Developing Powerful Athletes Part 2: Practical Applications

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ABSTRACT

In part 1 of this two-part review, we addressed the recent criticisms of the use of terms such as power, rate of force development, and explosiveness, over impulse. These terms were distinguished mechanically and conceptually for the benefit of the scientist and coach. In part 2, we use the key mechanical parameters underpinning power development and its relationship with the force–time characteristics and force–velocity profile of sporting movements, to evidence the planning of training drills and assist the strength and conditioning coach in devising periodized training programs.

INTRODUCTION

In part 1, we discussed that given most sporting actions occur in <0.3 seconds, rate of force development (RFD) may supersede peak force capability as a proxy measure of sports performance. Equally, we identified that given the variety of motor skills encompassed in any one sport, it is important to train power (or the ability to produce force at high and low velocities) across a spectrum of loads. Thus, the aim of this article (part 2) is to discuss training methods that achieve these goals. We will start by addressing methods to increase RFD, before examining those that improve power and then finally investigating the impact that strength training has on these goals. In doing so, we also aim to demonstrate the interdependence of each type of training method and why athletes are recommended to develop power from a solid foundation of strength.

RATE OF FORCE DEVELOPMENT

Although strength training typically targets peak force (e.g., the highest point noted in a force–-time curve of an isometric midthigh pull), ballistic training is generally advised to increase RFD, that is, force capability at the onset of movement (Figure 1). The capacity to increase RFD, or explosive strength as it is termed by many coaches and athletes, is largely attributed to the capacity to increase efferent neural drive, particularly by increases in the firing frequency of motor units (1). Thus, RFD is a function of neuromuscular activation and represents an individual's ability to accelerate objects (7,16,46). Given this summation of RFD, the recommendation to use ballistic training can also be explained when examining the influence of different loads on the force–time characteristics generated while squatting. Kubo et al. (27) examined back squats at loads of 0, 12, 27, 42, 56, 71 and 85% of 1 repetition maximum (1RM) and identified that, at all loads, there was a deceleration phase (and thus negative impulse) at the conclusion of the concentric portion and that the relative duration of this phase increased as the load decreased. This therefore makes it difficult to stimulate the neuromuscular system throughout the full range of motion. This issue is naturally avoided during ballistic training (and reduced during weightlifting exercises and variable resistance training) where the barbell can be accelerated throughout the whole range of movement.

Ballistic exercises may be best described as "explosive" movements (rapid acceleration against resistance), whereby the mass of interest (barbell and/or lifter) becomes a projectile. Plyometric training, medicine ball throws, and weightlifting and their respective derivatives are possibly best suited to train RFD because in addition to their ability to be adapted to the specifics of the sport, they encourage full acceleration, with deceleration of the system achieved mainly due to the effects of gravity, rather than due to the neuromuscular system actively

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KEY WORDS:
impulse; momentum; work; force; strength; speed

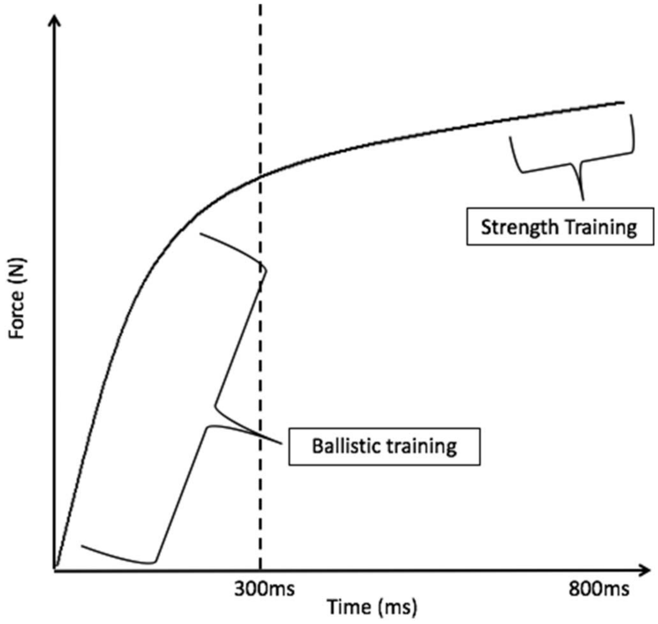

Figure 1. Although the interdependence of strength and power training dictates that both modalities affect all regions of the force–time curve, ballistic training is preferred to improve the rate of force development (or epoch defined impulse), generally within the first 300 ms of movement, while strength training is the preferred method to improve the peak height of the curve.

