Contraction force specificity and its relationship to functional performance

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Abstract
Best practice for improving strength and power through resistance strength training has been the subject of much research and subsequent conjecture. Much of the conjecture can be attributed to methodological discrepancies. The type of dynamometry used in testing, the training experience of research participants, the specific technique employed in a lift, and the methods of collection and calculation all impact on the final variables of interest. This review examines contraction force specificity by first addressing the methodological issues surrounding our interpretation of the results. Then we address the kinematics and kinetics associated with single and multiple repetitions in relation to the development of strength, power, and functional performance. This discussion provides the delimitations for analysis of subsequent training studies. Finally, recommendations are formulated with the aim of assisting assessment and training practice as well as providing directions for future research. The results of this review suggest that the enhancements in performance resulting from resistance training are context specific in experienced resistance-trained participants. Thus, specific conditioning could be required to achieve improvements in functional performance in this group.

Keywords: Resistance training, kinetics, kinematics, assessment

Introduction

Strength and power are critical to the performance of many athletic tasks and everyday activities (Stone, Moir, Glaister, & Sanders, 2002). Consequently, best practice for improving strength and power through resistance strength training has been the subject of much research and subsequent conjecture. Some of the conjecture can be attributed to the multi-factorial nature of strength and power. For example, strength has been generally defined as the peak force developed in a maximal voluntary isometric contraction, or as the maximum load that can be lifted for one repetition (1-RM). Power is defined as the rate at which mechanical work is performed or as the product of force and velocity (Abernethy, Wilson, & Logan, 1995; Harman, 1993; Sale, 1991). However, other definitions acknowledge the specificity of strength and power, their expression being affected by body position, movement pattern, velocity, contraction type, and contraction force (Sale, 1991). That is, strength and/or power exhibited under one set of conditions could be quite different under another set of conditions (Atha, 1981). The purpose of this review is to assess the effects of contraction force specificity on changes in strength, power, and functional performance.

Sale and MacDougall (1981) proposed that the optimal load (contraction force) for strength improvement depends on a needs analysis of the functional task of interest. It was suggested that if the activity involved a few brief contractions, 90–100% 1-RM training would be most specific, whereas if the activity involved a “large” number of contractions, 75–80% 1-RM training would be more appropriate. Sale and MacDougall (1981) suggested that the motor unit activation patterns and biochemical adaptations resulting from each loading scheme constituted a sound rationale for the use of these specific loading patterns. However, given the advances in strength and conditioning practice, the myriad of loading schemes or protocols available to the strength and conditioning practitioner and the individual responses known to occur to these different loading schemes, this proposition could be overly simplistic.
This review first addresses contraction force specificity in terms of the kinematics and kinetics associated with single repetitions. Then, the effect of multiple repetitions on the development of strength, power, and functional performance will be discussed. Methodological issues concerning our interpretation of the results from training studies will be critiqued. This discussion will provide the delimitations for analysis of subsequent training studies. Finally, recommendations will be formulated with the aim of assisting assessment and training practice as well as providing direction for future research.

**Repetition kinematics and kinetics**

It is generally accepted that maximal or near maximal forces are required to recruit and overload the higher threshold type II fibres and that heavy loads (~60% 1-RM and above) are necessary to achieve this (Bloomer & Ives, 2000; McDonagh & Davies, 1984; Sale, 1992). However, most studies have reported only the load used during training and/or testing and not the forces associated with the use of these loads. By definition, force is the product of mass and acceleration. Therefore, determining the acceleration profile of a lift is important, in that higher forces can result from greater accelerations as well as an increase in load. Consequently, if a given sub-maximal load is moved with maximal acceleration, it could impose a different stress on the neuromuscular system and hence result in different adaptations. Figure 1 illustrates the interrelation between muscle force, velocity, and power.

In traditional weight training lifts where the bar and/or load reaches a velocity of zero at the end of the concentric phase, deceleration occurs for a considerable portion of the contraction (Baker, Nance, & Moore, 2001b; Wilson, 1993). For example, loads of 81% 1-RM resulted in deceleration for 51.7% of the concentric phase during a bench press where the grasp was maintained on the bar at the end of the concentric phase (Elliott, Wilson, & Kerr, 1989). An alternative technique where the load (bar and/or oneself) is projected as in jumping and throwing has been termed “ballistic” training and can result in higher force outputs (Newton & Kraemer, 1994). In the following, we briefly review the kinematics and kinetics both of traditional and ballistic techniques for the upper and lower body.

**Upper body**

Newton, Kraemer, Hakkinen, Humphries and Murphy (1996) compared the kinetics, kinematics, and neural activation of a traditional bench press movement performed explosively (press) and a ballistic bench press throw in which the barbell was projected from the hands at the completion of the concentric phase (throw). Both the press and the throw were performed at 45% 1-RM. Several differences ($P < 0.05$) were observed for the concentric phase between the press and throw movements. Peak velocity (36%), mean velocity (27%), mean force (35%), and peak power (67%) were all greater for the bench press throw than the bench press. Additionally, the mean rectified and integrated electromyographic activity (EMG) of the pectoralis major, anterior deltoid, triceps brachii, and biceps brachii muscles was higher (19 – 47%) for the throw than the press. It was noted that when the bench press was performed in the normal manner, the traditional bench press movement resulted in a considerable deceleration phase (40%) before the conclusion of the concentric movement. For the bench press throw, however, acceleration occurred over 96% of the concentric movement, thus explaining the greater velocity, force, power, and neural activation found in the throw versus press. It was concluded that
“ballistic” training could be a superior mode of training for activities where projection of a load is required such as in throwing or passing. It was also suggested that ballistic training might be an effective way to overload the neuromuscular system effectively throughout the range of motion.

