Strategies for maximizing power and strength gains in isoinertial resistance training: Implications for competitive athletes

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Abstract  Isoinertial resistance is imposed during natural human dynamics, where muscles contract at varying velocities and joint angles. In many sports, the ability to produce greater force at faster speed is essential for successful outcomes. Hence, power training under isoinertial resistance (e.g., body mass, weights or flywheel, etc.) provides event-specific adaptive stimuli. Conventional power training consists of a combination of strength-oriented (> 70% 1RM) and speed-oriented (< 30% 1RM, e.g., plyometrics) methods, with the aim of being able to overcome variable external loadings across a range of velocities. An alternative maximum power output training (Pmax training, 30-70% 1RM) has been found to elicit equivalent or greater effectiveness compared to the conventional methods. It is, however, difficult to precisely reproduce the prescribed intensities, given several concerns associated with 1RM testing and the variable accuracies of the repetition-intensity or velocity-intensity relationship. No matter what level of resistance is assigned to an exercise, it is far more important to exert as much effort (or fastest concentric speed) as possible per repetition, otherwise, the training effects are reduced. At light intensities, however, a large portion of the concentric phase is spent in deceleration for the subsequent phase transition, which may limit effort. Making projectile motions, therefore, are necessary. The utilization of stretch-shortening cycle effects, with increased power ability, may give a further training edge. Coaches and trainees should be aware that successful movements in power training are defined as greater acceleration, speed and displacement for every repetition, rather than simply neat form or smooth repetitiveness.

Keywords: repetition-intensity relationship, velocity-intensity relationship, angle-torque-velocity relationship, projectile motion, stretch-shortening cycle

Introduction

In human dynamics, force exertion at a faster rate and speed is the key to accomplishing desired functional needs¹. Hence, power training, which aims to improve both force and speed components of muscle function, has been widely adopted, especially by competitive athletes¹. Generally, the training prescription concerns intensity (% 1RM or RM), number of sets and/or inter-set recovery, with successful movements defined as the correct form or smooth repetitiveness³. The intensity of an exercise is determined by the level of resistance during the exercise, usually the weight being lifted. Recent studies, however, reveal that effort, rather than intensity, has a greater impact on training effectiveness⁴,⁵. Particularly, maximum effort in every repetition is crucial, no matter what intensity, for optimizing training outcomes⁶. Hence, this article outlines the limitations of assigning training intensities, the basic characteristics of skeletal muscles, and the means to maximize training effort with evidence that effort indeed has an overwhelming effect compared to training intensity. The interpretations and implications for training populations, especially competitive power athletes, are summarized at the end.

Expression of training intensity

% 1RM. One-repetition maximum (1RM) refers to the maximum load that can be lifted for only one repetition, and has been used to assess an individual’s maximal strength⁷. In resistance training studies, relative values of the maximum strength (% 1RM) have been commonly used to allocate different training schemes to participants. Hence, the recommended intensities are expressed as % 1RM (e.g., 80% 1RM). The determination of 1RM, however, may produce a great degree of stress on the muscles, bones, and connective tissues that could cause an injury if not performed correctly⁸,⁹. Performing a 1RM also
increases blood pressure\(^{11}\). For example, during a 1RM leg press, systolic/diastolic arterial blood pressure can rise to an average of 31/284 with a Valsalva maneuver (closed glottis), and an average of only 198/175 with slow exhalation (open glottis)\(^{11}\). A 1RM test, therefore, requires familiarity with the lifting movement, a correct technique and careful supervision\(^8\). These considerations are magnified when testing adolescents and older adults\(^8\). 1RM testing may be a concern even for a trained population of athletes. This is because frequent measurements are needed to assess strength gains over time, which may interfere with the current training program given the considerable amount of time required per test per muscle group\(^12\). For example, in a study by Chapman et al. (1998)\(^{12}\), a 1RM bench press test for 98 subjects took six hours for three staffers to complete using five bench press stations. The time-consuming issue related to a 1RM test is further exaggerated when testing multiple body parts or exercises. Many trainees, therefore, prefer not to directly assess 1RM, or do not know their current 1RM values. Assigning a training intensity in % 1RM may therefore be unsuitable in practice for these reasons.

