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Peak Rate of Force Development and Isometric Maximum Strength of Back Muscles Are Associated With Power Performance During Load-Lifting Tasks

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Abstract

This study investigates the relationship between peak force and rate of force development (RFD) obtained from maximal voluntary isometric contraction (MVC) of the back muscles and the power produced during a loaded lifting task. A group of 27 resistance-trained and 41 recreationally physically active men performed a maximal isometric strength test of the back muscles and a deadlift to high pull while lifting progressively increasing weights. Peak RFD correlated significantly with the peak and mean power produced during a deadlift to high pull with lower weights (from 20 to 40 kg), with *r* values ranging from .941 to .673 and from .922 to .633. The r^2 values ranged from .89 to .45 and from .85 to .40, explaining 89%–45% and 85%–40% of total variance. There were also significant relationships between MVC peak force and peak and mean values of power produced during a deadlift to high pull with weights ≥60 kg (*r* in range from .764 to .888 and from .735 to .896). Based on r^2, a moderate-to-high proportion of variance was explained (58%–79% and 54%–80%). These findings indicate that peak RFD obtained from MVC of the back muscles may be predictive of power performance during a lifting task at light loads. In addition to MVC peak force produced by back muscles, the ability of subjects to develop a high force in a short time should be evaluated in order to gain deeper insight into a loaded lifting performance, namely, in those prone to low back pain.

Keywords

deadlift to high pull, maximal voluntary isometric contraction, peak and mean power, peak force, rate of force development

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For many years, isometric strength measurements were recommended as the standard for lifting tasks (Karwowski & Marras, 1999). This was based on evidence that low back pain is associated with inadequate isometric strength (DHHS [NIOSH], 1981). The risk of an individual sustaining an on-the-job back injury increases threefold when the task-lifting requirements are equal to or beyond the strength capacity. Static strength measurements significantly underestimate the loads on the spine during dynamic lifting. The predicted spinal loads under static conditions are 33%–60% less than those under dynamic conditions, depending on the lifting technique (DHHS [NIOSH], 1981). The recruitment patterns of trunk muscles (and thus the internal loading of the spine) are significantly different under isometric than under dynamic conditions. For instance, the peak hand forces, exhibited while dynamically lifting different submaximal loads, are not highly correlated with a person's isometric lifting strength in similar postures (Thompson, Chaffin, Hughes, & Evans, 1992). Low-to-moderate associations between

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isometric strength measurements and lifting capacity suggest that estimates of functional lifting capacity should not be based on static measurements alone (Rosecrance, Cook, & Golden, 1991). Dynamic lift tests are often a better simulation of the task being assessed and may be more appropriate for a population with back injury.

Lifting tasks require also a coordinated multilink activity. Significant negative correlations were identified between hip–back maximum relative to phase angle and leg lifting strength, knee extensor strength, knee flexor strength, back extensor strength, and back flexor strength (Yehoyakim, Bellefeuille, Côté, & Plamondon, 2016). The greater the strength of these muscles, the more synchronized the hip–back interjoint coordination. No significant relationships were reported with endurance test performance. Although the lifting task induced muscle fatigue, there were no significant fatigue-induced changes in lifting coordination (Yehoyakim et al., 2016). Tests of dynamic strength have stronger correlations than strength endurance (95% CI [.69, .89] vs. 95% CI [.21, .61]) to maximal lift capacity (Hydren, Borges, & Sharp, 2017). The authors identified the following six domains of physical performance predictive tests that had pooled correlations of .40 or greater for combined-sex samples: dynamic strength, power, isometric strength, strength endurance, speed, and isokinetic strength.

The evaluation of performance during such lifting tasks requires a test that best simulates the individual's spinal loading preconditions. It is particularly important to quantify kinetic and kinematic parameters that are able to discriminate between individuals and are sensitive to changes over time. A deadlift to high pull exercise that involves working the major muscle groups in the upper body and lower body, such as the abdomen, erector spinae, lower back and upper back, quadriceps, hamstrings, and the gluteus maximus, may best simulate the demands of a particular sport or job comprising of lifting tasks. A test was developed evaluating power performance during such a lifting task and a related methodology quantifying data variability under various conditions (Zemková, Cepková, Uvaček, & Hamar, 2016). Subjects performed the deadlift to high pull either with free weights or on the Smith machine with stepwise increasing weights up to a maximal power. During the diagnostic set, the power increases from lower weights, reaches a maximum, and then toward higher weights, it decreases again. Maximal values of peak power were achieved at about 80% of one-repetition maximum (1RM) and mean power at about 70% of 1RM. There were no significant differences in peak power during the deadlift to high pull on the Smith machine and with free weights from 20 to 45 kg. Their values were significantly higher during a deadlift to high pull with free weights than on the Smith machine when weights ≥50 kg were lifted. Mean power during a deadlift to high pull on the Smith machine and with free weights showed a similar tendency.

