BARBELL DEADLIFT TRAINING INCREASES THE RATE OF TORQUE DEVELOPMENT AND VERTICAL JUMP PERFORMANCE IN NOVICES

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ABSTRACT

Thompson, BJ, Stock, MS, Shields, JE, Luera, MJ, Munayer, IK, Mota, JA, Carrillo, EC, and Olinghouse, KD. Barbell deadlift training increases the rate of torque development and vertical jump performance in novices. *J Strength Cond Res* 29(1): 1–10, 2015—The primary purpose of this study was to examine the effects of 10 weeks of barbell deadlift training on rapid torque characteristics of the knee extensors and flexors. A secondary aim was to analyze the relationships between training-induced changes in rapid torque and vertical jump performance. Fifty-four subjects (age, mean ± $SD = 23 \pm 3$ years) were randomly assigned to a control ($n = 20$) or training group ($n = 34$). Subjects in the training group performed supervised deadlift training twice per week for 10 weeks. All subjects performed isometric strength testing of the knee extensors and flexors and vertical jumps before and after the intervention. Torque-time curves were used to calculate rate of torque development (RTD) values at peak and at 50 and 200 milliseconds from torque onset. Barbell deadlift training induced significant pre- to post-increases of 18.8–49.0% for all rapid torque variables ($p < 0.01$). Vertical jump height increased from 46.0 ± 11.3 to 49.4 ± 11.3 cm (7.4%; $p < 0.01$), and these changes were positively correlated with improvements in RTD for the knee flexors ($r = 0.30$–0.37, $p < 0.01$–0.03). These findings showed that a 10-week barbell deadlift training program was effective at enhancing rapid torque capacities in both the knee extensors and flexors. Changes in rapid torque were associated with improvements in vertical jump height, suggesting a transfer of adaptations from deadlift training to an explosive, performance-based task. Professionals may use these findings when attempting to design effective, time-efficient resistance training programs to improve explosive strength capacities in novices.

KEY WORDS leg flexors, leg extensors

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INTRODUCTION

Resistance training as an exercise mode has grown in popularity in recent decades. This method of training is often used by adolescents, athletes, non-athlete adults, elderly and clinical populations in a variety of settings (23). Its increased use as a training mode is a reflection of its role in eliciting health- and performance-related benefits. Benefits of resistance training have been reported to encompass improvements in cardiovascular, endocrine, body composition, and bone health–based parameters (29,37). However, enhanced physical performance and muscle function abilities that include increased strength, power, speed, balance, coordination, and agility are parameters often attributed to resistance training outcomes. Accordingly, resistance training is often used for the purpose of augmenting sport or other athletic-based performance tasks, and to aid in injury prevention (23,29).

Resistance training programs may vary widely as a result of a range of program design variables that include exercise intensity, volume (sets and repetitions), frequency, order, and exercise mode and selection. Previous studies have suggested that exercise training mode and selection may play an integral role in the training adaptation outcomes (23,29). Studies have examined the effects of resistance training on physical performance parameters using single-joint (8,12,20) and multiple-joint only training (11,16,24,38), as well as combined (single and multiple joint) (1,4,35) training programs. Although improvements in various physical performance parameters (i.e., muscle strength, size, power) have been reported in studies using different types of exercise training modes, experts have suggested and generally agree (23,29), that multiple-joint exercises may elicit training adaptations that tend to be more relevant to performance activities and functional movements.

In addition to the selection of appropriate training program design variables, a variety of performance-based outcome variables may be used to assess the adaptations to resistance training. The specific performance outcome variables used in testing provide a reflection of the training-induced adaptations. Training-induced physical performance outcomes are commonly assessed using measures of maximal isometric and dynamic muscular strength, power, speed, agility, and jumping performance (2). Recent studies have demonstrated high sensitivity of rapid strength characteristics to discriminate among various athletic-related abilities (27,34). Rapid strength characteristics, which include rate of force or torque development (RFD or RTD), are typically assessed from a force- or torque-time curve derived from an isometric maximal voluntary contraction (MVC). The capacity for rapid strength production is an important characteristic for physical performance tasks, because many sport or functional tasks (e.g., running, cutting, kicking, balance recovery) rely on the application of force in a short period of time (<250 milliseconds) (4). However, maximal strength expression requires longer time periods (>300 milliseconds), which may limit the functional relevance to various physical performance tasks (4). Support for high functional relevance of RTD compared with other muscle function variables has been shown by previous authors. For example, Thompson et al. (34) reported that early rapid torque (RTD at 50 milliseconds), but not maximal torque capacities discriminated playing status in Division I college football players. Recently, Palmer et al. (27) demonstrated that early RTD, but not peak torque, was predictive of professional status in elite soccer referees.

