409.9	722.6 ± 138.6
B20	1493.4 ± 462.3*	835.7 ± 151.3*
B25	1548.7 ± 515.8*	857.3 ± 164.4*
B30	1576.1 ± 533.0*†	884.0 ± 182.5*†

** denotes statistically significant different to NB ($p < 0.05$). † denotes statistically significant different to B20 ($p < 0.05$).*

Velocity

Results of deadlift condition on bar velocity are presented in Table 4. There was a significant main effect of deadlift condition on concentric mean velocity ($F_{(3,14)} = 45.91$, $p < 0.01$) and concentric peak velocity ($F_{(3,14)} = 45.77$, $p < 0.01$). *Post hoc* tests revealed that concentric peak velocity increased significantly ($p <0.05$) between NB and B20 (ES = 1.00; 95% CI [0.24 - 1.76]); NB and B25 (ES = 1.00; 95% CI [0.24 - 1.76]) NB and B30 (ES = 0.38; 95% CI [0.04 – 1.53]) and B20 and B30 (ES = 0.37; 95% CI [-0.72 – 0.72]). Additionally, concentric mean velocity increased significantly ($p < 0.05$) between NB and B20 (ES = 1.00; 95% CI [0.24 - 1.76]); NB and B25 (ES = 1.26; 95% CI [0.48 – 2.05]); NB and B30 (ES = 1.26; 95% CI [0.48 – 2.05]) and B20 and B30 (ES = 0.63; 95% CI [-0.10 - 1.37]). For both variables, no significant differences were observed between B20 and B25 and B25 and B30.

Table 4. Results of peak and mean velocity ($m \cdot s^{-1}$) during no band, B20, B25 and B30 conditions. Values are mean ± SD.

Condition	Peak Velocity ($m \cdot s^{-1}$)	Mean Velocity ($m \cdot s^{-1}$)
NB	1.2 ± 0.2	0.7 ± 0.1
B20	1.4 ± 0.2*	0.8 ± 0.1*
B25	1.4 ± 0.2*	0.9 ± 0.2*
B30	1.4 ± 0.3*†	0.9 ± 0.2*†

** denotes statistically significant different to NB ($p < 0.05$). † denotes statistically significant different to B20 ($p < 0.05$).*

DISCUSSION

The purpose of this study was to compare bar kinematics and muscle activation of the lower limb during a deadlift, across various conditions of accommodating elastic band resistance. The results showed that 1) concentric bar power and velocity progressively increased from NB to the highest accommodating resistance at B30 2) in general, peak MVIC% for the MG, ST and GM decreased with accommodating band resistance 3) No differences in peak MVIC% were observed for the VL and VM 4) No differences in mean MVIC% were observed for any muscle 5) No differences were observed between conditions in rate of activation for any muscle.

Our results showed that there was an overall increase in both mean and peak bar power and velocity as accommodating band resistance increased. These results agree with the previous research in both the squat (13) and deadlift (11). In the study by Galpin et al. (11), an increase in accommodating resistance contributing to the overall increased barbell load, caused a subsequent increase in bar velocity throughout the concentric phase of the deadlift. Mechanical power is defined as the product of force and velocity. Therefore, as the average load decreases with increasing accommodating band resistance, athletes were able to increase bar velocity, leading to overall increases in bar power. This result is not surprising, given that with greater band tension, there is less resistance at the bottom of the lift as more barbell weight is taken off to accommodate higher band tensions at the top. Interestingly, we found that bar velocity and power began to plateau at the heavier band resistance loads (B25 and B30), consistent with one previous finding (21). Wallace et al. (21) found that the increases in peak force with higher levels of banded resistance were significantly greater than the changes in peak force with low levels of band tension. Taken together with the results from this study, this suggests a trend towards a plateau after B30, such that band percentages greater than 25-30% of total load may have no added benefit to enhancing bar velocity and power. Indeed, Wallace et al. (21) demonstrated a significant decline in peak power from 85% of 1RM, where 20% of 1RM was from band tension, to 85% of 1RM where 35% of 1RM was from band tension.

Peak muscle activation decreased significantly in the MG and ST as band resistance increased but with no changes in the VL, which conflicts with findings in the squat of an increase in muscle activation. However, the biomechanical differences between the squat and deadlift, (12) including the potentiation effects during the lowering phase of the squat limit the comparability of these exercises. There was also a trend in the GM of decreasing muscle activation with increasing band resistance; consistent with previous studies using chains to provide variable resistance (5). These results might be explained by an initial lower concentric load as greater band tension was added to the bar. For example, in high resistance conditions (B30), lower levels of muscle activation would be required in the initial phase of the deadlift, to overcome the inertia of the bar, compared to a NB condition (21). Therefore, as the band-to-free weight ratio increases, less muscle activation would be required to maintain force production and bar momentum throughout the concentric phase. This is supported by our bar velocity data, whereby an increase in bar velocity is accompanied by a concurrent decrease in peak muscle activation of the MG, ST and GM. Despite no change in peak muscle activation across conditions, the anterior chain muscles (VL and VMO) demonstrated an ability to work at near maximal activation (>86% and >98%, respectively) even at the higher velocities, where the highest motor unit recruitment occurs for power adaptations (10). However, the result that mean MVIC% did not change across conditions demonstrates that the total work performed was not enhanced with increasing band tension.

The finding that rate of muscle activation (change in activation/change in time) was not different across conditions, is consistent with the decrease in peak activation and increase in bar velocity observed in this study. For example, average concentric load was greatest during the NB condition, resulting in the highest peak muscle activations. However, consistent with low bar velocity, the time taken to reach peak activation was longest in the NB condition. This combination of high peak activation over a longer period produces similar rates of activation to high resistance conditions. In the B30 condition, for example, peak activation was lowest, but the time taken to reach this peak activation was shorter. The overall result is a finding that rate of activation is similar across conditions with increasing bar velocity and decreasing peak activations.

This is the first study to demonstrate neuromuscular responses to banded resistance exercise during the deadlift. Overall, the results showed a progressive decrease in muscle activation of the posterior chain musculature as band resistance increased. However, for the GM in particular, results across individuals showed high variability (<43% to >100%), highlighting the importance of investigating inter-individual differences in anthropometrics or deadlift technique with VRT. Indeed, previous studies have demonstrated the effect of different deadlift exercises on muscle activation (5,8), highlighting that technique could be an important factor related to muscle activation patterns during VRT. It should also be noted that all testing was performed during a single experimental session and the testing of MVIC's prior to the testing of the deadlifts may have had some potentiating or fatiguing effects on the muscles being tested.

PRACTICAL APPLICATIONS

Practitioners prescribing the deadlift with banded variable resistance may wish to include additional posterior chain exercises that have been shown to elicit high levels of muscle activation. Conversely, in situations where load needs to be removed from the posterior chain such as highly intensified blocks of training that include large volumes of high speed running VRT with higher tension bands may be beneficial. They should also be aware that there may be no or only minimal additional benefits in power and velocity, when using a band tension that accounts for or exceeds approximately 30% of the total load. Athletes may gain the most benefit from performing the deadlift with banded variable resistance when it is implemented into a peaking or pre-competition phase, due to the increases in bar power and velocity. This may be of importance to athletes involved in vertical jumping performance (e.g. volleyball or high jump athletes) due to the requirement on them to have the combination of high force production coupled with high velocity actions.

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