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Review

EXPLOSIVE EXERCISES IN SPORTS TRAINING: A CRITICAL REVIEW

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ABSTRACT

Bruce-Low S, Smith D. Explosive Exercises In Sports Training: A critical Review. ***JEP****online* 2007;10(1):21-33. This paper reviews evidence relating to the effectiveness and safety of explosive exercises, such as Olympic style weight lifting, other weight training exercises performed at a fast cadence, and plyometric exercises, that are commonly used in the strength and conditioning training of athletes. Contrary to popular belief and the practices of many athletes, the peer-reviewed evidence does not support the view that such exercises are more effective than traditional, slow and heavy weight training in enhancing muscle power and athletic performance. In fact, such exercises do not appear to be any more effective in this regard than weight training at a relatively slow cadence, and some evidence suggests they are less so. Also, such explosive exercises do not transfer well (if at all) to athletic performance on the sports field, and present a significant injury risk. Therefore, such exercises should not be recommended in the strength and conditioning training of athletes, except those who need to learn the specific skill of lifting heavy weights fast, such as Olympic lifters and strongmen.

Key Words: Strength, Plyometrics, Performance

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1. INTRODUCTION

Strength and conditioning training is now an integral part of athletic preparation for all serious athletes and sports teams. However, the issue of how best to train to prepare for athletic competition is very controversial. Issues such as volume and frequency of training, choice of exercise and movement cadence are debated by athletes, coaches and exercise scientists.
One of the most controversial issues in this field is the use of ‘explosive’ exercises to increase strength and power. These can be defined as “resistance exercises characterized by maximal or near-maximal rates of force development or by high acceleration” (1). Typical examples of such exercises, commonly prescribed by strength coaches, are Olympic-style lifts such as the clean and jerk and snatch, and derivatives of these such as the power clean and hang clean. Also, so-called ‘plyometric’ exercises defined as “maximal, all out quality efforts in each repetition of exercise” (2, p.69), as well as performing any weight training exercises at a relatively fast cadence, are popularly believed to be effective in enhancing strength, power and the rate of force development. This is based on the fact that muscle fiber composition provides the potential for the neuromuscular system to produce fast speeds, in particular fast twitch fibers. However, the selective recruitment of muscle fiber types is impossible (3). As such, muscle fibers are recruited by the nervous system in a logical progression according to the force requirements and not the speed of movement (3). For example, slow twitch fibers meet the demands of low muscular intensity, whereas the fast twitch fibers are eventually recruited when the other fatigue resistant fibers are exhausted. Therefore slow twitch fibers are recruited first and fast twitch last and there is no definitive proof that undertaking explosive tasks will by-pass this process (3). Interestingly, Fleck & Kraemer (5) suggest that there are exceptions to the recruitment order by size when very high velocity movements are undertaken, although they provide no research data to support this claim.

The National Strength and Conditioning Association (NSCA), a prominent certification organization, recommends all of the above exercises for adult athletes (1). In addition, a recent position statement of the American College of Sports Medicine (6) suggested that explosive lifting was an effective way to enhance athletic performance. Many popular strength and conditioning textbooks also support this statement (e.g. 5). However, this view is not universal, and some authors advise athletes to avoid power cleans and other Olympic lifts due to question marks over both their effectiveness and safety (e.g. 3, 7). Indeed, two recent reviews (8, 9) have claimed that the research support for explosive training protocols is equivocal at best.

Somewhat surprisingly (given the importance of this topic for exercise scientists, strength and conditioning professionals and coaches) the peer-reviewed empirical research on this topic has never been systematically and comprehensively examined in a paper devoted purely to this purpose.

Therefore, the aim of the current review is to examine the effects of explosive training protocols, including Olympic lifts and their derivatives, plyometrics and other weight training exercises performed with a relatively fast cadence on muscle strength, power and sports performance. The evidence relating to the effects of these methods on muscle strength and power compared to slow and controlled weight training, the transfer of such training to enhanced performance on the sports field, and the injury risks from such training, will be examined. Evidence-based recommendations will then be given regarding the use of such training protocols to enhance sporting performance. The studies discussed in this review were discovered via a comprehensive literature search that included searches of relevant databases as well as searches of recent exercise physiology journals, searches of the reference lists of all the articles read, and internet searches.