Although many investigations have examined the effects of resistance training on maximal muscle strength, fewer studies have examined these training effects on explosive strength capacities, with mixed findings reported in the literature (1,4,16–18). Interestingly, although improvements in RFD have been shown when training using single-joint exercises (12,20), these changes have not been demonstrated in multiple-joint training studies (16,24,25,28,38). Lamas et al. (24) found no change in RFD following squat training and speculated this could have been a result of either a lack of test specificity or training effect. Although low test specificity of these studies may be a contributing factor to the lack of observed gains, it is plausible that the absence of RFD increases is the result of a nonexistent training effect. However, to our knowledge, previous studies have examined these training effects using only the squat (11,16,24,25,38,39) or leg press (28) exercises, and it is unknown whether the lack of improvements are a result of these specific multiple-joint exercises. Moreover, measures of lower-body testing used to evaluate training effects on RFD have been performed exclusively on the knee extensors; however, the knee flexors also contribute to these lower-body multiple-joint exercise movements. We know of no studies that have examined the effects of a multiple-joint training protocol on RFD or RTD of the knee flexors, which have been shown to be more sensitive to functional performance- and athletic-based abilities (7,27,34).

The deadlift is a simple exercise that requires force application through the lower-body kinetic chain. It involves the simultaneous activation of multiple agonists, particularly for the muscles of the knee joint (i.e., knee extensors and flexors; with the flexors [e.g., hamstrings] serving dual roles as knee stabilizers and hip extensors) (14). Thus, deadlift training may effectively elicit neuromuscular adaptations for functional strength-related performance tasks, with the potential of improving training efficiency because of the involvement of dozens of muscles exhibiting high cocontractions through a large range of motion (14). In addition, previous findings (31) show that the deadlift may enable acceleration periods throughout a large proportion of the lift, which may theoretically favor the development of muscular power (31). In practice, coaches have anecdotally contended that the deadlift may be a more specific performance exercise, because of its higher reliance on hip extension activation. However, no previous studies have examined the effects of deadlift training on rapid torque capacities, or the relationship of these training-induced changes with improvements in an explosive performance-based task (e.g., vertical jump). The purpose of this study was to examine the effects of 10 weeks of deadlift training on rapid torque characteristics of the knee extensors and flexors and to analyze the relationships between training-induced rapid torque changes and vertical jump performance.

METHODS

Experimental Approach to the Problem

This study used a randomized controlled design with repeated measures to investigate the influence of 10 weeks of deadlift training on rapid torque and vertical jump performance characteristics in previously untrained college-aged men and women. Subjects performed isometric MVCs and countermovement vertical jumps before and after a 10-week deadlift training intervention that consisted of 5 sets of 5 repetitions, 2 times per week. This investigation tested the hypothesis that 10 weeks of barbell deadlift training would elicit small but significant increases in rapid torque capacities for both the knee extensors and flexors. We also hypothesized that changes in rapid torque would be associated with improvements in vertical jump performance, which would serve as an indication of the degree of transfer of training adaptations to explosive performance-based abilities. The data presented herein are part of a larger investigation.

Subjects

Fifty-four college-aged men and women who were not engaged in any form of structured physical activity were recruited to participate in this study. The subjects were randomly assigned to either a control (9 men, 11 women; age, range 19–28 years mean ± *SD* = 22.9 ± 2.3 years; height = 172.2 ± 8.2 cm; body mass = 73.8 ± 17.1 kg) or training group (17 men, 17 women; age range 18–30 years, age = 22.8 ± 3.0 years; height = 173.3 ± 9.9 cm; body mass = 75.9 ± 14.7 kg). The subjects were screened for health-related issues during the initial visit. None of them reported any current or ongoing neuromuscular diseases or recent musculoskeletal injuries that would prevent them from performing the deadlift movement. The study was approved by the Texas Tech University Institutional Review Board and all subjects provided written informed consent before involvement in the study. This investigation was conducted during the summer of 2014.

During the enrollment process, all potential subjects were told that if they wished to participate in the study, lower-body strength training outside the laboratory was not permitted. Two hours per week of light/moderate physical activity (e.g., walking, jogging, swimming) outside the investigation were permitted, but none of the subjects were actively involved in endurance sports or aerobic training. Potential subjects who were not confident that they could follow these instructions were not enrolled in the investigation. For the subjects in the training group, adherence to the physical activity guidelines was periodically verified by the second author, who supervised nearly all the 680 training sessions. Detailed nutritional guidelines were not provided, and the subjects were not asked to provide food logs. The subjects were asked to avoid the use of dietary supplements throughout the investigation. Coffee/caffeine consumption was permitted as long as each subject's intake was kept consistent.