Furthermore, there were substantial individual differences in velocity and power production during a deadlift to high pull with the weight at which maximal power was achieved (e.g., 50 kg), which was seen mainly during the second part of the exercise (i.e., while performing the upright row; Zemková et al., 2016). This was ascribed to a significant association ($r > .80$) between the power produced during a deadlift to high pull and an upright row on the Smith machine as well as with free weights.

In particular, the deadlift to high pull with free weights should be applied for the evaluation of power performance during lifting tasks. The movement pattern during this exercise is most likely closer to the task-lifting requirements of daily life and many sport activities when compared to the one performed on the Smith machine. It may also be more easily applied in practice as it does not require a special weight stack machine for testing. As shown, it is an acceptably reliable test when considering both stability of measurement and test–retest reliability. The test is sensitive in distinguishing lifting performance in healthy young subjects.

This test was used in the study, which evaluated the effect of 3 months of resistance and aerobic training programs on power produced during a lifting task in overweight and obese individuals (Zemková et al., 2017). The resistance training enhanced power output during a deadlift high pull with weights from 30 to 50 kg (~40%–60% of 1RM). The group that participated in the aerobic training failed to show any significant improvement of power performance during the deadlift high pull. This was the first study to demonstrate that the deadlift high pull with free weights may be a suitable test for evaluating a lifting performance in overweight and obese subjects.

In addressing the prevention of low back pain in such individuals with a predominantly sedentary lifestyle, the assessment of the ability to produce a high force in a short time during a maximal voluntary isometric contraction (MVC) of the back muscles could provide useful information about whether a person is capable of performing lifting tasks without incurring injury. Given that this ability may be a better predictor of power performance during a lifting task than maximal back muscle strength, its assessment should be a more appropriate and safer alternative for those prone to low back pain. The aim of the study was to investigate the relationship between peak force and the rate of force development (RFD) obtained from MVC of the back muscles and power produced during a deadlift to high pull under varied loading conditions.

Methods

Participants

A group of 27 resistance-trained men (age 23.2 ± 2.4 years, height 181.9 ± 9.3 cm, body mass 87.8 ± 11.6 kg) and 41 recreationally physically active men (age 21.0 ± 1.9 years, height 178.6 ± 8.7 cm, body mass 81.4 ± 9.9 kg) volunteered to participate in the study. All participants had experience with resistance training including exercises for strengthening the trunk muscles. The participants were included in the study only if they subjectively did not report pain in the lumbar region during the maximal isometric strength test. They were excluded if they had cardiorespiratory, orthopedic, neurological, and/or other conditions that were contraindications for dynamic resistance exercise. Individuals who had previously undergone surgery and/or other medically invasive procedures for low back pain were excluded from participation in the study. All participants were informed of the procedures and main purpose of the study. The verbal informed consent to participate in the study was provided. All information and data obtained were anonymized and stored in password-protected computers, which could only be accessed by the researchers. Projects were approved by the Ethics Committee of the Faculty of Physical Education and Sport, Comenius University in Bratislava (Nos. 3/2017 and 4/2017). The procedures presented were in accordance with the ethical standards on human experimentation as stated in the Helsinki Declaration.

Experimental Protocol

A randomized counterbalanced testing protocol was used to evaluate the relationship between variables obtained from MVC of the back muscles and the power produced during a loaded lifting task. Before testing, participants were given a visual demonstration of the proper exercise technique and were informed of the instructions during testing. They were requested to avoid any strenuous exercises prior to the study. The testing procedure and time of day were identical for all participants.