2. EFFECT OF EXPLOSIVE EXERCISES ON MUSCLE STRENGTH AND POWER.

Given the rather strident manner in which many weight training authorities promote the use of explosive exercises (e.g. 1), it seems reasonable to assume that a strong body of scientific evidence must have been built up to support their use. However, one of the most striking results of our literature search was the relatively small number of studies that have actually tested the effects of explosive exercises, and the even smaller number of studies that have compared their effects to that of the slow, controlled weight training advocated by some authors (3, 10, 11). However, the studies that have been completed have produced some very interesting findings. For example, LaChance and Hortobagyi (12) compared the effects of repetition cadence on the number of push-ups and pull-ups subjects could complete. They found that subjects could complete fewer repetitions when performing two-second concentric and two-second eccentric muscle actions than when performing fast, self-paced repetitions, and that they could complete even fewer repetitions when performing two-second concentric and four-second eccentric contractions. Therefore, the difficulty of the exercise decreased as repetition cadence decreased. For example, subjects performed 96% more pull-ups in 16% less time, and 145% more push-ups in 51% less time, when performing the fast repetitions than when performing repetitions with a 2/4 cadence. This suggests that faster repetitions involve less muscle tension, making it difficult to see how a faster speed of movement could be more productive. The findings of Hay et al. (13), who measured joint torque in three males while performing biceps curls, also seem to support this view. Hay et al. (13) found that with short duration lifts (< 2 s) very little joint torque was required to move the weight through most of the range of motion (ROM), as after the beginning of the movement the weight continued to move under its own momentum. Therefore, fast movements do not provide as much muscle tension as slow movements through most of the ROM, suggesting that faster repetitions, such as those performed with ‘explosive’ exercises may not produce optimal strength increases through a muscle’s full ROM.

Other studies have found no significant difference in strength increases from slow and fast-paced repetitions. For example, to examine the effects of different repetition cadences commonly used by weight trainers Berger and Harris (14) assigned their subjects into fast (1.8 s), intermediate (2.8 s) and slow (6.3 s) repetition groups, each of which performed one set of the bench press three times per week for 8 weeks. All groups significantly increased strength, with no significant between-group differences. Young and Bilby (15) compared slow versus explosive barbell squats. Again, both methods significantly increased 1 RM, as well as isometric peak force, vertical jump, thigh circumference and muscle thickness. Interestingly, the change in the rate of force development was 68.7% for the explosive group compared to only 20.5% for the slow group, whereas the change in

1RM was 31% for the slow group compared to 12.4% for the explosive group. However, these differences were not significantly different, and indeed there were no significant between-group differences found in the study. Palmieri (16) examined the effects of varying repetition cadences within a 10-week training program consisting of squats and machine exercises. A slow cadence group performed the concentric part of each repetition in 2 s or more, a fast cadence group performed it in 0.75 s or less, and a combination group spent the first 6 weeks performing fast cadence repetitions and the last 6 on slow cadence repetitions. All groups improved significantly in the 1RM squat (slow group 25%, fast 20% and combination group 20%) and lower body power (slow group 3.7%, fast group 3.8%, combination group 3.2) and there were no significant between-group differences. Interestingly, however, when the combination group switched to the fast cadence condition they failed to produce any further increases in the dependent measures.

The above studies clearly do not support the view that explosive exercises are superior to slow weight training for enhancing muscle strength, power or hypertrophy. However, the important question still remains of how well increases in strength or power translate into better performance on the sports field. The following section will examine this issue.