Testing Procedures

Each subject completed a familiarization session before the pretest. During the familiarization, the subjects practiced the isometric strength testing protocol, which consisted of performing 2–3 MVCs of the knee extensors and flexors on an isokinetic dynamometer (Biodex System 3; Biodex Medical Systems, Shirley, NY, USA). The subjects were also familiarized with the countermovement vertical jump test procedures. Forty-eight hours after familiarization, the subjects reported back to the laboratory for the pretest measurement session where they again performed the isometric strength tests of the knee extensors and flexors and countermovement vertical jumps. For both data collection sessions (i.e., pretest and posttest), the subjects were asked to: (a) refrain from any vigorous physical activity or lower-body exercise within 48 hours of testing, (b) drink plenty of water, (c) maintain their normal dietary habits, and (d) attempt to get 7–8 hours of sleep the evening before testing. In addition, for each subject, the testing sessions occurred at approximately the same time of day (±1 hour). For the subjects in the training group, the posttest was scheduled a minimum of 72 hours following the final training session. The same investigator performed all the testing for this study.

Isometric Strength Testing

All isometric strength testing was performed on the left leg using the Biodex isokinetic dynamometer. The subjects were seated with restraining straps placed over the trunk, pelvis, and thigh, and the input axis of the dynamometer was aligned with the axis of rotation of the knee. Before the MVCs, the subjects performed a warm-up protocol consisting of 3 submaximal isometric muscle actions of the knee extensors and flexors corresponding to ~50% of their perceived maximum, for a duration of 10 seconds for each muscle action. Following the warm-up, the subjects performed 2 isometric MVCs for the knee extensors and flexors at leg angles of 60 and 30° below the horizontal plane, respectively (10). Each MVC was 6 seconds in duration. A 2-minute rest period was provided between all MVCs. The order of muscle group testing was randomized. During all MVCs, the subjects were verbally instructed for the knee extension and flexion MVCs to "push" or "pull," respectively, as "hard and fast as possible." Strong verbal encouragement was provided throughout the duration of each MVC (34).

Signal Processing

The signal analyses procedures used in the present study have been used in our previous work (33). The torque signal was sampled from the dynamometer and processed off-line with custom written software (Labview 8.5; National Instruments, Austin, TX, USA). The scaled torque signal (Newton-meters, $N \cdot m$) was filtered with a 10-Hz cutoff frequency. The passive baseline torque value was considered the limb weight and subtracted from the signal so that the new baseline value was $0\ N \cdot m$. All subsequent analyses were performed on the scaled, filtered, and gravity-corrected torque signal.

Peak rate of torque development (RTDpeak) was determined from the peak value of the first derivative of the ascending portion of the torque-time curve. Rate of torque development was quantified from the linear slope of the torque-time curve at time intervals of 0–50 (RTD50) and 0–200 (RTD200) milliseconds. These time intervals were selected to represent maximal (RTDpeak), early (RTD50), and late (RTD200) rapid torque characteristics due to the potentially unique physiological information provided during the distinct time phases (4,32,33). The onset of contraction was determined as the point when the torque signal reached a threshold of $7.5\ N \cdot m$ for the knee extensors, and $4\ N \cdot m$ for the knee flexors (33).

Countermovement Vertical Jump Testing

Before and immediately after the training intervention, the subjects were tested for no-step countermovement vertical jump height using the guidelines described by Kraemer and Fleck (22). The testing was performed with a Vertec (JUMPUSA.com, Sunnyvale, CA, USA). Before jump testing, standing reach height was determined. To accomplish this, the subjects stood directly below the Vertec's vanes with their feet approximately hip-width apart and toes pointed forward. The subjects then reached their dominant hand as high as possible and pushed aside the Vertec's vanes. Standing reach height was thus defined as the highest vane that was touched with the dominant hand while both feet remained flat on the ground. Once standing reach height was determined, the subjects performed countermovement vertical jump testing. To do so, they stood directly under the Vertec with the dominant shoulder directly below the lateral edge of the lowest vane. The subjects then performed a maximal countermovement jump, and pushed aside as many vanes as possible with the dominant hand. Detailed

TABLE 1. Mean (*SD*), % change, and Cohen's *d* values for RTD for the knee extensors and flexors and vertical jump variables pre- and posttraining for the control and training groups.*†