Assessment of Maximal Back Muscle Strength

Before testing began, the participants warmed up by doing two submaximal isometric trials so as to become accustomed to the testing procedure. They were then placed into the appropriate position, based upon the knee and hip angles (141° and 124°, respectively) that were set up by a handheld goniometer. The position chosen corresponds to the portion of the clean lift where the highest power is produced (Garhammer, 1993). Once the participants were in position, they initiated the exercise after a countdown "3, 2, 1, pull." Participants performed three MVCs as forcefully and as quickly as possible for a minimum of 3 s. They were given verbal encouragement at each contraction. At least 2 min of rest was provided between MVC efforts. The instantaneous force was displayed in real time as visual feedback on a monitor positioned in front of the examiner. Force was measured by means of the FiTRO Back Dynamometer (FiTRONiC, Slovakia). Analogue signals were AD converted and sampled by the computer at the rate of 1,000 Hz. The device consists of a handlebar attached to a floor-mounted load cell (Figure 1). The height of the handlebar above the floor was established for each individual during familiarization trials. Peak force and peak RFD were analyzed.

Figure 1. Assessment of maximal back muscle strength using the FiTRO Back Dynamometer.

Assessment of Muscle Power During a Lifting Task

After a standardized warm-up (i.e., dynamic flexibility and stretching routine) and a specific warm-up (i.e., two submaximal effort trials), the participants performed two repetitions of a deadlift to high pull with free weights. The exercise was performed with maximal effort in the lifting phase with stepwise increasing weights (10 kg at lower and 5 kg at higher weights). A rest interval of 2 min was applied between the individual sets. The greater of the two attempts was used for the analysis.

Figure 2. Assessment of muscle power during a lifting task using the FiTRO Dyne Premium.

Emphasis was placed on the proper technique of the exercise. The participants assumed a hip width stance with the knees slightly flexed and the toes pointed straight ahead. The grip was approximately shoulder width. Then they lifted the bar as high as possible off the floor, to about chin level. During the upward movement phase, the participants were asked to keep their knees slightly flexed and the torso in a flat back position. When the deadlift to high pull with higher weights was performed, two laboratory assistants stood behind the participant to impede possible falls.

Basic biomechanical parameters during the deadlift to high pull with free weights were monitored by means of the FiTRO Dyne Premium (FiTRONiC, Slovakia). The device was placed on the floor and anchored by a nylon tether to a bar (Figure 2). Participants performed the exercise while pulling on the nylon tether on the device. Both peak and mean values of power in the lifting phase were analyzed. The power obtained using this device was reported to be a reliable parameter during squat jumps and biceps curls (Jennings, Viljoen, Durandt, & Lambert, 2005), bench presses (Zemková et al., 2015), as well as deadlift to high pull on the Smith machine and with free weights (Zemková et al., 2016).

Statistical Analysis

Statistical analysis of the collected data was performed using the SPSS program for Windows, version 18.0 (SPSS, Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation (*SD*).

The calculation of the sample size was conducted with $\alpha = .05$ (5% change of Type I error) and $1 - \beta = .80$ (power 80%) and using the results from previous study that identified differences in velocity and power production during deadlift to high pull among healthy young individuals (Zemková et al., 2016) and during a maximal isometric strength test of the back muscles in physically active and sedentary young individuals (Poór, Pecho, & Zemková, 2017). This provided a sample size of 23 for this study. Only male participants were included in the study, based on the recommendation that females should be considered separately in lifting-related studies (Yehoyakim et al., 2016).

Associations between parameters obtained from MVC of the back muscles and power produced during a deadlift to high pull with different weights were assessed using Pearson's product moment correlation coefficient (r). A standard multiple regression analysis was conducted to determine which independent variables of maximal back muscle strength were significant predictors of power performance during a lifting task. The amount of variance explained is reported by the coefficient of determination (r^2). The level of significance was set at $\alpha = 5\%$.

Results

Resistance-trained men ($n = 27$) and recreationally physically active men ($n = 41$) were recruited from university students. There were no significant differences in age, height, and body mass between these two groups.

As expected, peak and mean power produced during a deadlift to high pull were significantly higher in resistance-trained than in recreationally physically active men, however, only with weights ≥50 and 60 kg, respectively (Figure 3(a) and (b)). Maximal values of peak and mean power were achieved at 55 and 70 kg in resistance-trained men and at 40 and 60 kg in recreationally physically active men. Similar between-group differences were observed for peak and mean velocity produced during a deadlift to high pull (Figure 4(a) and (b)). A group of resistance-trained individuals also performed better during MVC of the back muscles as compared to recreationally physically active men, which may be corroborated by significantly higher peak force (3229.4 and 2540.3 N, $p = .001$) and peak RFD (21005.7 and 8011.0 N/s, $p = .000$; Figure 5).