decelerating the system. Also, weightlifting and its derivatives produce some of the highest power outputs of any exercise modality (37). For example, the relatively low velocities involved in powerlifting exercises such as the deadlift, results in approximately 12 W per kg of body mass (BM) of power. By contrast, weightlifting derivatives can produce power outputs as high as 80 W per kg of BM; for a review of relative power outputs across exercises, readers are directed to the study by Suchomel and Comfort (38).

It is also worth noting that the second pull is the phase of weightlifting that has been shown to generate the greatest vertical ground reaction forces, RFD, and power output (17,35). For example, the study by Comfort et al. (11) found that, for force–time characteristics, midthigh clean pulls (i.e., taking the bar from the midthigh and concluding without the catch phase) produced higher values compared with power cleans and even hang power cleans (taking the bar from just above the knee). This finding is unsurprising, however, as there is a reduced displacement and therefore time available during a midthigh clean variation, compared from the knee or hang. As such, force has to be higher to produce the impulse required to accelerate the system to ensure adequate displacement, especially if catching the bar. This information should be greeted with relief by strength and conditioning coaches because some athletes can find learning or achieving the body positions of the full versions of weightlifting challenging and cannot realize their benefits until an extended period has been spent mastering them. Also, the fact that performing the lift starting from the midthigh may be better than from the floor, means issues regarding athlete mobility (e.g., limited dorsiflexion) can be avoided.

Again to the coaches' avail, the study by Suchomel et al. (43) found that the jump shrug (again initiated from above the knee and through a countermovement) produced significantly greater peak force, velocity, and power, than both the hang clean and the high pull across all tested loads (30, 45, 65, and 80% 1RM hang clean). This was also confirmed by Suchomel and Sole (39), with differences between the lifts attributed to specific task constraints. For example, they note that the goal of the jump shrug is to jump as high as possible, whereas for the clean, it is to catch the load. The intent to catch may lead to incomplete triple extension, especially at heavier loads (43). In turn, this may decrease RFD and potentially, over time, result in a diminished training stimulus (39). Furthermore, with the goal of the jump shrug being to jump as high as possible, it naturally requires acceleration throughout almost the entire movement, leading to greater force and velocity characteristics, again partly explained by the data of the study by Kubo et al. (27) highlighted above. Of course, however, this can also be explained using Newton's second law. That is, this need to jump (as opposed to drop under the bar and catch) requires a greater net impulse, which, when coupled with further reductions in displacement (and thus movement time), places a greater demand on the rapid application of force and therefore RFD. Table 1 identifies some ballistic exercises that, based on the information above, should form the basis of power training. The programming of these is discussed in the latter part of this article, and readers are also directed to the work of Suchomel et al. (40) for information on how weightlifting derivatives can be manipulated for the same purpose.

POWER AND THE FORCE–VELOCITY CURVE

In part 1, we noted that the velocity at which we can move an object is determined by its mass and that, when lifting to maximize power output, our intent should always be to apply maximal and rapid force (thus ensuring maximal neural recruitment) (1). This is because as long as we are maximizing force output, we can improve impulse over a given period, which in turn would increase velocity. Furthermore, we noted that most sports use a variety

Table 1
Example ballistic exercises aimed at increasing explosive strength

Exercise	Coaching notes
MB chest pass, slam, overhead throws, and throws with rotation	It is important to note that these MB exercises are for the legs, so if the athlete does not load with a countermovement or is not encouraged to jump when releasing it, it gravitates toward an upper-body exercise.
Weightlifting and their derivatives	Although weightlifting is an excellent resource, novice lifters may benefit most from pulls above the knee and from midthigh. Lifts from above the knee negate athlete mobility issues, with many unable to correctly attain a deep-squat position. The best (and simplest) exercise may be jump shrugs, which also ensures a full triple extension action.
Loaded jump squats	This exercise produces high impact forces at landing, so the athlete must progress gradually. Arguably, without the use of an electromagnetic braking device, jump shrugs and hex bar jumps may be better advised.
Slow and fast plyometrics	There is an abundance of drills available here from jumping up to a box, landing from a box and drop jumps, including multiple hops and in various directions
Seated MB throws (similar to above)	Similar to the MB drills identified above, however, being seated directs all force development to the upper body
Bench press throw	This is a good way of performing an upper-body ballistic lift with very heavy load (of course lighter weights can also be used), which is not available with a MB. If the weight cannot be "thrown" consider using bands and chains to enable full acceleration throughout the lift.