Similarly, Cronin, McNair and Marshall (2001) compared the kinetic and kinematic characteristics of an explosive bench press where the bar was held at the completion of the concentric phase and an explosive bench press throw across loads of 30 – 80% 1-RM. Significantly higher mean velocities (4.4%), peak velocities (6.7%), mean power outputs (5.8%), and peak power outputs (9.1%) occurred during the bench press throw than the traditional bench press (figures given are means across all loads). It was noted that the higher peak velocities were achieved later in the concentric phase for the throw, indicating that the bar was being accelerated over a greater portion of the concentric phase. Loads of 50 – 70% 1-RM maximized mean power output, whereas 50 – 60% 1-RM loads maximized peak power output.

Newton and Wilson (1993) also examined the effect of load on the kinetics and kinematics of an explosive countermovement bench press throw. Participants were instructed to perform a ballistic bench press with loads of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% of the pre-established 1-RM. Maximum mechanical power output was produced at 30% and 40% of 1-RM, consistent with the classical force – velocity relationship. It was noted that as load increased, the velocity – time profile became increasingly dissimilar to those encountered in dynamic athletic performance. Newton and Wilson (1993) suggested that previous training studies examining power development with traditional weight training techniques failed to produce significant increases because of the deceleration phase that occurs during the latter part of the movement. Similarly, Baker, Nance and Moore (2001a) examined the load that maximized the mean mechanical power output during explosive countermovement bench press throws in a group of highly trained athletes. Maximum power output occurred at loads of around 55% 1-RM, although it was noted that loads in the range of 46 – 62% 1-RM also allowed for high power outputs. The mean mechanical power output at these loads was 598 ± 99 W.

**Lower body**

Baker *et al.* (2001b) examined the power outputs during jump squats across a range of loads in power-trained athletes. Maximum strength (1-RM) was assessed using a full-squat exercise and power output was assessed across loads of 40, 60, 80, 100, and 120 kg. These absolute loads represented equivalent loads of approximately 25, 38, 51, 64, and 75% of 1-RM respectively (mean across study groups). To analyse power outputs, the barbell mass was added to the body mass of the athlete so power output was related to the total system mass. It should be noted that there has been a discrepancy in some research procedures leading to incorrect assertions on the percentage 1-RM loading to maximize power outputs (Baker, 1995). Using the system mass, the mean mechanical power output for the concentric flight phase of the jump squat at each load was determined. Participants performed countermovement jumps to a self-selected depth. Mean power output (1772 W) was maximized at loads representing 55 – 59% of the 1-RM full squat strength, although it was noted that loads representing 47 – 63% of the 1-RM full squat strength also produced similar power outputs. Similarly, Weiss *et al.* (2002) examined power outputs in jump squats across loads of 30, 60, and 90% 1-RM and reported peak power outputs of 1711 W at 60% 1-RM.

In contrast to the ballistic squat technique used in the studies above, studies using traditional squatting techniques such as the half squat have reported much lower maximum power outputs. For example, Izquierdo, Hakkinen, Gonzalez-Badillo, Ibanez and Gorostiaga (2002) investigated power output across loads of 30, 40, 50, 60, 70, 80, 90, and 100% 1-RM in several groups of athletes. Maximum power output occurred between 45 and 60% and was reported to be 385 – 755 W. This is considerably lower than in other studies using ballistic techniques.

Poprawski (1987) examined the effect of contraction force specificity by comparing the strength and power outputs of an elite shot putter with those of a group of sub-elite putters (14.6% mean difference in best throw distance between the elite and sub-elite putters). Maximal strength (1-RM) was assessed across a range of traditional weight training and Olympic style lifts. Velocity and power were measured with 20 – 140 kg squats (representing 10 – 70% 1-RM or 6 – 45% of system mass 1-RM) and 20 – 80 kg snatch (representing 18 – 73% of 1-RM or 6 – 26% of system mass 1-RM). While the elite putter was slightly stronger than the group mean in the bench press (1.4%), snatch (7.9%), power clean (5.3%), and squat (7.8%), the major differences occurred in tests of speed and power at heavy loads in those respective exercises. For example, the elite putter’s snatch velocity ranged from 4.1% faster than the mean at 20 kg to 22.1% faster at 80 kg. Similarly, his squat velocity was 2.4% higher at 40 kg but 25.7% higher at 140 kg. Poprawski (1987) concluded that movement velocities at higher loads (50 – 70%) were critical determinants of athletic success in stronger athletes, whereas for less strong athletes lighter loads (50% 1-RM) optimized power development. Poprawski (1987)
suggested that strength coaches should therefore concentrate on increasing the speed of weight training movements with sub-maximal loads as opposed to striving for constantly increasing the load lifted in training.