There were significant correlations between peak RFD and power produced during a deadlift to high pull with

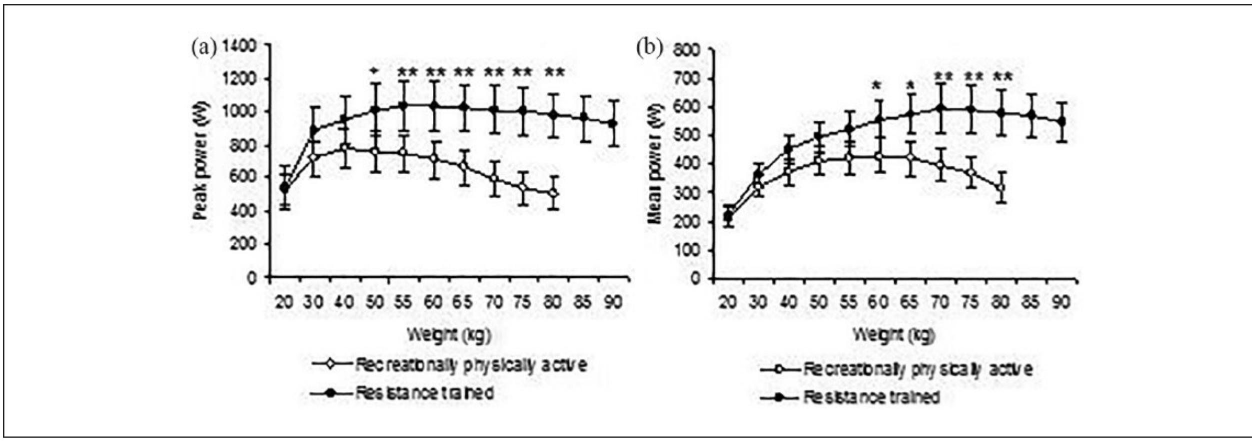

Figure 3. Peak power (a) and mean power (b) produced during a deadlift to high pull with different weights in resistance-trained and recreationally physically active men.
*$p < .05$. **$p < .01$.

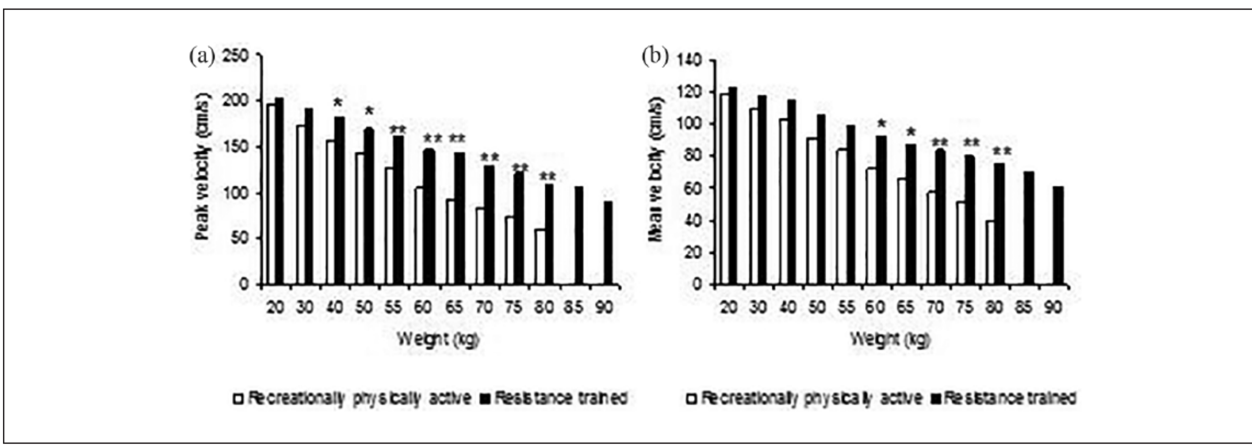

Figure 4. Peak velocity (a) and mean velocity (b) produced during a deadlift to high pull with different weights in resistance-trained and recreationally physically active men.
*$p < .05$. **$p < .01$.