MB = medicine ball.

of motor skills that span the entire force–velocity curve, and thus, it is considered prudent to ensure that training programs adequately cover all points. This is principally achieved by manipulating training load, with training velocity an outcome of this. Furthermore, the importance of using multiple loads (and therefore velocities) is evidenced by studies demonstrating that neuromuscular adaptations are specific to training velocity (25,26,30,32); this has also been summarized by Haff and Nimphius (15). Across these studies, strength training has been shown to predominantly shift the high-force region of the force–velocity curve to the right (Figure 2A), while training focusing on the generation of speed, predominately shifts the high-velocity region of the curve to the right (Figure 2B). Training at maximum power output predominantly effects the curve at the region corresponding best to the exercise used (Figure 2C). These findings explain why a mixed-methods approach to training is generally advised, where strength and power are trained simultaneously, but one is subject to greater emphasis during a particular training block (15,44). Furthermore, the use of multiple exercises (and not just multiple loads within the same exercise) can be a useful training tool because the kinematics of some exercises is better matched to certain loads. For example, pulling-based derivatives of weightlifting exercises enable the use of loads above an athlete's 1RM clean (as the lifter is no longer constrained by having to catch the bar) and thus can further emphasize the high-force (strength–speed) region of the force–velocity curve, above catch-based derivatives. Similarly, jump shrugs enable lighter loads to be used than those permitted during catch-based weightlifting variations (given that when attempting to catch, technique may be compromised if the load is too light) and some pulling variations (as the bar may either be rapidly accelerated toward the chin or too high vertically) and thus allow further emphasis on the high-velocity (speed) region of the force–velocity curve. Suchomel and Comfort (38) show how a spectrum of loads can be best paired with exercises to support power-based training, by plotting a theoretical force–velocity curve with respect to weightlifting derivatives (see Ref. 38 for further reading).

SPEED–STRENGTH AND BARBELL VELOCITY ZONES

Within the strength and conditioning community, velocity and force are often regarded as synonymous with speed and strength, respectively, and hence, power is often referred to as speed–strength. Furthermore, a distinction can be made between speed–strength and strength–speed (45), suggesting these are separate physical capacities pertaining to defined areas of the curve and are an important division when prescribing strength and conditioning programs. Speed–strength

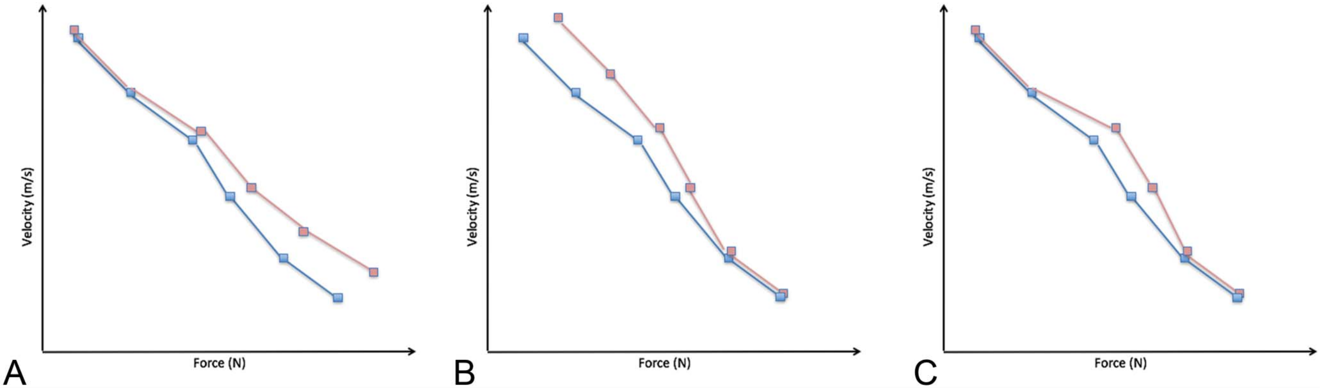

Figure 2. Hypothetical change in F–v curve based on training load. (A) Strength-based power training. (B) Velocity-based power training. (C) Training at P_{max} (i.e., the load that maximize average power). Of note, however, the position at which the line flattens is exercise dependent, as Pmax often occurs at varying loads.