3. THE EFFECT OF EXPLOSIVE EXERCISES ON SPORTS-RELATED PERFORMANCE MEASURES.

It has been argued that, because most sports involve the performance of high-velocity muscle contractions, weight training exercises performed at a high velocity will better prepare athletes for sports performance than slow weight training. This argument, often stated in weight training textbooks (17, 5), was summed up thus by Cissik (18): "*If an exercise is performed at slow speeds, then we become stronger at slow speeds. However, there is little transfer to faster speeds. If exercises are performed at faster speeds, then we become stronger at faster speeds*" (p. 3). To examine the effects of specific aspects of athletes' training programs, such as repetitions cadences, on sports performance is not easy, as there are so many potential confounding factors. However, various studies have examined the effects of explosive and non-explosive training protocols on dependent measures thought to be more closely related to sports performance than measures of muscle strength. This section will examine findings from these studies. It is important to note, however, that whereas some of these measures do appear to have face validity (e.g. measuring kayak sprint performance in kayak performers), there is little or no evidence to support the ecological validity of some of them. For example, as Carpinelli (19) noted, despite its widespread acceptance, the vertical jump has not been shown to correlate well with performance of any sport-specific activity.

An interesting study that did use a measure that appears to possess good ecological validity was that of Liow and Hopkins (20), who investigated the effect of slow and explosive weight training on kayak sprint performance. The two programs differed only by the time it took to undertake the concentric action of the movement (slow – 1.7 seconds and explosive - < 0.85 seconds). Both training methods improved performance (mean sprint time over the 15 meters increased by 3.4 % [slow training] and 2.3 % [explosive training] with the 90% confidence limits for pairwise differences being ~±1.4%). Through expressing uncertainty of an effect as 90% confidence or likely limits of the true value of the effect, Liow and Hopkins (20) suggest that slow weight training was more effective than explosive training (rated as 'possible' with a 74% confidence limit) for improving the acceleration phase of sprinting, where as explosive training was more effective than slow training (rated as 'possible' with a 54% confidence limit) for improving speed maintenance. Blazevich and Jenkins (21) examined slow and explosive training velocities in hip flexion and extension, knee extension and flexion and the squat, using 30-50% 1RM for the high velocity group and 70-90% IRM for the low velocity group. They observed significant increases in 20m acceleration time ($p<0.01$), squat strength ($p<0.05$) and hip extension at 1.05 rad·s^{-1} for the athletes as a whole. However, they found no significant differences ($p>0.05$) in torque measurements for hip extension and flexion, or 1 RM for the squat or sprint performance between the slow and explosive training groups.

Given the importance of the issue of transfer of training, Baker and Nance's study investigating the relationship between Olympic lifting and sprint performance (22) was particularly interesting. Using trained Australian rugby league players ($n = 20$) they observed only weak correlations between hang clean and sprint performance ($r = -0.34$ for 10m sprints and $r = -0.24$ for 40m sprints). Therefore, the coefficients of determination (r^2) of .12 and .06 show that only 12% and 6% of the variance in the 10m and 40m sprint respectively are associated with hang clean performance. In practical terms, therefore, this shows that the assumption that there is considerable transfer from Olympic style lifting to sprint performance is incorrect; in fact, there is very little.

Several interesting studies have compared the effects of various types of explosive training, slow weight training and plyometric training (a type of training aimed at enhancing the ability of body structures to perform the stretch-shortening style, often involving depth jumps and other explosive exercises). Wilson et al. (23) compared the effects of traditional resistance training (3-6 sets of 6-10 RM squats), plyometric training and explosive training (loaded jump squats), performed twice/week for 10 weeks with experienced trainees. The traditional and explosive groups improved peak power equally on a 6 s cycle test. Both groups also increased significantly on vertical and counter-movement jump, with the explosive group increasing to a greater degree. However, the explosive group had been practicing jumping and the traditional group had not, so this was to be expected. Only the traditional group increased significantly on maximal knee-extension force. In a follow-up study, Wilson et al. (24) compared the effects of traditional weight training (squats and bench presses) with plyometric training (depth jumps and medicine ball throws). Fourteen variables related to strength and power were tested, and the traditional group increased significantly on seven variables whereas the plyometric group increased only on three. Also, both groups increased significantly on counter-movement jump, with no significant between-group difference. Similarly, Holcomb et al. (25) compared the effects of resistance training and plyometric-style training involving various types of depth jump, finding no significant between-group differences in increases in jump height or power performance. These authors concluded that plyometric training was no more effective for increasing power than traditional resistance training.