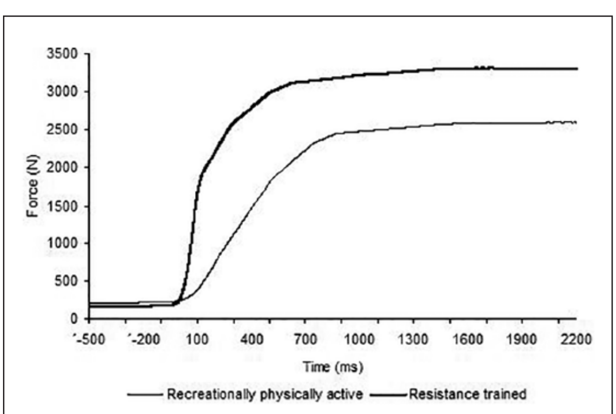

Figure 5. Force-time curves obtained from MVC of the back muscles in resistance-trained and recreationally physically active men. MVC = maximal voluntary isometric contraction.

weights from 20 to 40 kg (Table 1). The multiple regression analysis identified peak RFD as a significant predictor of a lifting performance with lower loads. This variable accounted for approximately 69% of the variability in power performance during the deadlift to high pull. On the other hand, peak force obtained from MVC of the back muscles correlated significantly with peak and mean power produced during the lifting task with weights ≥60 kg. This resulted in an explained variance in range from 54% to 80%, respectively.

Discussion

Peak RFD obtained from MVC of the back muscles correlated significantly with power produced during a deadlift to high pull with lower weights (from 20 to 40 kg). On the contrary, there was a tendency toward stronger

Table 1. Correlations Between Parameters of MVC of the Back Muscles and Muscle Power During a Deadlift to High Pull With Different Weights.

	Peak power		Mean power	
	r [95% CI]	r^2	*r* [95% CI]	r^2
20 kg				
Peak force	.515 [0.498, 0.530]	.27	.520 [0.507, 0.536]	.27
Peak RFD	.941 [0.957, 0.924][a]	.89	.922 [0.906, 0.939][a]	.85
30 kg				
Peak force	.563 [0.646, 0.579]	.32	.568 [0.555, 0.585]	.32
Peak RFD	.896 [0.881, 0.910][a]	.80	.861 [0.848, 0.881][a]	.74
40 kg				
Peak force	.640 [0.627, 0.657]	.41	.598 [0.583, 0.611]	.36
Peak RFD	.673 [0.650, 0.688][b]	.45	.633 [0.617, 0.647][b]	.40
50 kg				
Peak force	.645 [0.630, 0.658]	.42	.630 [0.616, 0.647]	.40
Peak RFD	.550 [0.536, 0.567]	.30	.536 [0.520, 0.556]	.29
55 kg				
Peak force	.677 [0.662, 0.695]	.46	.656 [0.640, 0.672]	.43
Peak RFD	.548 [0.525, 0.566]	.30	.507 [0.490, 0.525]	.26
60 kg				
Peak force	.764 [0.748-0.780][b]	.58	.735 [0.720-0.748][b]	.54
Peak RFD	.333 [0.317-0.349]	.11	.421 [0.406-0.437]	.18
65 kg				
Peak force	.807 [0.795, 0.823][a]	.65	.774 [0.757, 0.790][b]	.60
Peak RFD	.315 [0.298, 0.330]	.10	.369 [0.352, 0.386]	.14
70 kg				
Peak force	.831 [0.818, 0.846][a]	.69	.812 [0.795, 0.829][a]	.66
Peak RFD	.301 [0.284, 0.319]	.09	.286 [0.269, 0.304]	.08
75 kg				
Peak force	.840 [0.826, 0.854][a]	.71	.819 [0.802, 0.836][a]	.67
Peak RFD	.298 [0.283, 0.316]	.09	.251 [0.236, 0.268]	.06
80 kg				
Peak force	.857 [0.842, 0.873][a]	.73	.843 [0.828, 0.858][a]	.71
Peak RFD	.168 [0.155, 0.182]	.03	.150 [0.135, 0.167]	.02
85 kg				
Peak force	.861 [0.846, 0.877][a]	.74	.859 [0.844, 0.874][a]	.74
Peak RFD	.129 [0.111, 0.144]	.02	.124 [0.109, 0.138]	.02
90 kg				
Peak force	.888 [0.874, 0.903][a]	.79	.896 [0.880, 0.911][a]	.80
Peak RFD	.116 [0.102, 0.134]	.01	.103 [0.088, 0.116]	.01

Note. MVC = maximal voluntary isometric contraction; RFD = rate of force development.
[a]Significant ($p < .01$). [b]Significant ($p < .05$).

relationships between peak isometric force and the lifting performance when the weight increased (≥60 kg). This indicates that individuals with higher RFD are able to achieve greater power performance during a deadlift to high pull when lower weights are lifted, whereas those with higher isometric maximum strength produce greater power also at higher weights.