can be defined as the ability to quickly execute a movement against a relatively small external load and is assessed in terms of speed of movement. Conversely, strength–speed may be considered as the ability to quickly execute a movement against a relatively large external load and is assessed in terms of mass lifted. These terms are intended to signify a gradual shift in training emphasis from strength (low velocity) to speed (high velocity) as the athlete journeys along the force–velocity curve ensuring full coverage. This can be achieved through appropriate exercise selection and the gradual reduction in load (i.e., % 1RM) as emphasis shifts from strength, strength–speed, speed–strength, and finally to speed (Table 2). Although the demarcation of which load corresponds to speed–strength and strength–speed is rather arbitrary, one may suggest that up to, and including the load that produces peak average power for a particular exercise, signifies speed–strength; above this load and up to the 6RM load (i.e., strength training load) would be classed as strength–speed (Figure 3).

These demarcations can now also be defined using devices that measure barbell velocity (Table 2 and Figure 3). Typically, for powerlifting type exercises, mean concentric velocity (MCV) is used due to its high reliability (23,24) and better representation of concentric velocity, when compared with peak concentric velocity (23). It is well reported that the MCV achieved at maximal loads can vary between individual strength levels (20,48) and exercises (20,28,34), which would therefore affect the velocity zones that relate to strength, strength–speed, speed–strength, and speed. This variation, including that noted between different devices, therefore warrants the need for individualized velocity profiling to be conducted. In contrast to these traditional lifts (but following the same principles), weightlifting exercises should use peak velocity to determine load because they are ballistic in nature and the entirety of the movement is not as critical for the evaluation of the lift (29). Furthermore,

Table 2
Example exercises based on training emphasis

Strength	Strength-Speed	Speed-Strength	Speed
Bench press (0.10–0.4 m/s)	Bench press throw	Plyometric push-up	Seated medicine ball chest pass (>1.5 m/s)
Squat (0.23–0.6 m/s)	Jump shrug from hang (>1.0 m/s) Jump squat (40% BM)	Jump to box Jump squat (20% BM)	Med ball throw (>1.5 m/s) Jump squat (BM) (>2.0 m/s)
Deadlift	Power clean (>1.2 m/s)	Power snatch (>1.5 m/s)	Jump to box (>2.0 m/s)

It should be noted that the emphasis of an exercise can be altered by changes in loading. As noted above, a change in loading will inversely affect the velocity.

BM = body mass.

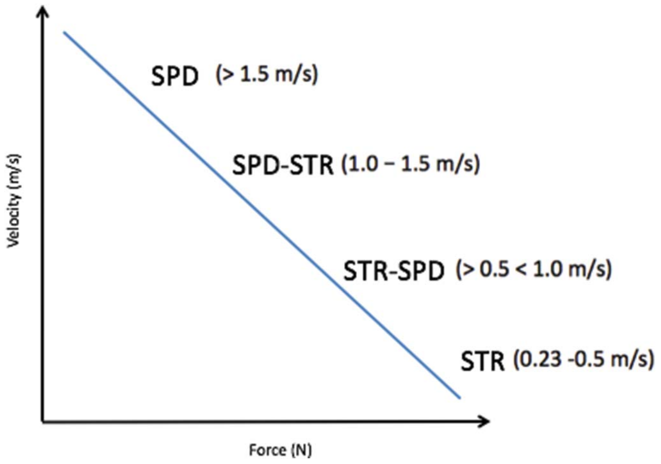

Figure 3. Adaptation of F–v curve, substituting force for strength (STR) and velocity for speed (SPD). Velocity bands shown are for the back squat and may vary between individuals.

and as expected given the discussion above, peak velocity occurs during the second pull of the clean and snatch (18), with this point marking the critical moment of the exercise, because it determines the subsequent barbell displacement and thus is a clearer determinant of success (29).