It appears from the literature reviewed that due to the ability to accelerate a load through the entire concentric phase, ballistic techniques produce superior force, velocity, and power outputs than traditional training techniques. However, there is no literature, to our knowledge, on the force–velocity–power profile of lower body ballistic techniques (e.g. jump squat) across the load continuum. Furthermore, determining the force–velocity–power profiles of the lower body as a function of system mass is required, as much of the literature has failed to calculate the kinetic variables of interest in such a manner. If such profiles are related to functional performance measures, our understanding of assessment and conditioning practice should be improved. Finally, it should be noted that although a greater understanding of single repetitions is required, strength and power training is characterized by multiple repetitions and sets. Consequently, understanding contraction force specificity would have greater practical application.

Set kinetics and kinematics

When set characteristics are examined rather than single repetitions, further insight into the acute stresses imposed on the body by various resistance training techniques or loading schemes is gained. Cronin and Crewther (2004) investigated the temporal, kinematic, and kinetic characteristics of three equi-volume training loads of experienced weight trainers. Three sets were tested at different loads (30, 60, and 90% 1-RM) and each set was equated by volume (repetitions × load) to ensure the total load lifted was identical. Testing was conducted using a “ballistic squat” where participants were instructed to jump with maximal intensity. Cronin and Crewther reported that a single repetition at 90% 1-RM produced greater mean and peak forces and time under tension than a single repetition at the lighter loads, but when equated by volume the 30% 1-RM condition produced significantly greater time under tension, peak and total power outputs. These findings draw attention to the importance of considering the kinetics and kinematics over a set, as opposed to a single repetition.

Cronin and Crewther (2004) commented that strength and power research should adopt a set kinematic and kinetic approach to gain a better understanding of the nature of the mechanical adaptations elicited by different loading patterns. It was also suggested that regimes other than volume (sets × repetitions × load) should be equated to improve identification of the mechanical determinants of strength, power, and functional performance. For example, maximal strength is thought to be enhanced best by training that involves “near-maximal tension of essentially non-fatigued” muscles (Atha, 1981; Pincivero, Lephart, & Karunakara, 1998). As such, high tension or forces and time under tension are thought to be prerequisites for optimal strength development. Therefore, equating one of these factors would be beneficial to disentangle its effects on strength development.

As evidenced by the paucity of literature in this area, there is a need for this type of research. Furthermore, realization that adaptation of muscle depends on some interaction between mechanical, hormonal, and metabolic responses (Enoka, 2002), gaining an understanding of these responses during typical strength and power training sessions would develop greater understanding and enhance training prescription. Such an approach will provide a framework for a greater insight into the adaptations associated with longitudinal training studies.

Methodological issues

Research that has investigated the development of strength and power has been typified by a considerable variation in the methods used. The scope of this variation makes comparisons difficult and hence definitive conclusions practically impossible. For example, the vast majority of research has been short in duration (8–12 weeks) and therefore the application of findings to long-term training is questionable, as the influence of neural and morphological mechanisms change with training duration (Moritani & deVries, 1979). Research in this area is also typified by a wide spectrum of loading parameters that include differences in: (a) volume; (b) intensity (percent 1-RM); (c) total work output; (d) tempo of concentric–eccentric contractions; (e) frequency; (f) rest/recovery time–density; and (g) types of contraction. Further confounding our understanding in this area are the modes of dynamometry used and variety of strength power measures reported. Finally, many muscle groups have been studied, limiting the ability to generalize results, especially in the case of uni-articular and bi-articular muscles. To discuss each of these limitations is outside the scope of this review. However, brief mention will be made of three key issues that are thought to be influential to subsequent discussion.

Assessment

Many of the discrepancies found in the strength literature can be attributed to the different types of dynamometry used to assess strength and power. Three
modes of dynamometry are generally used: isometric (constant angle), isokinetic (constant velocity), and isoinertial (constant gravitational load), the latter of which is also referred to as isotonic (Abernethy et al., 1995). For a full treatise of the issues and controversies surrounding these three modes of dynamometry, the reader is directed to specific reviews on this topic (Abernethy et al., 1995; Atha, 1981; Sale, 1991). One issue of interest, however, is that the magnitude of the strength/power gains is probably dependent on the assessment mode being similar to the training mode (Morrissey, Harman, & Johnson, 1995). For example, Dons, Bollerup, Bonde-Petersen and Hancke (1979) used both isometric and isoinertial testing to measure the changes in maximal strength of three groups (control, 50% 1-RM, and 80% 1-RM training groups). After 7 weeks of training, the 80% 1-RM group significantly increased 1-RM (42.3%) but did not demonstrate a significant increase (4%) in maximum voluntary isometric contraction (MVIC). Dons et al. (1979) commented that their results confirmed specificity of training in that dynamic training did not affect static performance. Using similar methods, Jones and Rutherford (1987) studied the response of the quadriceps to different training regimes. One group performed unilateral isometric training at 80% MVIC for 4 s each separated by a 2-s rest period. The number of repetitions was not stated. Another group performed six repetitions at 6-RM (80% 1-RM), training one leg with concentric contractions and the other with eccentric contractions. Tests before and after the 12-week programme included MVIC assessment, which increased markedly more in the isometric training group (35.0 ± 19.0%) than in the concentric and eccentric training groups (15.0 ± 8.0% and 11 ± 3.6% respectively). Thus, it appeared that the greatest change in muscle strength was again found when the mode of training matched that of testing. Similar results (see Table I) have also been reported in other studies (Hakkinen & Komi, 1986; Wilson, 1993).