Tricoli, Lamas, Carnevale and Ugrinowitsch (26) claimed that combining heavy resistance training with Olympic weightlifting improved a broader range of performance measures when compared to combining heavy resistance training with vertical jump training. The study observed increases in performance as measured by changes in a battery of tests that included sprinting (10m and 30m), agility, squat jump, countermovement jumping and half squat 1RM. However, this paper only produced two significant between-group differences, i.e. that the weightlifting group improved their 10m sprint times by 3.66% and the squat jump by 9.56% ($p<0.05$) compared to the vertical jump group who did not improve significantly (2.7% for both the 10m sprint times and squat jump). Results of these studies do not support the conclusion that Olympic weightlifting is effective in producing broader performance increases. In addition, evidence does not support the effect of body weight exercises, such as vertical jump training, in enhancing performance.

McBride et al. (27) noted that training with lighter loads increased movement velocity capabilities. However, they only observed trends and not significant increases in sprint times when jump squats equating to a load of 30% of 1RM were undertaken, whereas an 80% of 1RM group were actually significantly slower in the sprint performance test. Interestingly, the 30% and 80% groups did not produce any significant increase in agility performance either. This suggests there is minimal transfer from squat jumps to actual performance.

In a review of strength training Delecluse (28) also observed that strength training is very important to increasing sprint performance when used appropriately. Delecluse (28) continues that a combination of 3 training methods is most beneficial to enhancing sprint performance 1) heavy traditional resistance training (which is classified as hypertrophy and neural activation training) 2) speed strength training (e.g., plyometrics) and 3) sprint associated training (e.g., over-speed and hindered running). Although this may be the case according to Delecluse (28), the article concludes by admitting that the design of a training programme for elite level sprinters is about being individual to the client's needs and as such appears to be impossible to produce a 'one fits all' and 'instant' training programme.

Sleivert, Backus and Wenger (29) compared traditional to Olympic style lifting over a period of 8 weeks. Their results produced significant increases in 10 RM values (although neither groups showed transfer of these gains to isometric or isokinetic strength or rate of torque development) and increased cycle ergometer power output. However, there were no significant differences between the groups suggesting there is little difference in adaptation to traditional weight training compared to Olympic style lifting.

More recently Harris, Stone, O'Bryant, Proulx and Johnson (30) reported that there appears to be little effect of resistance training on performance (in particular sprint performance) supporting the concept that Olympic lifting (for example) does not increase sports performance. Harris et al. (30) compared traditional weight training, explosive training and a combination of the both to ascertain the most effect training method to enhance power as measured by a selection of field tests (vertical jump (VJ), vertical jump power, Margaria-Kalamen power test, 30-m sprint, 10-yd shuttle run, and standing long jump). When the groups were compared, the combination group improved their 10 yard shuttle times (2.4%) significantly ($p<0.05$) compared to the traditional weight training and explosive training (increase in time of 1.0% and 1.6% respectively). However, the traditional weight training group increased their quarter squat (by 33.9%) significantly ($p<0.05$) more than the explosive group (15.5%). The explosive training group did not improve in any of the variables to a significantly greater extent than the other groups. Harris et al (30) concluded that combination training is the most effective training method. However, due to very few significant differences between the groups it is hard to see how they have concluded this from their results. The obvious conclusion from these results is that there is little transfer between explosive training and dynamic performance.

In addition, research by Toji, Suei and Kaneko (31) investigated the differences when training was performed by adult collegiate athletes using five repetitions at 30% maximum strength (Fmax) followed by five isometric contractions (100% Fmax) and compared to five repetitions at 30% Fmax and five contractions undertaken at high speed with no load (0% Fmax) on the elbow flexor muscles. Training was performed 3 days a week for 11 weeks, producing significant increases in maximum power for both groups after this period of training. However, the power increase was significantly greater in the elbow flexor muscles when isometric contractions were used compared to the explosive unloaded exercises. The results from Toji et al (31) suggest that isometric training at maximum strength (100% Fmax) is a more effective form of training to increase power production than no load training at maximum velocity.