		Control group			Training group					
	Variable	Pre	Post	% Change	Pre	Post	% Change	Interaction (*p*)	Cohen's *d* (training group, pre-post)	Cohen's *d* (between-group, postdifferences)
Knee extensors	RTDpeak ($N\cdot m\cdot s^{-1}$)	604.0 (239.6)	586.5 (292.7)	−2.9	668.9 (337.0)	835.6 (236.2)‡§	25.0	0.02	0.57	0.94
	RTD50 ($N\cdot m\cdot s^{-1}$)	532.4 (226.8)	509.0 (235.7)	−4.4	580.8 (284.8)	737.3 (184.7)‡§	26.9	<0.01	0.65	1.08
	RTD200 ($N\cdot m\cdot s^{-1}$)	366.5 (141.3)	343.4 (148.6)	−6.3	408.1 (185.1)	501.1 (137.0)‡§	22.8	<0.01	0.57	1.10
Knee flexors	RTDpeak ($N\cdot m\cdot s^{-1}$)	310.2 (117.4)	300.8 (128.6)	−3.0	305.1 (141.1)	370.1 (127.2)‡	21.3	<0.01	0.48	0.54
	RTD50 ($N\cdot m\cdot s^{-1}$)	234.0 (111.4)	227.8 (118.9)	−2.6	199.6 (94.6)	297.5 (98.8)‡§	49.0	<0.01	1.01	0.64
	RTD200 ($N\cdot m\cdot s^{-1}$)	208.8 (74.0)	185.4 (65.8)‡	−11.2	208.8 (98.5)	248.0 (86.3)‡§	18.8	<0.01	0.42	0.82
Vertical jump height (cm)		45.7 (10.9)	46.0 (11.1)	0.7	46.0 (11.3)	49.4 (11.3)‡	7.4	<0.01	0.30	0.30

*RTD = rate of torque development; RTDpeak = peak rate of torque development.
†Interaction effects are reported as group (training vs. control) × time (pre vs. post) values from the mixed analysis of variance.
‡Significant ($p \leq 0.05$) within-group differences.
§Significant between-group differences for the post time point.

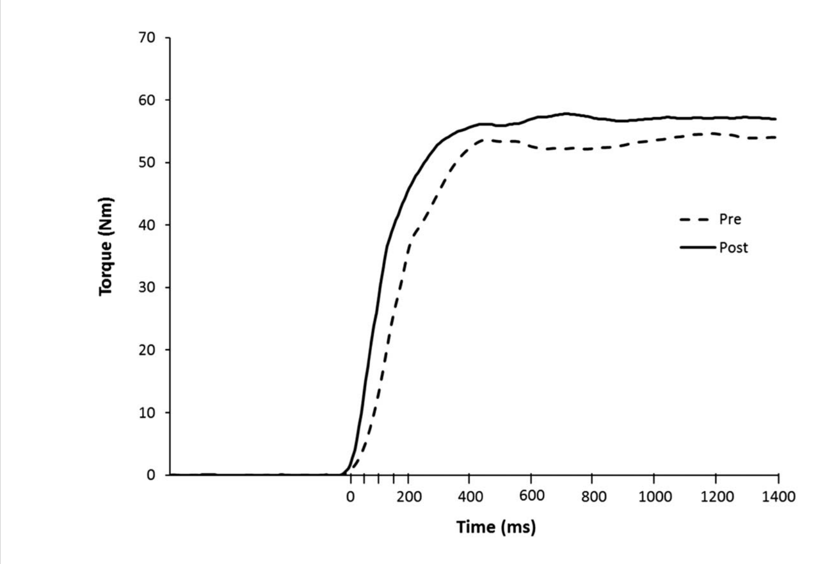

Figure 1. Torque-time tracings obtained for 1 subject for the knee flexors before (Pre) and after (Post) 10 weeks of deadlift training. Note the differences between Pre and Post tracings for the slope of the rising torque phase of the curve.

instructions regarding arm action or jumping technique were not provided, but the subjects were encouraged to try to "be explosive" during each jump. The subjects were allowed to perform attempts until no additional vanes were reached, and a 1-minute rest period was provided between each jump. For the majority of cases, the maximal jump height was established within 2–3 attempts. Maximal countermovement jump height was determined by subtracting the standing reach height from the maximal absolute jump height.