To help monitor and regulate training to ensure the athlete is training in a velocity range that best represents the biomotor in which they are trying to elicit change, the implementation of velocity cutoffs can help determine when a set is complete, based off a predefined decrement in velocity. For example, an athlete looking to develop lower-body strength-speed may perform 4 sets of jump squats at 75% of bodyweight, which is where the greatest impulse is produced (31)—see part 1. During the first set, the athlete may achieve a MCV of 0.95 m/s, which is also their fastest rep. The velocity loss allowed maybe set at 20% from that value (0.76 m/s). Thus, when the prescribed percentage velocity loss limit (20%) is exceeded, the set would be terminated. This method has previously been shown to (a) increase strength gains and (b) enhance ballistic outcome measures such as jump height, more so than higher cutoffs of 40% (8,9), despite a 40% difference in training volume (8). Furthermore, in ensuring the athlete performs all repetitions within an acceptable proximity of the intended velocity, fatigue across the set and indeed the training session is comparatively less, given the subsequent reduction in volume. Finally, we should state that high-velocity training, when performed under load, is not necessarily attempting to replicate the actual movement velocities attained in sport. Anecdotally (acknowledging that as of yet there is no peer-reviewed research to support its efficacy), this can be achieved and even superseded through bungee cords and resistance bands, for example. In the case of the former, it is also often necessary to spend sufficient time accelerating to achieve such speeds.

DEVELOPING RATE OF FORCE DEVELOPMENT AND POWER THROUGH STRENGTH

Strength training is a fundamental component in the development of power, given that power is largely dependent on the ability to exert high forces (and is thus subject to an athlete's strength capacity). This can be noted by the high and positive correlation between peak power and maximum strength (r = 0.77–0.94) (2), in both the upper-body and lower-body (3–5). It is not difficult to corroborate the interdependence of strength and power (beyond the obvious mechanics that $P = F \times v$) by using $v = F \times t/m$ (where P = power, F = force, m = mass, a = acceleration, v = velocity, and t = time). This equation represents a rearrangement of Newton's second law of motion: $F = ma \rightarrow F = m \times v/t \rightarrow v = F \times t/m$. The equation ($v = F \times t/m$) now reveals that to increase velocity (v), it is necessary to increase the magnitude or duration of the force applied (or both), which results in an increase in impulse, or alternatively, decrease the mass of the system. However, not all of these are possible as the athlete may be unable to decrease system mass (either BM or sports implement mass), or increase the duration of movement; in fact, a decrease in duration may be wanted or even needed. Consequently, only one option remains, namely to increase force production (strength). Furthermore, the influence of force can also be explained when we consider the work–energy theorem (see part 1), which states that the net work performed on an object is equal to the change in kinetic energy. In the context of jumping and noting that jump height should be calculated based on take-off velocity (as per the impulse-–momentum theorem), velocity can be calculated as follows: $\mathrm{v} = \sqrt{\left(2 \times \mathrm{F} \times \mathrm{s}/\mathrm{m}\right)}$. Given mass is limited in its ability to alter (assuming a lean athlete) and push-off distance is anatomically constrained (or the optimization is outside the control of the strength and conditioning coach), force is the variable that exerts the most influence. Finally, as mentioned, the impulse–momentum theorem is also an important consideration for power activities as, for example, jump height is determined by take-off velocity, which, in turn, is determined by net impulse (the impulse applied to BM). The equation shows that a large impulse is needed to produce a large change of momentum. Again, force must