Repetition-intensity relationship. As an easier and more applicable way to identify loading intensities, the relationship between the maximal number of repetitions (or RM value) and intensity (% 1RM) has been developed. The relationship allows an estimation of intensity from the number of repetitions performed with a given submaximal load. Extrapolation of one’s 1RM is also possible with submaximal liftings, reducing many of the associated concerns related to a 1RM test. A number of different equations have been reported for the repetition-intensity relationship or the prediction of 1RM; with the data being fitted by either linear, exponential, inverse or power functions\(^{7,12-14}\) (Table 1). When heavier loads are used (10RM or heavier), the predicted intensities are close to an agreement among the equations, and 1RM values well predicted (within an average of 5.7 kg). The relationships, however, are never identical; with a larger variation among the previous equations when predicting intensities or 1RM values using lighter loads\(^7\) (Table 2).

Abadie et al. (1999)\(^{15}\) found that the regression equation that had been established before training was still valid after technique practice. By contrast, many other studies showed that the equation could be affected by training experience, gender, muscle groups involved, and individual differences\(^{16-18}\); attributable to muscular, neurological, metabolic or endocrinal disparities, or genetic influences\(^8\). Moreover, Sakamoto and Sinclair (2006)\(^{19}\) reported that, using a within-subject study, movement velocity immediately affected the repetition-intensity relationship. At any given intensity (40-80% 1RM), the number of repetitions was greater for faster lifting speeds, with the speed effect being greater for lighter intensities.

Velocity-intensity relationship. An alternative method for predicting loading intensity was recently developed by Gonzalez-Badillo and Sanchez-Medina (2010)\(^{20}\), where the mean concentric propulsive velocity, attained at the

| Author         | Equations                                                                 | R\(^2\) |
|----------------|---------------------------------------------------------------------------|---------|
| Brzycki (1993)\(^8\) | % 1RM = 102.78 – 2.78(Reps)  
1RM = Wt / ([102.78 – 2.78(Reps)] / 100) | 0.67    |
| Epley (1985)† | % 1RM = 100 / [0.033(Reps) + 1]  
1RM = [0.033(Wt)/(Reps)] + Wt | 0.96    |
| Landers (1985)\(^13\) | % 1RM = 101.30 – 2.671(Reps)  
1RM = Wt / ([101.30 – 2.671(Reps)] / 100) | 0.72    |
| Lombardi (1989)‡ | % 1RM = 100 / ([Reps\(^{0.1}\)]  
1RM = Wt(Reps\(^{0.1}\)) | 0.88    |
| Mayhew et al. (1992)\(^4\) | % 1RM = 52.2 + 41.9e\(^{-0.055(Reps)}\)  
1 RM = Wt / ([52.2 + 41.9e\(^{-0.055(Reps)}\)] / 100) | 0.92    |
| O’Conner et al. (1989)‡ | % 1RM = 100 / [0.025(Reps) + 1]  
1RM = [0.025(Wt)/(Reps)] + Wt | 0.94    |

Wt: submaximal weight (kg) lifted, Reps: the number of repetitions performed.

†cited in Chapman et al. (1998)\(^{12}\); ‡cited in Mayhew et al. (1995)\(^9\). R\(^2\) (between predicted 1RM and actual 1RM) are based on Mayhew et al. (1995)\(^7\).
maximum effort during Smith machine bench press, was utilized. The propulsive phase was defined as the portion of the concentric phase during which bar acceleration was greater than gravitational acceleration; i.e., \( a \geq -9.8 \text{ m/s}^2 \). Their equation for the velocity-intensity relationship was as follows:

\[
\text{Mean propulsive velocity (MPV) = 0.00003Load}^2 - 0.0204\text{Load} + 1.889 \quad (R^2 = 0.98)
\]

Where MPV and Load are expressed as m/s and % 1RM, respectively.

Gonzalez-Badillo and Sanchez-Medina (2010)\(^{20}\) also reported that their equation remained valid following 6 weeks of training\(^{20}\). This new method eliminates the need for submaximal lifting until failure (required to establish the repetition-intensity relationship), and has been utilized in training studies to prescribe intensities, or to evaluate fatigue\(^{4,5,21,22}\). The velocity-intensity relationship, however, needs to be established per exercise like the repetition-intensity relationship\(^{22}\), and necessitates a Smith machine to ensure a smooth vertical movement, as well as a string- or cable-potentiometer to measure lifting speed. Moreover, the correct technique, the maximum propulsive effort, and consistent kinetic outflows have to be assured between trials. The above constraints may make the velocity-intensity relationship unable to completely replace the 1RM assessment or use of the repetition-intensity relationship for all exercise types.