Barbell Deadlift Training

The subjects in the training group performed deadlift training at the Texas Tech University Human Performance Laboratory 2 times per week for 10 weeks (20 sessions total). A minimum of 48 hours of rest was provided between training sessions, with the majority of the subjects training on either Mondays and Thursdays or Tuesdays and Fridays. In the event that a subject missed 2 consecutive training sessions, they were removed from the study. Individualized instruction and verbal feedback regarding exercise technique was provided throughout the study. Specifically, the subjects were taught to perform the deadlift with their feet shoulder width apart, and their toes pointed forward. The starting position involved the barbell making light contact with the anterior portion of both legs, with the tibias aligned in a vertical position. During the exercise, the subjects were instructed to maintain their cervical spine in a neutral position throughout the range of motion. The arms were held just outside of the thighs, and the subjects were allowed to use either a pronated or an alternated grip, depending on personal preference. Particular attention was paid to each subject's lower back to ensure that all repetitions were performed with the lumbar spine in a rigid, extended position. As proper technique was our primary focus, detailed instructions concerning lifting velocity were not provided, and the subjects were not encouraged to move the weight explosively. Rather, each repetition was performed in a controlled manner with approximately 2-second lifting and lowering phases interspersed with a brief pause at the top of the range of motion. The subjects were instructed to briefly stop between repetitions and not bounce the weight from the floor. To ensure that the range of motion was consistent across all subjects, 4.5 kg bumper plates (17.5″ in diameter) were added to the barbell for all external loads less than 61.2 kg. The use of the Valsalva maneuver was taught and encouraged. Weight belts and wrist straps were not permitted, but chalk was allowed and recommended. During the course of the study, 3 injury events were reported, but none of the subjects withdrew from the study as a result of an injury.

Given that the majority of the subjects in the present study were unable to perform the deadlift exercise correctly at the onset of training, and that previous authors (5) have suggested untrained individuals do not perform repetition maximum testing for the deadlift, repetition maximum testing was not performed in this study. Thus, the training loads were not based on the results from strength assessments (i.e., percent of 1 repetition maximum). Instead, a nontraditional method of training load determination was used that involved the subject lifting the heaviest external load possible, which allowed them to complete 5 sets of 5 repetitions with correct technique. Following each set and training session, additional weight was added to the barbell based on the subject's ability to complete the desired number of repetitions and the investigator's perception of the quality of training. Progressive overload was facilitated by adding 0.45–2.2 kg to the barbell for each training session. On a few cases in the beginning of the study, 4.5 kg increases were made. In the event that 5 repetitions of a set could not be completed, or if exercise technique was compromised because of fatigue, 0.45–2.2 kg was subsequently removed from the barbell. If the subjects were unable to complete 5 repetitions for all 5 sets, a sixth set was allowed so that a total of 25 repetitions were always performed during each session. All training sessions began with

2 warm-up sets of 5 repetitions. Three minutes of rest were provided between each set. The mean ± *SD* external loads used in this investigation increased from 66.2 ± 22.3 to 123.1 ± 21.8 kg for men and 37.8 ± 7.0 to 70.7 ± 12.2 for women.

Statistical Analyses

Analyses of covariance with the pretest and posttest values serving as the covariate and dependent variable, respectively, were considered as a means of examining these data. However, many of the analyses violated the homogeneity of regression assumption (36). As a result, 7 separate 2-way mixed factorial analyses of variance (group [training vs. control] × time [pretest vs. posttest]) were used to examine the rapid torque and jump height variables. When appropriate, follow-up analyses included dependent and independent samples *t*-tests with Bonferroni corrections. In addition Cohen's *d* statistics were calculated in which values of >0.20, 0.50, and 0.80 corresponded to small, medium, and large effect sizes, respectively (9). Pearson product-moment correlation coefficients (*r*) were used to determine relationships between vertical jump and RTD variables. The statistical analyses were performed using SPSS software version 21.0 (SPSS Inc., Chicago, IL, USA). An alpha level of $p \leq 0.05$ was considered statistically significant for all comparisons. All noncorrelational data are presented as mean ± *SD* except for in the figures where data are presented as mean ± *SE* for clarity of presentation.

RESULTS

There were no differences between the training and control groups for age ($p = 0.90$), body mass ($p = 0.64$), or height ($p = 0.68$). Mean values, percent change of the mean values, and Cohen's *d* effect size values are presented in Table 1 for all the RTD and vertical jump height variables. Figure 1 provides an illustration of the changes before and after training in the torque-time tracings for 1 subject in the training group. For RTDpeak, there was a significant group × time interaction for the knee extensors ($p = 0.02$) and flexors ($p < 0.01$). For both the knee extensors and flexors, follow-up analyses revealed no differences between groups for the pretest comparisons ($p = 0.45$–0.89). However, for the posttest comparisons, the training group exhibited greater RTDpeak for the knee extensors ($p < 0.01$), but not the knee flexors ($p = 0.06$). Dependent *t*-tests revealed significant pretest to posttest increases in RTDpeak for the training group for the knee extensors ($p < 0.01$) and flexors ($p < 0.01$) but not for the control group ($p = 0.62$–0.69).