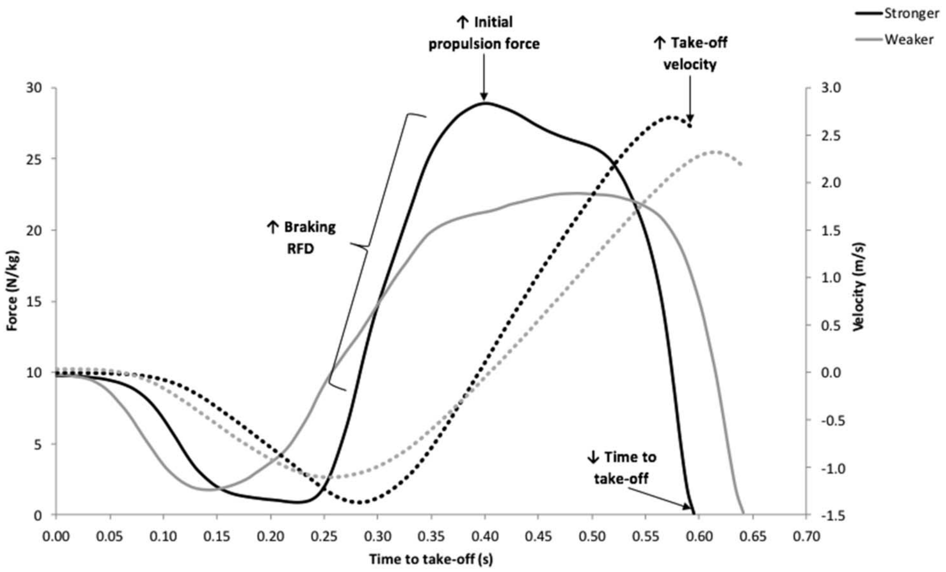

Figure 4. Comparison of force, power, RFD, and movement time, during a countermovement jump, between stronger and weaker athletes (37). RFD, rate of force development.

dominate because of the short duration of most sports movements.

Therefore, force and time must be measured if athlete improvement is to be appropriately monitored, ideally through analysis of a force–time trace. Figure 4 illustrates how increases in strength (and thus RFD) can change the jump profile of an athlete, such that performance (height and duration) is improved (37). These conclusions lead to a common question; how strong should we make our athletes? Clearly, the underpinning physics suggests that there is no upper limit, with researchers suggesting that athletes who can lift 2 × BM during a back squat can express higher power outputs in vertical and horizontal jumping than their weaker (e.g., 1.6 × BM) counterparts (6,12,13,33,36,47); thus, this seems to be an appropriate benchmark.

Bompa and Carrera (10) effectively describe the interrelationship between strength training and ballistic training. They propose that power is developed through a physiological strategy involving 2 phases. The first phase involves the recruitment and training of fast-twitch fibers through strength training as described by the size principle of motor unit recruitment (21); that is, you have to lift heavy enough to actually recruit type IIa, and especially type IIx fibers. The strength-training phase is considered fundamental given the high correlation ($r = 0.75$) between the percentage of type II fibers and power output, and their role as velocity increases (14). The second phase involves increasing the firing frequency of these fibers (which are now of a greater volume) through ballistic training. Remember, $P = F \times v$, so maximum gains will occur if both of these components are trained. For example, the study by Cormie and McBride (12) compared a power-training group (7 sets of 6 jump squats with the optimal load for maximal power output, i.e., BM) with a strength–power group (5 sets of 6 jump squats at the optimal load for maximal power output and 3 sets of 3 squats with 90% of their 1RM). Results revealed that combined lower-body strength–power training was as effective as power training for improving maximum jump height and maximum power output in the jump squat, and it was more effective than power training at producing all-around (i.e., from BM to 80 kg) improvements in the load–power relationship of the jump squat. Unfortunately, no results were presented to illustrate whether there were any differences in jump strategy (e.g., to the duration of or force applied to each phase), to determine whether there was a different response regarding how changes in impulse result in an increase in jump height. Perhaps, the best example of athletes involved in this combined (mixed methods) strength and power training are weightlifters. These athletes are reported to produce the highest (ratio-scaled) values for isometric RFD and power output in weighted and unweighted vertical jumps (19).

Cormie et al. (13) have also shown that, in weaker individuals, both modes (strength and power) are equally effective at enhancing power and overall athleticism. In this study, relatively weak men (1RM back squat <1.6 × BM) had their jumping and sprinting performances, along with changes to their force–velocity profile, muscle architecture, and neural drive tested, after a 10-week (3/week) training intervention of either strength training or ballistic-power