The application of the repetition-intensity or velocity-intensity relationship may reduce some of the concerns associated with a 1RM test. However, the accuracy, accessibility or availability may become an issue due to individual variation and equipment constraints. Even a direct assessment of 1RM may be flawed when not conducted correctly, or regularly after a strength gain or loss. These confounders make it practically impossible for trainees to precisely reproduce prescribed intensities or to know the training intensity currently being used, despite

Table 2. Predicted intensity (% 1RM) from the maximum number of repetitions (reps) using the equations listed in Table 1.

| Reps | Brzycki* | Epley | Landers* | Lombardi | Mayhew et al. | O’Conner et al. |
|------|---------|-------|----------|----------|---------------|-----------------|
| 1    | 100     | 97    | 99       | 100      | 92            | 98              |
| 2    | 97      | 94    | 96       | 93       | 90            | 95              |
| 3    | 94      | 91    | 93       | 90       | 88            | 93              |
| 4    | 92      | 88    | 91       | 87       | 86            | 91              |
| 5    | 89      | 86    | 88       | 85       | 84            | 89              |
| 6    | 86      | 83    | 85       | 84       | 82            | 87              |
| 7    | 83      | 81    | 83       | 82       | 81            | 85              |
| 8    | 81      | 79    | 80       | 81       | 79            | 83              |
| 9    | 78      | 77    | 77       | 80       | 78            | 82              |
| 10   | 75      | 75    | 75       | 79       | 76            | 80              |
| 11   | -       | 73    | -        | 79       | 75            | 78              |
| 12   | -       | 72    | -        | 78       | 74            | 77              |
| 13   | -       | 70    | -        | 77       | 73            | 75              |
| 14   | -       | 68    | -        | 77       | 72            | 74              |
| 15   | -       | 67    | -        | 76       | 71            | 73              |
| 16   | -       | 65    | -        | 76       | 70            | 71              |
| 17   | -       | 64    | -        | 75       | 69            | 70              |
| 18   | -       | 63    | -        | 75       | 68            | 69              |
| 19   | -       | 61    | -        | 74       | 67            | 68              |
| 20   | -       | 60    | -        | 74       | 66            | 67              |

*the equations aim to identify intensities of 10 or less RM.
extensive research of effective or optimum intensities in resistance training for particular purposes. Recent studies, however, have indicated that the intensity of resistance training may not be as important as has been previously considered\(^4,5\). Intensity is just one approach to increasing the motor units recruited, and more effective strategies with greater influence on training effectiveness exist. We will discuss this in later sections.

**Constant length or speed training**

Research using isolated animal muscles has unveiled the unique features of skeletal muscles, namely the length-tension-velocity relationships\(^23\) (Fig. 1). These curves have been successfully reproduced in human dynamics as the angle-torque-velocity relationship using force transducers or isokinetic devices\(^24-32\).

The angle-torque relationship is commonly explained in text books stating that the relative positions of the actin and myosin filaments change as the muscle contracts with the number of effective cross-bridges decreased or optimized\(^34\). Furthermore, the contractile force conducted through the tendon does not always act perpendicularly to the bone, but part of the force acts in parallel with the bone, which may provide stabilization of the joint. The perpendicular and parallel components of the contractile force to the bone changes with joint angles, which also contributes to the angle-torque relationship mechanisms\(^35\).

The torque-velocity relationship may be explained by different speed abilities that exist between myofibers. The maximum contractile speed of a muscle fiber may depend on the rate-coding, the cross-bridge rate constant related to myosin ATPase activity, and the number of sarcomeres in series\(^34\). During maximum isometric or isokinetic contractions, the central motor commands may be near maximum, which triggers the recruitment of nearly all motor units. For isometric or slow speed contraction, most of the recruited fibers have enough time to accomplish successive cross-bridge cycles, resulting in a high-torque production\(^14\). When the speed of filaments passing one another increases, slow-twitch fibers with slower rate constants are, however, unable to form as many cross-bridges per unit filament-travel\(^30\). Hence, mainly the contractile force produced by the fast-twitch fibers are integrated to the torque output during fast movement.

The curvature of the angle-torque-velocity relationship can be altered by training, however the adaptive changes are specific to training\(^30,31,36\). It has been well documented that after weeks of isometric or isokinetic training, the strength gain is most promising at the joint angle or velocity of training, with “a transfer of strength gain” being possible near the joint angle or velocity at which the training has been undertaken\(^5,25,30-32,36-38\). The selective adaptations of muscles are proposed to result from specific alterations in the following aspects: 1) morphological (cross sectional area, the number of sarcomeres in series or the pennation angle), 2) neurological (neurotransmitter activity, recruitment patterns of the motor units, agonist-antagonist activation or Golgi-tendon organ activity), and 3) biochemical (myosin ATPase activity), to match with the external training stimuli\(^5,20,32,36-39\). The contributions of