For RTD50, there was a significant group × time interaction for the knee extensors ($p < 0.01$) and flexors ($p < 0.01$). For both the knee extensors and flexors, follow-up analyses revealed no differences between groups for the pretest comparisons ($p = 0.23$–0.52). However, for the posttest comparisons, the training group exhibited greater RTD50 for the knee extensors ($p < 0.01$) and flexors ($p = 0.02$). Dependent *t*-tests revealed pretest to posttest increases in RTD50 for the training group for the knee extensors ($p < 0.01$) and flexors ($p < 0.01$) but not for the control group ($p = 0.57$–0.79).

For RTD200, there was a significant group × time interaction for the knee extensors ($p < 0.01$) and knee flexors ($p < 0.01$). For both the knee extensors and flexors, follow-up analyses revealed no differences between groups for the pretest comparisons ($p = 0.39$–0.99). However, for the posttest comparisons, the training group exhibited greater RTD200 for the knee extensors ($p < 0.01$) and flexors ($p < 0.01$). Dependent *t*-tests revealed pretest to posttest increases in RTD200 for the training group for the knee extensors ($p < 0.01$) and flexors ($p < 0.01$), whereas for the control group, there was no pretest to posttest difference for the knee extensors ($p = 0.22$) but there was a significant decrease for the knee flexors ($p = 0.01$). Pretest to posttest difference scores for all RTD variables are shown in Figure 2; the changes in all RTD variables for both the knee extensors and flexors were greater ($p < 0.01$–0.02) in the training compared with the control group.

For vertical jump height, there was a significant group × time interaction ($p < 0.01$). However, the follow-up analyses

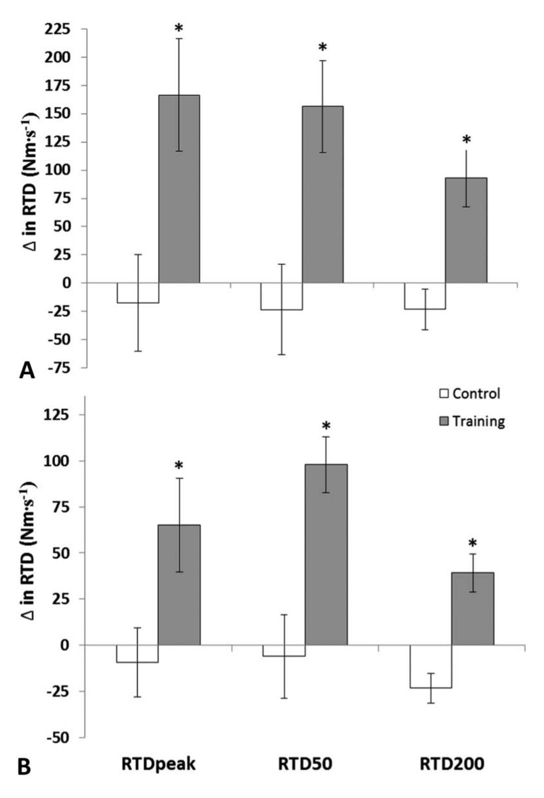

Figure 2. Pre- to posttraining changes in peak rate of torque development (RTDpeak), RTD at 50 (RTD50) and RTD at 200 (RTD200) milliseconds for the (A) knee extensors, and (B) knee flexors in the training (filled bars) and control (open bars) groups. *Significantly different from the control group ($p \leq 0.05$). Data are mean ± *SE*.

revealed no differences between groups for either the pretest ($p = 0.92$) or posttest ($p = 0.29$) comparisons. Dependent *t*-tests revealed pretest to posttest increases in vertical jump height for the training group ($p < 0.01$), but there was no pretest to posttest difference for the control group ($p = 0.44$). In addition, pretest to posttest training-induced changes in vertical jump height were correlated to changes in knee flexor RTD at peak ($r = 0.37$; $p < 0.01$), 50 milliseconds ($r = 0.30$; $p = 0.03$), and 200 milliseconds ($r = 0.37$; $p < 0.01$), but no correlations were observed for the knee extensor RTD at peak ($r = 0.19$; $p = 0.17$), 50 milliseconds ($r = 0.21$; $p = 0.13$), and 200 milliseconds ($r = 0.23$; $p = 0.10$). However, knee flexor RTD changes were correlated to knee extensor changes for RTDpeak ($r = 0.36$, $p < 0.01$), and RTD200 ($r = 0.52$, $p < 0.01$), but not for RTD50 ($r = 0.15$; $p = 0.27$).