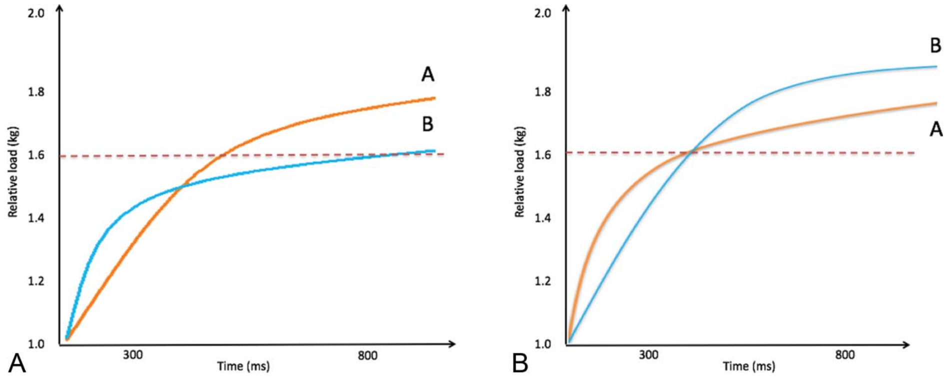

Figure 5. (A and B) To appropriately use the force–time curve, relative force must be labelled along the y-axis. This is because while having a high RFD is certainly a desirable characteristic, it is still essential that an athlete have the requisite strength (~1.6 × body weight) from which to engage in mixed-methods training. Given peak force in both athletes has surpassed this threshold, the trace may be interpreted as follows: Athlete A would benefit most from ballistic training while athlete B would benefit most from strength training. Naturally, their training swaps in the next mesocycle, given the force–time traces should then appear as per B. RFD, rate of force development.

training. Both groups showed similar improvements in the performance measures but through different mechanisms. The ballistic-power training group increased the rate of electromyography rise during jumping, producing more force and increasing RFD, resulting in greater acceleration and movement velocity in shorter periods. In the strength training group, results were consequent to maximal neural drive (demonstrated through increases in maximal integrated EMG) and muscle thickness, which increased contractile capacity and thus reducing the relative load. This enabled greater force and RFD, and the ability to accelerate their mass to a greater degree, and again over a shorter period.

It is apparent therefore that maximum strength is a key factor in developing high-power outputs and that, to fully develop an athlete's power potential, strength and conditioning coaches should include strength training within their periodized programs. Of note, because strength levels may only be maintained for 2 weeks (22), it is prudent to incorporate strength sessions throughout the entirety of a periodized program so as to optimize and maintain high levels of power output through training and come the time of competition (44). Suchomel et al. (41) nicely surmise that strength should be perceived as a "vehicle" for driving the enhancement of power and RFD, and we recommend reading (42) for a more in-depth analysis of the significance of strength and how it may be trained.

CONCLUSION AND PRACTICAL APPLICATIONS

Armed now with this deeper understating of the interdependence of strength and power, we must return to the profiles of athlete A and B, as presented in part 1 (see Figure 5A below). This figure can now be seen as a simplification of how the force–time curves of athletes can be used to classify training windows, given that (a) increases in impulse naturally accompany increases in strength (when time is held constant), (b) weaker individuals benefit most from strength training, regardless of their profile, and (c) while it is desirable to have a high RFD, it is still essential that the athlete produce the required force over a given duration (impulse). As such, when reporting force–time traces, it is important to note the relative force capacity along the y-axis, to ensure the athlete has sufficient strength to now engage in a periodized approach of mixed-methods training.

Given peak force in both athletes is above the recommended 1.6 × BM (Figure 5A), the trace may be interpreted as follows: Athlete A would benefit most from an emphasis on ballistic training while reducing the focus on strength development, while athlete B would benefit most from an emphasis on strength training, with a reduced focus on ballistic training. As they undertake this training, the graphs would reverse, albeit now with higher values (Figure 5B). In the next training block, therefore, they would swap training emphasis, with this pattern of periodization continuing throughout the mesocycle or macrocycle. Importantly, however, had strength capacity been <1.6 × BM in both athletes, then they should simply continue with a strength emphasis. We should also reiterate that a training emphasis infers that (normally) one biomotor is targeted for improvement, while others are maintained as best as possible. So, a power emphasis implies the goal of this training block is to increase an athlete's rapid expression of force (at high and low loads). Strength is still trained, however, albeit with much less volume, to ensure this biomotor quality (i.e., peak force capacity) is maintained as best as possible (therefore, frequency and intensity may remain). This approach is guided by their interdependence, for example, power training will seem ineffective if strength capacity diminishes.

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