Interestingly, Moore, Hickey and Reiser (32) observed significant ($p<0.05$) increases in performance (measured using countermovement vertical jump, 4 repetition maximum squat, 25-m sprint, and figure-8 drill) after a 12 week, tri-weekly training programme incorporating traditional weight training combined with Olympic style lifting (OSL) and also traditional weight training (TWT) combining plyometric style exercises (PE). Moore and colleagues (32) found significant increases ($p<0.05$) in vertical jump for the OSL (9%) and PE (7%) groups, in squat performance (299% for the OSL and 280% in the PE group), a decrease in the 25m sprint times (11% and 9% for OSL and PE respectively) and significant ($p<0.05$) increases in foot speed (12.3% for the OSL and 12.2% for the PE groups). However, Moore et al (32) did not find any significant differences between the training groups, suggesting that there is no advantage of training using either Olympic style lifting or plyometric exercises when they are combined with traditional strength training.

This is further supported by the findings of Tuomi, Best, Martin and Poumarat (33) who investigated the effects of comparing weight training only (WTO) and weight training combined with jump training (WTC) for a 6 week training programme. Their results showed both groups increased their maximal force/explosive force after the training regime. However, the group combining weight training and jump training were the only group to significantly increase their jump height performance during the countermovement jump. Their results suggest that a change in maximal strength and/or explosive strength does not necessarily cause changes in combined movement patterns such as the stretch-shortening cycle.

Newton and McEvoy (34) compared the effect of slow, controlled resistance training and explosive medicine ball throws in Australian baseball players. Only the resistance training group significantly increased throwing velocity, and this group also increased 6 RM bench press to a significantly greater degree than either the explosive group or control group. Interestingly, there was no significant difference between these latter two groups. This finding should not be a surprise to exercise physiologists, given that muscles produce greater power at slower speeds of movement (35).

Possibly the most interesting study to compare the effects of resistance training and plyometric-style (depth jumping) exercises was performed by Clutch, Wilton, McGowan and Bryce (36). In this study, half the subjects were members of a weight training class and the other half were volleyball players. Subjects were divided into four groups: a resistance training only group, a resistance training and depth jumping group, a volleyball playing and resistance training group, and a volleyball playing, resistance training and depth jumping group. All groups significantly increased vertical jump after 16 weeks of training, with the exception of the group that only did resistance training. There were no significant differences among the other three groups. The authors concluded that depth jumping provided no additional benefit to performing resistance training and practicing the specific skills involved in volleyball. Therefore, it appears that the only training necessary to optimize performance of a specific skill is the performance of that skill and separate resistance training. This finding was supported by Kotzamandis, Chatzopoulos, Michailidis, Papaiakovou, Patikas (37) who observed that increases in performance (measured by 30m sprint) were significantly greater when subjects combined resistance training with sprint training when compared to just weight training. This suggests that sprint training will obviously increase sprint performance more than when subjects just strength train. However, Kotzamanidis and colleagues (37) failed to observe the effects of comparing weight training only versus sprint training only. This would have been important to show whether the most effective method was the sprint training, the strength training or a combination of the both.

Cronin and Hansen (38) investigated strength and power as predictors of sports speed. They observed that the fastest players in their squad of professional rugby league players over 5, 10 and 30 meters tended to jump higher in the countermovement jump and jump squat. They conclude that specific sport speed can be best trained through plyometric training and loaded jump squats. However, this conclusion appears very premature given that the study did not actually examine the effects of such training methods.

The transfer of gains made in training to actual sports performance was investigated by Cronin, McNair and Marshall (39). They showed that undertaking two forms of explosive training (bungy squat jumps and non-bungy squat jumps) improved the ability to squat jump with greater power, but this did not transfer to improved performance measured by agility performance. Hoffman, Cooper, Wendell and Kang (40) also observed no increases in performance (measured by agility, 40 yard sprint, 1RM bench press, vertical jump and vertical jump power) after a 15 week Olympic weightlifting training programme. This is particularly interesting given the high popularity of Olympic lifts for the purposes of enhancing athletic performance. That is not to say that Olympic weightlifting does not improve strength and power; of course it does, as Gonzalez-Badillo, Izquierdo and Gorostiaga (41) clearly showed that this form of training increased their subjects' ability to Olympic-lift more weight. Others have found this form of training more valuable than power lifting (40) when increasing the ability to squat a greater amount of weight. Our point is, however, that the evidence suggests that those not involved in weightlifting, powerlifting or strongman-type events will derive little or no benefit from performing such lifts.