This specificity of assessment has been proposed to be a result of the mechanical and neural activation differences between isometric and dynamic contractions (Nakazawa, Kawakami, Fukunaga, Yano, & Miyashita, 1991; Ter Haar Romeny, Denier van der Gon, & Gielen, 1982). It seems imprudent to use isometric testing to measure dynamic performance and vice versa.

It would appear that dynamic performance should be assessed using dynamic (i.e. isoinertial and/or isokinetic) contractions. To date, the relative effectiveness of isokinetic and isoinertial dynamometry to monitor the changes in strength and power resulting from dynamic training methods is unclear, possibly because of the limited number of studies conducted. Murphy and Wilson (1997) examined the ability of isokinetic and isoinertial tests to reflect training-induced changes in performance. Testing consisted of a squat jump using an absolute load of 10 kg, an eccentric squat movement loaded at 200% of body mass, peak torque during an isokinetic knee extension movement at two speeds (1.05 and 4.7 rads s⁻¹), power output during a 6-s cycle test, sprinting speed over 40 m, and a 1-RM squat. It is unclear whether all participants were experienced weight

<table>
<thead>
<tr>
<th>Study</th>
<th>Frequency</th>
<th>Duration</th>
<th>Sets × repetitions</th>
<th>Load</th>
<th>Volume equation</th>
<th>% Change in MVIC</th>
<th>% Change in 1-RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric training</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Amusa and Obajuluwa (1986)</td>
<td>3 times a week</td>
<td>10 weeks</td>
<td>3 × 6 s</td>
<td>50–100% of max. load that could be held for 6 s</td>
<td>No</td>
<td>+83.0%</td>
<td>+65.8%</td>
</tr>
<tr>
<td>Jones and Rutherford (1987)</td>
<td>3 times a week</td>
<td>12 weeks</td>
<td>4 s</td>
<td>80% MVIC</td>
<td>No</td>
<td>+35.0%</td>
<td>N.A.</td>
</tr>
<tr>
<td>Dynamic training</td>
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<tr>
<td>Dons et al. (1979)</td>
<td>3 times a week</td>
<td>7 weeks</td>
<td>1 × 20</td>
<td>50% 1-RM</td>
<td>Sets × reps × load</td>
<td>+4.5%</td>
<td>+23.8%</td>
</tr>
<tr>
<td>Hakkinen and Komi (1981)</td>
<td>3 times a week</td>
<td>12 weeks</td>
<td>1–6 reps per set</td>
<td>80–100% 1-RM</td>
<td>Not stated</td>
<td>+2.4%</td>
<td>+20.3%</td>
</tr>
<tr>
<td>Jones and Rutherford (1987)</td>
<td>3 times a week</td>
<td>12 weeks</td>
<td>4 × 6</td>
<td>80% 1-RM (concentric)</td>
<td>No</td>
<td>+15.0%</td>
<td>N.A.</td>
</tr>
<tr>
<td>Thorstensson et al. (1976)</td>
<td>3 times a week</td>
<td>8 weeks</td>
<td>9 × 6</td>
<td>78% 1-RM</td>
<td>No</td>
<td>16–30%</td>
<td>+73%</td>
</tr>
<tr>
<td>Voigt and Klausen (1990)</td>
<td>3 times a week</td>
<td>16 weeks</td>
<td>3 × 6</td>
<td>6-RM</td>
<td>No</td>
<td>No change</td>
<td>+27.3%</td>
</tr>
</tbody>
</table>
trainers, although the authors stated that all of them were involved in a variety of recreational activities, including weight training. Training consisted of four to six sets of the squat exercise at a load of 6–10 RM, performed twice a week for 8 weeks. The only strength measure to change significantly over the training period was the 1-RM squat (20.9%). This result is not unexpected given that heavy squats were used in training. The only other variable to change markedly was sprint time, which was reduced by 2.2%. The increase in 1-RM was the only measure of muscular performance to be related to the improvement in sprint performance ($r = -0.41$). Thus, the isoinertial 1-RM measure was more discriminating to changes in performance than the isokinetic tests. Several other studies have reported similar findings (Abernethy & Jurimae, 1996; Elliott, Sale, & Cable, 2002; Jurimae, Abernethy, Quigley, Blake, & McEnery, 1997; Newton & Waddell, 1993).

Despite the popularity of isometric and isokinetic tests in research, the literature indicates that they are inferior to isoinertial measures in predicting performance or tracking changes longitudinally. This is thought to be a result of the large neural and mechanical differences between isometric and isokinetic tests to functional movements such as running and jumping (Abernethy et al., 1995; Wilson & Murphy, 1996). Even though isokinetic contractions are dynamic in nature, isokinetic dynamometry involves the measurement of force/torque and or power through a range of motion with the movement performed at constant angular velocity. However, human movement is typified by changing velocities and accelerations. Furthermore, the inability of many isokinetic dynamometers to assess stretch–shorten cycle (SSC) activity further detracts from the validity of such an approach, although more recent isokinetic dynamometers do allow SSC contractions to be assessed (Wilson, Walshe, & Fisher, 1997). In terms of assessment velocity, a great deal of research has used velocities that are disparate to the actual movement velocities of activities such as sprinting and jumping. Further compromising the validity of isokinetic dynamometry is that these assessments are predominantly performed in a non-specific posture (seated) and involve knee flexion–extension type movements. Therefore, the motion tends to be uni-articular and open chain in nature. Finally, joint range of motion during assessment typically differs from that found during tasks such as sprinting and jumping. Therefore, the external validity of isokinetic testing is questionable, particularly when compared with isoinertial assessment. Isoinertial dynamometry is the mode of choice for the training and assessment of strength and power, as it allows the closest replication to typical movement patterns and hence has greater face validity than the other contraction modes.