Discussion

The primary findings of the present study showed that 10 weeks of deadlift training elicited improvements in the rapid torque characteristics of both the knee extensors and flexors, and these increases were related to vertical jump improvements. The training protocol used in the present study elicited increases of 22.8–26.9% and 18.8–49.0% in all the rapid torque variables of the knee extensors and flexors, respectively. In agreement with the present findings, some previous studies have reported increases in RFD following dynamic resistance training (1,4,12,20,35). In contrast, other investigations have reported either no changes (6,16,18,24,28,38), or decreases (25) in RFD or RTD following training. The discrepancies among studies are likely because of differences in subject training status (resistance trained vs. untrained), training mode and variables (i.e., single- vs. multiple-joint exercises, volume, load, frequency, training duration, contraction speed), methodological differences in isometric MVC testing procedures, and differences in the calculations and time intervals of RFD or RTD variables. For example, when examining rapid torque changes with training, a number of studies have used single-joint isokinetic (8,12) or dynamic constant external resistance training (20) protocols, whereas others have involved multiple-joint training (11,16,24,25,38,39). Specifically, studies on single-joint knee extensor training have reported relatively large effects on rapid torque capacities, showing RFD increases of 56.3–62% following 6 weeks of isokinetic training (12), and 101.8% following 8 weeks of heavy knee extension training (20). Thus, single-joint training has been demonstrated to enhance RFD capacities, particularly when specificity of testing is applied.

We know of no other studies that have examined the effects of barbell deadlift training on rapid torque characteristics. However, several previous authors have used the squat exercise for lower-body training when examining rapid force changes. Interestingly, in contrast to single-joint training of the knee extensors, the majority of the studies involving squat-only training have reported no statistically significant changes in lower-body RFD (11,16,24,38,39). Marshall et al. (25) actually reported a decrease in knee extensor RFD following squat training. The results from these studies (11,16,24,25,38,39) are all in contrast to the significant increases in all RTD variables following deadlift training in the present study. A number of factors may be responsible for these discrepant findings among studies. For instance, a closer inspection of the squat studies reveals that some of them used shorter training periods (24,38,39), and resistance trained subjects (16,24,25,38) in comparison with the 10-week training period and untrained subjects used in this investigation. Moreover, in 1 of 2 squat training studies using nonresistance trained subjects, Young and Bilby (39) used a half-squat rather than full-squat exercise, which given the lower range of motion-and-joint-specific training effects, may have attenuated the possibility for greater gains in RFD. It is also noteworthy that although both the studies using nonresistance-trained subjects did not report statistically significant gains in RFD, the pre- to postgroup mean increases in RTD were 33.5% and 21.1–45.4% for Cormie et al. (11) and Young and Bilby (39), respectively, which are more similar to the present percent increases. In addition, different isometric testing modes have been used across these multiple-joint training studies that have included knee extensions (16,25), leg press (24), and squat (11,38,39) MVCs. This further complicates comparisons across studies because of the inherent differences in testing specificity.

Despite the many training-related differences among investigations examining changes in RFD or RTD, the most distinct characteristic between this study and previous publications is the training mode itself. The present increases in RTD resulting from deadlift training are in contrast to the overall lack of increases observed from training with the squat exercise. Therefore, it is possible that the movement characteristics for the squat vs. deadlift exercises are dissimilar in terms of torque-time characteristic adaptations to training. Because this is the first study examining torque-time changes resulting from deadlift training, these findings provide new insight into these specific adaptation characteristics. Despite commonly perceived similarities between the squat and deadlift exercises, the findings of Hales et al. (19) provide support for distinct movement characteristics. In particular, their findings showed that the deadlift exercise yielded greater bar velocities and distinct knee extension movement during the initial ascent phase (start of concentric contraction), compared with the squat. Furthermore, Hales et al. (19) demonstrated that the knee angle at lift off corresponded to 54.3 and 113.8° (0° = full extension) for the deadlift and squat, respectively. This angular position of the knee during the onset of the deadlift is more specific to the angle typically used during isometric testing (~60–70°), which is the angle where knee extensor strength is near maximal capacity (10,13). This may be influential because the initial pull from the floor requires considerable force to overcome the inertia of the load and is often considered the mechanically hardest part of the movement. Another important difference between the squat and deadlift exercises is the presence of an eccentric contraction phase before concentric contraction for the squat, which elicits a stretch reflex to help initiate upward movement of the load at the bottom of the range of motion. However, the deadlift does not have the advantage of an eccentric loading phase or the stretch reflex for load acceleration at lift off. Thus, the barbell load must be moved from a standstill, beginning with a concentric contraction. Accordingly, an explosive concentric contraction would appear to be required to exert enough upward momentum to "break" the bar from the ground. Taken together, these kinetic and kinematic factors may yield a high reliance on rapid strength capacities, particularly during the lift-off phase of the deadlift movement. The reliance on an explosive concentric contraction at the lift-off phase of the deadlift may be supported by the greater velocity at this early phase compared with the squat movement (19). These biomechanical differences highlight some possible explanations for the observed differences among studies evoked by squat or deadlift training on rapid strength changes. However, further research is necessary to extend upon these findings, perhaps examining whether similar results are observed using more resistance trained populations.