Overall, therefore, given the high popularity of explosive exercises amongst athletes, and the enthusiastic recommendations given by some exercise certification organizations (1, 3) for athletes to perform such exercises, it is surprising that there exists virtually no evidence that these types of exercises are any more effective than traditional, slow weight training in enhancing sports performance. Indeed, some of the studies above suggest that slow weight training is actually more effective in this regard. One other criticism that has been made of explosive exercises, however, is that they may be associated with a greater risk of injury than slow weight training (5, 10). Therefore, the following section will examine this contention.

Table 1: comparison of performance effects of slow and explosive training protocols.

Reference	***Measure***	***Training protocol***	***Performance increase***
LaChance and Hortobagyi (12)	Self-paced vs 2/4	Study examined acute effects of different cadences on performance	When self-paced, subjects completed 96% more pull ups when self paced in 16% less time compared to 2/4
Liow and Hopkins (20)	Slow 1.7s Fast <0.85s	3-4 sets of 80% 1RM	Slow training increased acceleration performance. Fast training improved speed maintenance.
Moore, Hickey and Reiser (32)	Countermovement vertical jump, 4RM squat 25m sprint and figure 8 drill	<u>Plyometric group</u> Split squat jumps, tuck jumps and bounds <u>Olympic group</u> Hang clean, deadlift <u>Weight training</u> Squat, hamstring curl calf raises	<u>Plyometric group</u> 7% increase in vertical jump, 280% for squat, 9% for sprint 12.2% for foot speed <u>Olympic group</u> 9% increase in vertical jump, 299% for squat, 11% for sprint 12.3% for foot speed
Harris, Stone, O'Bryant, Proulx and Johnson (30)	vertical jump (VJ), vertical jump power, Margaria-Kalamen power test, 30-m sprint, 10-yd shuttle run, and standing long jump	Traditional weight training (TWT), vs explosive training (ET) vs a combination group (COM) of the both	COM increased 10-yard shuttle by 2.4% TWT increased their quarter squat by 33.9% which was significantly more than the explosive group (15.5%). ET did not improve in any of the variables to a significantly greater extent than the other groups.
Tricoli, Lamas, Carnevale and Ugrinowitsch (26)	10m and 30m sprint times, squat jump, countermovement jump (CMJ), agility test, and half squat 1RM	<u>Olympic training (OT)</u> 3x6RM High pull, 4x4RM power clean, 4 x 4RM clean and jerk <u>Vertical Jump training (VJ)</u> 6 x 4 double leg hurdle hops, 4 x 4 alternated single leg hurdle hops, 4 x 4 single leg hurdle hops, 4 x 4 40cm drop jumps <u>Both groups</u> 4 x 6RM half squats	OT significantly improved their 10m sprint times by 3.66% and the squat jump by 9.56% compared to the vertical jump group who did not improve significantly (2.7% for both the 10m sprint times and squat jump). Both groups improved the CMJ, No significant changes in either group for half squat 1Rm, 30m sprint and agility test, thus suggesting a limited performance improvement using these training methods.
Baker and Nance (22)	10m and 40m sprint, 3RM squat and power clean	Study examined relationship between sprint performance and power tests.	Weak correlations between hang clean and sprint performance (r = -0.34 for 10m sprints and r = -0.24 for 40m sprints). In practical terms, therefore, this shows that the assumption that there is considerable transfer from Olympic style lifting to sprint performance is incorrect; in fact, there is very little.