**Training volume**

Volume is most commonly measured as the total product of repetitions, sets, and load (expressed as percent 1-RM). Equating by volume is the most common method by which research compares the effect of load (contraction force) on various outcome measures. Alternative methods include equating by total time under tension, electromyographic (EMG) activity, or total mechanical work performed (Moss, Refsnes, Abildgaard, Nicolayesen, & Jensen, 1997). However, most research in this area has failed to equate loading between training protocols in any form (Berger, 1962; Harris, Stone, O’Bryant, Proulx, & Johnson, 2000; Hisaeda, Miyagawa, Kuno, Fukunaga, & Muraoka, 1996; Schmidtbleicher & Buehrle, 1987; Takarada et al., 2000; Wilson, 1993). Therefore, the results from such studies are difficult to interpret, as the reported differences between various training protocols could be a result of differences in training volume rather than specific kinematic and kinetic characteristics of different loading intensities. For example, after an extensive review of strength research, Atha (1981) concluded that there was little difference between 2-RM and 10-RM loading in the strengthening effects produced but that a true load–gain relationship was unresolved due to the different number of repetitions required in each loading scheme. Thus, making conclusions about the efficacy of various training protocols that are not equated in some manner appears highly questionable.

In a widely quoted study, Berger (1962) sought to determine the optimum number of repetitions per set to produce the greatest gains in maximal strength. Six participant groups were defined according to the number of repetitions to failure they performed (2, 4, 6, 8, 10, or 12 repetitions). Each group performed only one set, so the 2-repetition group performed a total of only 6 repetitions per week, whereas the 12-repetition group performed 36 repetitions per week. Thus the training groups were not equal in terms of volume of training. After completing a 12-week training programme, the participants who trained with 4, 6, or 8 repetitions produced greater mean changes in 1-RM strength than the groups that used 2, 10, or 12 repetitions. Berger (1962) concluded that the optimum number of repetitions per set for improving strength was 3–9. However, the interactions between load and number of repetitions (volume) are impossible to disentangle in such a methodology. That is, both load (contraction force) and volume have some effect on the resulting strength gains but it is impossible to determine their relative contribution from such a design. Furthermore, in practice it is widely accepted that one set, regardless of the number of repetitions or load, is not sufficient volume for optimum strength gains in experienced
trainers (American College of Sports Medicine, 2002). Therefore, extrapolating these findings to common practice is problematic. Despite this, Berger (1962) has frequently been quoted in the literature to justify claims for the optimal training load/force to increase maximal strength. To gain a true appreciation of the effect of contraction force on strength and power development and improved functional performance, research methodologies need to equate the load lifted in some manner. Research of this kind will improve strength and conditioning knowledge and practice.

Training status

The training status of the participants may also influence the results of resistance training studies (see Table II). For example, a widely quoted review of strength training research is that by McDonagh and Davies (1984). These authors reviewed research from 1949 to 1983 and based their findings largely on studies involving novice participants. Strength increases were presented as the percent change in MVIC per day, load was expressed as percent 1-RM (converted with the authors’ empirically designed formulae where required), and the duration of each contraction was listed in seconds. The key result of the review was that 66% 1-RM was the critical threshold for the development of isometric and isotonic strength. This review became central to many assertions about the optimal load for the development of strength. However, it is problematic to extrapolate findings from novice weight training participants to more experienced weight trainers. Indeed, it has been suggested that initial strength increases for novices will occur rapidly as a result of almost any resistance training method (Chestnut & Docherty, 1999; Wilson, 1993).

Many training studies have used novice weight trainers as participants to compare the effects of different training protocols on strength, power, functional performance, and/or changes in muscle cross-sectional area (CSA). Most of these have found little difference in the magnitude of the adaptations resulting from the different training protocols. For example, Chestnut and Docherty (1999) used two groups of novice weight trainers. One performed eight sets of four repetitions at 4-RM (~85% 1-RM) of various triceps and bicep exercises and the other performed four sets of ten repetitions with 10-RM (~70% 1-RM) of the same exercises. Measurements before, during, and after the 10-week training period included triceps bench press and standing bicep curl 1-RM and mid upper arm CSA. It was observed from the results that both groups demonstrated increases in forearm extensor and flexor 1-RM and upper arm CSA, with no difference in the rate of improvement between groups. Chestnut and Docherty (1999) suggested that the inexperience of the participants was responsible for the “generic” training response between the groups and that a more experienced group of participants would have responded differently to the same training. Other studies using novice participants have also reported similar results for various resistance training protocols. For example, Hisaeda et al. (1996) compared the effect of heavy (4- to 5-RM) and light (15- to 20-RM) training loads on strength and CSA over the course of an 8-week study using novice weight trainers. All participants increased their strength (32.5% and 20.3% for the heavy and light groups respectively, mean peak torque across four separate angular velocities) and CSA (3.1% and 3.9% for the heavy and light groups respectively, mean across five MRI scan sites). However, there were no differences between the rates of improvement in these groups. Young and Bilby (1993) also compared the effects of different training techniques on the strength, power, and CSA of novice weight trainers. Participants were enrolled on a training programme differentiated by voluntary contraction speed. One group was instructed to perform slow controlled contractions and the other to perform a slow eccentric contraction followed by an explosive concentric contraction. Strength, power, and muscle hypertrophy were assessed before and after a 7½-week training programme. Again improvements in strength, power, and hypertrophy were observed in each group with no inter-group difference. In addition, Lyttle, Wilson and Ostrowski (1996) investigated the relative effectiveness of lighter (approximately 30% 1-RM) loads performed in a ballistic manner (POW), whereby the load was projected at the end of the concentric phase, compared with a combination of heavy (60–85% 1-RM) traditional weight training exercises and plyometric training (COM) on novice weight-trainers. Volume was equated between groups using the total number of sets and repetitions. After 8 weeks of twice weekly training, increases in 1-RM were observed for both training groups (14.7% and 14.8% for the POW and COM groups respectively), with no differences in the rate of improvement between groups. The rates of improvement over a range of functional performance measures were also statistically non-significant between the groups.