A novel aspect of this study was the training-induced increases in knee flexor RTD, with a particularly high increase (49%) at the early RTD (RTD50) time phase. Interestingly, the results of the present study showed that a simple deadlift exercise protocol elicited significant increases in rapid torque capacities in both the agonist and antagonistic muscle groups spanning the knee joint. Although a majority of studies have examined the effects of training on rapid force characteristics of the knee extensors, no studies have examined these effects for the knee flexors, which have functional importance for performance abilities and injury risks. The early RTD (RTD50) characteristics of the knee flexors have been shown to be sensitive markers of athletic-related performances. For example, several studies have demonstrated that early knee flexor RTD more effectively discriminates athletic (34), professional referee (27), and fall risk (7) status compared with conventional isometric peak torque capacities. Thus, 10 weeks of deadlift training may be an effective training protocol to elicit marked improvements in knee flexor explosive muscle function characteristics, which has promising implications for sport and recreational performances, and possibly injury and rehabilitative purposes. It is possible that other training (i.e., sets, repetitions or frequencies yielding greater total volume), or higher movement velocities may further enhance the improvements of deadlift training. Thus, further research is warranted examining comparisons between other lower-body resistance exercises (e.g., squat, leg press, plyometrics) and routines in comparison with the present findings, so that the most optimal training strategies for RTD enhancement may be elucidated.

Our findings demonstrated relatively similar RTD increases across the time intervals (peak, early, and late), with an exception being the markedly higher increase in RTD50 for the knee flexors. These similar increases across the different phases of the torque-time curve were not expected, based on the findings of previous studies showing distinctly different training-induced changes in early vs. late RFD time phases (8,12,26). For example, de Oliveira et al. (12) showed that fast-velocity isokinetic knee extensor training produced increases in the early ($<$90 milliseconds), but not later time phases. In contrast, Andersen et al. (4) reported multiple and single-joint lower-body high-intensity (6–12 repetition maximum) strength training yielded increases at later (250 milliseconds), but not earlier, time phases. However, it is possible that the deadlift exercise may elicit increases at all phases of the torque-time curve, because of its unique demands for both rapid and maximal strength capacities. As mentioned previously, explosive force may be a requirement early in the lift-off portion of the deadlift, whereas maximal strength production is an important component of this exercise throughout the entire range of motion. Given that previous authors have revealed that maximal strength capacities and improvements are more associated with the later (200 milliseconds) RTD time phase (3,4), it would be expected that the maximal strength demands of the deadlift may also provide the basis for these later RTD (RTD200) increases.

Although previous studies (15,21,30,38) have shown significant increases in vertical jump performance following high-intensity lower-body resistance training, the present study is the first to demonstrate vertical jump increases as a result of training using the barbell deadlift in the absence of other exercise interventions. The 7.4% increase in vertical jump height shown in this study is similar to the findings of other lower-body resistance training investigations (4.8–10%) (15,30,38). The improvements in vertical jump height suggest that the neuromuscular adaptations as a result of deadlift training were effectively transferred to an explosive performance-based task. Although a number of neuromuscular adaptations from lower-body training may be contributors to the observed increased vertical jump height, these findings are among the first to demonstrate that training-induced changes in RTD were related to the vertical jump improvements ($r = 0.37$). Of interest, however, was that these relationships (RTD vs. vertical jump changes) were only revealed for the knee flexors, but not the knee extensors. We speculate this finding may be a reflection of the importance of the knee flexors for functional performance-related tasks (i.e., jumping, sprinting, agility), which may be supported by previous findings (21,27,34). Nonetheless, the enhanced explosive lower-body capacities elicited from deadlift training may provide improvements in athletic-related performance tasks; however, further research is warranted to determine the extent of these specific training effects on various sport and performance tasks.

Practical Applications

Ten weeks of barbell deadlift training resulted in enhanced explosive strength characteristics for the knee extensor and flexor muscle groups. Furthermore, the changes in explosive strength induced by training were related to increased vertical jump height. These findings highlight the effectiveness of a simple deadlift training program that involved 20 training sessions of only 5 exercise sets per session. These findings also suggest that when performed in the absence of other exercises, barbell deadlift training may be a time-efficient method to simultaneously improve explosive strength of both knee extensors and flexors. These adaptations were transferred to a nonspecific, explosive performance-based task (vertical jump), highlighting the utility of barbell deadlift training to potentially enhance physical performance abilities. We caution that these findings are context specific, and may not be applicable to highly trained athletes, or those performing a variety of training exercises (squats, power cleans, etc.).

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