4. INJURY RISKS FROM EXPLOSIVE EXERCISE

It appears that not only is ‘explosive’ weight training unnecessary for increasing muscle power, but also such training poses considerable injury risks. Many authors have expressed concerns regarding the relatively great initial and terminal stresses on the involved tendons, ligaments and muscle fascia that explosive training produces. For example, Kulund (42) noted that injuries to the wrist, elbow and shoulder were commonplace when individuals performed fast, Olympic-style lifting. Rossi and Dragoni (43) observed that of the 390 cases of lumbar spondylolysis from their 3132 subject cohort, 22.68% occurred as a result of weightlifting. Hall (44) found that fast lifting speeds greatly increased shear forces in the lumbar region. Also explosive lifting can apparently lead to spondylolysis (45, 46). For example, Kotani et al. (45) found that 30.7% of a sample of weightlifters, all of who performed explosive lifts, suffered from this problem. Reeves et al. (47) found that 36% of weight lifters had spondylolysis compared to 5% of the normal population; in Duda’s (46) study of Olympic lifters, the figures were 44% and 4.2% respectively. In a study of weight training injuries in football players, Risser et al. (48) found that 60% of their sample who performed Olympic-style lifts suffered from low back problems, compared to only 14.3% of athletes who did not perform such movements. Konig and Biener (49) noted that 68% of their sample of Olympic lifters had suffered an injury as a result of their weight lifting, and 10% of these required at least 4 weeks’ recovery before being able to return to lifting weights. Granhed and Morelli (50) also found that 46% of retired weight lifters had physical problems caused by their lifting. Bryzcki (51) even cites the case of an experienced athlete who fractured both of his wrists when attempting a power clean.

A case study by Crockett et al. (52) described the case of an NCAA division 1 basketball player who suffered from a sacral stress fracture as a result of compressive forces generated down the spine as a result of performing explosive exercises on a commercial jumping machine. Though use of the machine had apparently enabled the athlete to improve his vertical jump, the very serious injury prevented him from playing entirely.

The above studies are hardly attractive advertisements for the benefits of explosive training. Of course, any weight training program involves some risk of injury, such as minor strains and sprains, but the major injuries noted above should not be considered acceptable when one of the main justifications for strength and conditioning training in athletes is that it reduces injury risk. Greater structural strength makes a structure less likely to be damaged when forces are exerted against it, and therefore strength training can be of great value for injury prevention. This has been shown quite graphically in research examining the effect of specific exercise for the lumbar spine on the incidence of low back injury (53). Interestingly, in this study and others using slow weight training to prevent and rehabilitate low back problems, almost no training-related injuries have been reported (54, 55, 56), in contrast to the explosive exercise studies noted above. Some have argued that the risks of injury inherent in explosive lifts are simply part and parcel of the injury risks of competing in sports (4). However, when individuals are already participating in potentially injurious activities, to add other dangerous activities to their training schedule hardly seems justified, especially when there is no evidence that such activities will aid them in any way. Of course, Olympic weightlifters and strongmen, whose sports involve completing explosive lifts, will have to train with such lifts, as this is central to their sport. Such individuals need to accept injury risk from explosive lifts as an occupational hazard. However, athletes in other sports do not need to, and in our opinion should not, accept the risks of performing such lifts; they are simply unnecessary for all other athletes.

From the evidence presented, therefore, we contend that as well as being unnecessary to enhance performance, (indeed the evidence simply does not support the idea that explosive exercises improve sporting performance), advocating explosive lifting is questionable from an ethical standpoint as such training may cause injury. The NSCA (1) and ACSM (6) guidelines are rather ironic in this respect, given that one of the main benefits of strength training is (or at least should be) a reduction in injury risk (57).

5. CONCLUSIONS

Explosive exercise, including Olympic lifts and variations of these, plyometric-style training, and traditional weight training exercises performed with a very fast cadence, are very popular with athletes, and are advocated by many self-proclaimed experts in the field of strength and conditioning. It is often claimed that such exercises translate better into enhanced sporting performance compared to weight training with a slow cadence. However, as we have shown, there is little evidence that these training techniques are effective in enhancing athletic performance, and no evidence that they are more effective than relatively safe, slow weight training. In fact, some studies suggest that slow weight training may be more effective in enhancing strength and power. Also, there is considerable evidence that explosive exercises pose considerable injury risks: we contend that these risks are ethically unacceptable. As such we recommend that, as supported by the literature, a training regime that encompasses slow, controlled weight training in combination with the sport specific training is all that is necessary to enhance both muscle strength and power and in turn improve actual sporting performance.

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