In contrast to studies using novice participants, those that have used more experienced weight trainers have tended to find much smaller gains in performance even with more prolonged training programmes. Hakkinen, Komi, Alen and Kauhanen (1987) examined changes in MVIC and 1-RM over a one-year training period in elite competitive
Table II. The effect of training status on resistance training-induced changes in strength and power.

<table>
<thead>
<tr>
<th>Study</th>
<th>Frequency</th>
<th>Duration</th>
<th>Sets × repetitions</th>
<th>Load</th>
<th>Training</th>
<th>Volume equation</th>
<th>% Change in strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novice participants</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Chestnut and Docherty (1999)</td>
<td>3 times a week</td>
<td>10 weeks</td>
<td>8 × 4</td>
<td>85% 1-RM</td>
<td>Isoinertial</td>
<td>Sets × reps × load</td>
<td>+15%/+6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 × 10</td>
<td>70% 1-RM</td>
<td></td>
<td></td>
<td>+17%/+9.5%</td>
</tr>
<tr>
<td>Dons et al. (1979)</td>
<td>3 times a week</td>
<td>7 weeks</td>
<td>1 × 20</td>
<td>50% 1-RM</td>
<td>Isoinertial</td>
<td>Sets × reps × load</td>
<td>+23.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 × 12</td>
<td>80% 1-RM</td>
<td></td>
<td></td>
<td>+42.3%</td>
</tr>
<tr>
<td>Hakkinen and Komi (1981)</td>
<td>3 times a week</td>
<td>12 weeks</td>
<td>1 – 6 reps per set</td>
<td>80–100% 1-RM</td>
<td>Isoinertial</td>
<td>Not stated</td>
<td>+20.3%</td>
</tr>
<tr>
<td>Hisaeda et al. (1996)</td>
<td>3 times a week</td>
<td>8 weeks</td>
<td>5 × 15 – 20</td>
<td>15- to 20-RM</td>
<td>Isoinertial</td>
<td>No</td>
<td>+20.3%b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 × 4 – 5</td>
<td>4- to 5-RM</td>
<td></td>
<td></td>
<td>+32.5%</td>
</tr>
<tr>
<td>Lyttle et al. (1996)</td>
<td>2 times a week</td>
<td>8 weeks</td>
<td>2 – 6 × 8</td>
<td>30% 1-RM</td>
<td>Ballistic</td>
<td>Sets × reps × load</td>
<td>+14.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 – 3 × 6–10</td>
<td>6- to 10-RM</td>
<td>Combined</td>
<td></td>
<td>+14.8%</td>
</tr>
<tr>
<td>Thorstensson et al. (1976)</td>
<td>3 times a week</td>
<td>8 weeks</td>
<td>9 × 6</td>
<td>78% 1-RM</td>
<td>Isoinertial</td>
<td>No</td>
<td>+73%</td>
</tr>
<tr>
<td>Young and Blyby (1993)</td>
<td>Novice</td>
<td>3 per week</td>
<td>4 × 8 – 12</td>
<td>8- to 12-RM</td>
<td>Slow</td>
<td>No</td>
<td>+21.7%</td>
</tr>
<tr>
<td></td>
<td>7½ weeks</td>
<td></td>
<td>4 × 8 – 12</td>
<td>8- to 12-RM</td>
<td>Fast</td>
<td></td>
<td>+20.1%</td>
</tr>
<tr>
<td><strong>Experienced participants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baker (2001)</td>
<td>2 times a week</td>
<td>29 weeks</td>
<td>Not stated</td>
<td>Not stated</td>
<td>Not stated</td>
<td>Not stated</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>2 times a week</td>
<td>19 weeks</td>
<td>Not stated</td>
<td>Not stated</td>
<td>Not stated</td>
<td>Not stated</td>
<td>+4.9%</td>
</tr>
<tr>
<td>Hakkinen and Komi (1981)</td>
<td>3 times a week</td>
<td>12 weeks</td>
<td>1 – 6 reps/set</td>
<td>70–100% 1-RM</td>
<td>Olympic lifts</td>
<td>Not stated</td>
<td>+6.4%</td>
</tr>
<tr>
<td>Hakkinen et al. (1987)</td>
<td>1 year</td>
<td>Not stated</td>
<td>Mean 78% 1-RM</td>
<td>Olympic lifts</td>
<td>Not stated</td>
<td></td>
<td>+1.7%</td>
</tr>
<tr>
<td>Moss et al. (1997)</td>
<td>3 times a week</td>
<td>9 weeks</td>
<td>3 – 5 × 2</td>
<td>90% 1-RM</td>
<td>Contractile time</td>
<td></td>
<td>+15.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 – 5 × 7</td>
<td>35% 1-RM</td>
<td></td>
<td></td>
<td>+10.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 – 5 × 10</td>
<td>15% 1-RM</td>
<td></td>
<td></td>
<td>+6.6%</td>
</tr>
<tr>
<td>Wilson et al. (1993)</td>
<td>2 times a week</td>
<td>10 weeks</td>
<td>3 – 6 × 6–10</td>
<td>6- to 10-RM</td>
<td>Slow</td>
<td>No</td>
<td>+8.7%c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 – 6 × 6–10</td>
<td>Bodyweight</td>
<td>Explosive</td>
<td></td>
<td>+1.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 – 6 × 6–10</td>
<td>30% MVIC</td>
<td>Explosive</td>
<td></td>
<td>+7.0%</td>
</tr>
</tbody>
</table>