Such a lifting task requires coordinating the activation of the core musculature, either for stability or mobility, with involvement of the muscles of the upper and lower extremities. To evaluate the lifting performance, maximal effort single repetitions with increasing weights until the maximal power is reached are usually applied. This represents a more suitable testing procedure for the general population as compared to the one based on 1RM (Hamar, 2008). It is known that the 1RM corresponds to the highest load that can be lifted for the whole concentric phase and therefore depends on the strength developed in the weakest portion of the exercise. Analyzing velocity or acceleration in this crucial portion of the lift may be interesting, in particular when a participant reaches his or her 1RM. During the lifting, average peak load velocities occur in the range

1.00–1.48 m/s (Butler, Andersson, Trafimow, Schipplein, & Andriacchi, 1993; Leskinen, 1985; Schipplein, Trafimow, Andersson, & Andriacchi, 1990; Troup, Leskinen, Stalhammar, & Kuorinka, 1983), while high-speed lifts occur beyond a 2–4 s time frame (Waters, Putz-Anderson, Garg, & Fine, 1993). Compression on the spine was reported to increase directly with trunk velocity (Marras, Sommerich, & Granata, 1991), and fast lifts may dramatically increase the load on the spine (Hall, 1985). Maximum load acceleration occurs about one fifth of the way through the lift (20% of the time of the lift). Maximum L5/S1 moments and compressive and shear forces peak early in the lift. The maximum compressive force often coincides with the maximum vertical acceleration of the load. As speed increases, the maximum compressive force also increases. The maximum moment and shear force are significantly higher at fast speeds, but there is no effect between slow and normal speeds.

A measurement of power outputs during modified resistance exercises using computer-based diagnostic systems allows functional assessments of lifting performance under real sport or job-specific conditions. It may represent a more specific and therefore more appropriate method for both sedentary and physically active individuals when compared with most other laboratory tests. Though these appear to be safe and reliable, most dynamometers used in laboratories provide artificial movement patterns, suffer from a lack of sensitivity to differentiate between individuals, and are not specific enough to reveal training effects, in addition to being rather expensive for use in daily practice. Moreover, free weights and weight exercise machines are preferred by athletes and are available in most universities' sports centers for testing of college students. However, one has to be careful when a deadlift to high pull with higher weights is performed.

In particular, sedentary individuals should perform the loaded lifting task with extreme caution. Those prone to low back pain should avoid using an additional load. An appropriate alternative for this population is the test of maximal back muscle strength. Instead of peak force, one should evaluate the ability of subjects to produce a high force in a short time. The multiple regression analysis provided in the present study identified peak RFD as a significant predictor of a lifting performance with light loads. However, a high isometric maximum strength of the back muscles is necessary for athletes to produce great power during a lifting task at higher weights. Taking into account the importance of core stability and strength in physical performance and probably also in the prediction of injuries, their assessment should be included in the testing not only of athletes but also of the general population. Addressing underlying variables that have the ability to reveal back problems associated with sedentary lifestyle or excessive loading of core muscles can significantly reduce their incidence in later years.

Conclusions

Peak RFD obtained from MVC of the back muscles correlates significantly with power produced during a deadlift to high pull with lower weights. The strong relationship between the ability to develop a high force in a short time and the power performance during a lifting task implies that gains in RFD after the exercise program may be related to the increase in lifting performance at light loads. These findings also indicate that peak RFD obtained from MVC of the back muscles may be predictive of power performance during a lifting task. However, one needs a high isometric maximum strength of the back muscles for great power production when lifting higher weights. Therefore, these variables should be included in functional performance analysis of either healthy college graduate students and office workers with a prevalently sedentary lifestyle or highly resistance-trained athletes and construction workers with job demands based on lifting tasks. Alternatively, this method can be applied for healthy individuals who may benefit from testing by predicting the risk of low back pain.

Declaration of Conflicting Interests

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