a(pre-mid/mid-post); bmean peak torque; cpeak isokinetic torque.
weightlifters. Individual coaches set the programmes for each athlete and therefore training diaries were kept for the year to quantify the training performed. Although no specific details of training were given, exercises consisted predominantly of dynamic Olympic-style lifts at a mean load of 78% 1-RM (with some small variations throughout the year). Over the course of the study, changes in MVIC and 1-RM were reported to be small and insignificant (3.5 and 1.7% respectively). Hakkinen et al. (1987) suggested that the magnitude of the neuromuscular adaptations during strength training in elite strength athletes differed from those reported for untrained participants. Little change in performance from resistance training in experienced resistance-trained athletes has been reported in several studies. For example, Baker (2001) studied the changes in strength and power of a group of elite national rugby league and college-aged rugby league players over the course of a season (29 and 19 weeks respectively). Although not stated explicitly, these athletes would have had a resistance training background, as indicated by their 1-RM bench press scores (elite: 137.9 ± 13.3 kg; college: 110.3 ± 17.0 kg). Training over the course of the study consisted of twice weekly whole-body resistance training sessions, two or three 20- to 30-min high-intensity conditioning sessions, three to five team practice sessions (which typically involved an inherently high degree of energy system conditioning) and, although not stated, presumably one game per week as well. Training was periodized for volume and intensity over the course of the season. Tests were conducted at the start of the season, one to two times periodically during the season, and at the end of the season. These tests included 1-RM bench press, maximum power output during bench press throws of 40, 50, 60, 70, and 80 kg, and maximum power output during jump squats at loads of 40, 60, 80, and 100 kg. For the elite players, no significant change was observed for any of the variables tested. The college-aged group increased their 1-RM strength in the bench press (4.9%) from the pre-season test to the test performed in week 9. It then remained unchanged until week 19. No other variable changed significantly over the course of the season for the college-aged group. It was suggested that the magnitude of resistance training gains are dependent on training experience, with the greater strength training experience of the elite rugby league players reducing the scope for strength improvements compared with the college players.

In summary, novice participants have been used in most resistance training studies. However, it would appear that novices respond with generic and large strength increases to a very broad range of resistance training stimuli. In contrast, the results of the small number of studies involving highly trained resistance-trained athletes suggest that little change in strength occurs in these groups even over the course of one year of intense training. Thus, the validity of generalizing findings from novice participants to athletes with experience in weight training is problematic.

Contraction force and training studies

A limited number of studies on contraction force specificity have tried to account for these methodological considerations. The following studies attempted to address these limitations and therefore form the basis of subsequent discussion. Moss et al. (1997) had three groups of “well-trained” participants train the elbow flexors of the non-dominant arm while the dominant arm served as a control. The groups trained at 90% 1-RM for two repetitions (G90), at 35% 1-RM for seven repetitions (G35), or at 15% 1-RM for ten repetitions (G15). All groups trained with three to five sets and were equated for total time under tension based on EMG activity (muscle activation). Participants were encouraged to perform each lift as explosively as possible, but the weight was held rather than projected at the end of each concentric contraction. Changes in performance were assessed using a 1-RM bicep curl as well as the force and power outputs recorded from the bicep curl over a range of loads. All groups increased 1-RM strength, although the improvements in strength were greater for G90 than G15. The mean increases were 15.2% in G90, 10.1% in G35, and 6.6% in G15. These results are noteworthy for two reasons. First, experienced trainers were used, thus eliminating the generic response of novice participants discussed earlier. Second, the significant strength increases for G35 and G15 were elicited with loads traditionally considered to be too light for generating sufficient force to stimulate the required neuromuscular adaptations. Power was tested across a range of loads from 2.5 kg to 90% 1-RM. Significant increases in power were observed at all loads for G90 and G35, and at loads between 15% and 50% 1-RM for G15. The increases in power output were not different between the three groups at loads ≤50% 1-RM. However, the increase in power at the higher loads (70% and 90% 1-RM) was greater for G90 and G35 than G15. Overall, the results of this study suggest some form of contraction force specificity, in that the magnitude of the strength and power increases across different loads was related to the loads that were used in training.

McBride, Triplet-McBride, Davie and Newton (2002) examined the effects of heavy (80% 1-RM) versus light (30% 1-RM) load training on strength,
power, and speed in experienced weight trainers. Jump squats were used for both training and testing, and groups were equated for volume using the product of sets, repetitions, and load (%RM). After 8 weeks of training, both groups increased their 1-RM (10.2% and 8.2% for the 80% 1-RM and 30% 1-RM groups respectively) with no difference between the groups. However, the results of contraction force-specific tests showed clear differences in the effect of training between the groups. More marked changes in jump squat heights at 30% 1-RM were observed in the 30% 1-RM group than the 80% 1-RM group (15.3% and −2.7%, respectively). The change in peak velocity during jump squats at 30% 1-RM was also greater for the 30% 1-RM group than the 80% 1-RM group (8.1% vs. −0.5%). In addition, the time required to complete a 10-m sprint was reduced in the 30% 1-RM group (−1.6%) but not in the 80% 1-RM group (+4.9%). McBride et al. (2002) commented that the results supported the use of lighter loads performed in a ballistic manner in training for functional performance improvement. However, superior performance was only found on one of the functional performance measures.

Adams, O'Shea, O'Shea and Climstein (1992) also investigated the effects of contraction force specificity by comparing the differential effects of three training protocols on the vertical jump performance of experienced weight trainers. The squat group trained with heavy squats at loads of 70–100% of pre-training 1-RM. No contraction velocity was stated. The plyometric group trained with depth jumps from 51 to 114 cm and other plyometric jumping exercises. A third group trained with a combined protocol of heavy squats and depth jumps. Intensity was modulated through the 6-week training period to periodize the training effect. Consideration was given to the equalization of volume and intensity between training groups, although exact equalization was elusive due to the different training modalities used. All groups improved their jump height (3.3 cm, 3.8 cm, and 10.7 cm for the squat, plyometric, and combined groups respectively), but between-group comparisons showed that the combined group achieved a greater improvement than the other two groups. This indicates that the combination of heavy training and unloaded jump training was more effective in improving vertical jump performance than either training modality alone. This could relate to the contraction force-specific requirements of vertical jumping. That is, higher force application is needed at the start of the movement so as rapidly to increase velocity from zero, followed by higher velocity and lower forces as the jump progresses (Newton & Kraemer, 1994).

Conclusions

Although research methodology has evolved, few studies have equated load in some manner and used isoinertial assessment and training techniques to study strength and power changes in experienced weight trainers. This may be due to the accessibility of participant groups to researchers. Novice participants and/or student populations are generally accessible and can be easily divided into experimental and control groups. However, it is more problematic to find a suitable cohort of participants from an athletic population and very difficult to ask a group of athletes to stop training so as to form a control group. Methodological designs must be closely considered when attempting to translate research findings to training prescription in terms of the optimum contraction force for the improvement of strength, power, and functional performance. Novice weight trainers respond with strength increases in response to a wide range of stimuli, whereas experienced weight trainers show only small improvements in strength with similar training programmes. Therefore, the validity of extrapolating findings from novice trainers to experienced trainers is questionable. The challenge lies in improving muscular performance in more experienced trainers, particularly those with several years of consistent training background. Future studies should concentrate on using experienced participants, preferably from an athletic population. Ideally, these training studies should use specific isoinertial loading schemes and the test protocols should assess performance over the force–velocity continuum so as to gain a greater understanding of the effect of load on muscular function. When comparing the effectiveness of multiple training strategies, the volume of training should be equated between participant groups to allow direct comparison between the training methods. Finally, further analyses of kinetic, kinematic, and electromyographic variables across sets will provide greater insight into the stimuli required for strength and power development than simply measuring the changes in strength. It could be that the predilection of research and conditioning practice on improving power is misplaced. That is, strength qualities such as impulse, rate of force development, and explosive strength could predict athletic performance better and hence it is the development of these qualities upon which research and strength training should focus.

The results of this review suggest that the enhancements in performance resulting from resistance training are context specific in experienced resistance-trained participants. Thus, specific conditioning could be required to achieve improvements in functional performance in this group. Our results indicate that “heavy” weight training leads to
improvements where the movement of high forces is required, in particular 1-RM strength. Lighter weights (loads of approximately 10–60% 1-RM) have previously been considered too light to stimulate the neuromuscular adaptations required for increasing maximal strength. However, it appears that lighter loads improve both maximal strength and muscular power as long as they are performed in a ballistic manner. Similarly, combining heavy and light training schemes also appears to be an effective mode for improving muscular function and may be particularly useful where force application is required in a range of functional tasks. Until training studies address the limitations discussed throughout this review, the best and safest course of action for those interested in improving the functional performance of muscle could be to use a mixed training strategy using both heavy and light loads. Realizing that all human movement is an integration of force and velocity, such an approach is appealing. That is, most sports involve a mixture of activities that span the force–velocity capability of muscle. For example, shot putters have to drive their quite sizeable mass through the circle before throwing a relatively light put. Rugby players not only have to wrestle and tackle each other but also kick and throw a ball. Intuitively it would seem prudent continuously to adjust the resistances used for power training, as athletic performance is typified by many force–velocity characteristics. Furthermore, as one of the principles of training is variation (periodization), this approach appears sensible.

References


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