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**Fig. 1** The length-tension-velocity relationship reprinted from Friden & Lieber (1992)\(^33\).
these factors are, however, still debatable. The general implication of these phenomena is that joint angles or velocities required in sporting activities should be well covered in resistance training to maximize performance improvement. To do so, training using isokinetic dynamometry may be recommended in strength gain, rather than the conventional weight loading method, given that the maximum effort can be achieved at all joint angles and angular velocities used. However, multiple attempts at various joint angles or velocities are necessary to assure all possible muscle lengths and contraction velocities required in sporting events. Moreover, isokinetic dynamometers are expensive, take time for set-up, and designed for single-joint exercises unless customized attachments are used. Critically, purely isometric or isokinetic contractions may be rare or unrealistic in practice. Instead, isoinertial resistance is commonly imposed in natural human dynamics with muscles contracting both eccentrically and concentrically to decelerate or accelerate the involved joints within the effective range of motion. Given the specificity theory of muscle adaptation, training under isoinertial resistance may be ideal.

Isoinertial resistance

Isoinertial resistance, or dynamic constant external resistance, utilizes the mass of an object, and has been widely applied in training (using body mass, weights or flywheel, etc.). This loading system is often described as isotonic resistance (consistent level of force), but is considered literally incorrect (explained in detail later in Effort rather than intensity). In sports, athletes have to maneuver their bodies, swing tools or propel a ball by throwing or kicking against inertia and the gravitational pull. In each motion, the involved joints are moving at varying speeds with the muscles stretched for a counter-movement, changing the direction rapidly into a concentric contraction with a large acceleration, achieving the top contraction speed, and then contracting eccentrically for a rapid deceleration over a wide range of motion. This complex sequence is repeated in repetitive movements such as running, cross-country skiing or rowing, with the involved joints moving like pendulums. It is therefore ideal for sporting individuals if the force or torque ability, depicted in Fig. 1, improves entirely (a parallel upward shift), rather than partially at limited muscle length and velocity. Another key factor for increased speed and power ability during the complex movement sequence is better utilization of the properties of the stretch-shortening cycle (SSC, described in the next paragraph). Isoinertial resistance training can mimic the complex sequence of human dynamics, and allow skill acquisitions necessary for maximized SSC effects, which may not be accomplished by artificial isometric or isokinetic training.

Stretch-shortening cycle (SSC)

It has been well established that pre-stretched muscle during eccentric contraction can generate higher force, power output or work done during subsequent concentric contraction compared to non-pre-stretched muscle. For example, jumping performance or height is greater during countermovement jump (jump following a lowering of the body or a countermovement) and during drop jump (jump following a landing from a raised platform) than that of squat jump (jump without a countermovement). The possible mechanisms for the enhanced performance seen during SSC, compared to simply shortening muscle, include: 1) time availability, 2) storage and re-utilization of elastic energy, 3) potentiation of the contractile component of muscle, and/or 4) stretch reflex.

Time availability. Despite an instruction to execute a movement as fast as possible, it takes time before force reaches its maximum level. This is associated with the time constant in the excitation and contraction dynamics of muscle, and limitations in the rate at which the central nervous system generates control signals. Asmussen and Bonde-Petersen (1974) found a delay of 300 ms for the force to reach the maximum level during squat jump. In contrast, a countermovement or eccentric pre-stretching allowed the muscle to build up a maximum active state (pre-activation) before the start of the concentric contraction, thus allowing a muscle to be maximally contracted throughout a greater proportion of the contractile phase.

The pre-activation of the muscle is particularly important when generating force instantaneously within a limited time period.

Storage and re-utilization of elastic energy. During eccentric contraction, potential energy can be stored in the stretched muscle-tendon complex. This energy can be, in turn, partially utilized in the subsequent concentric contraction. Storage and re-utilization of the energy may occur, especially when the muscles are forcibly stretched immediately before shortening. This mechanism has been evidenced via increases in force production, power output and work done despite smaller EMG amplitudes during submaximal SSC activities. If a movement is repetitive such as walking, running or hopping, mechanical energy can be conserved in elastic structures during SSC and the metabolic cost can be lowered, resulting in an improved economy or efficiency of these repetitive movements. It has been shown, in general, that the degree of excess positive work done during SSC tends to be greater with a longer muscle length and a faster stretching and shortening speed. Furthermore, if the time between muscle stretching and subsequent shortening was reduced, a greater proportion of the stored elastic energy would be returned to the muscle. Some researchers, however, have argued that the enhanced performance during
SSC could not be fully explained by the time availability or the storage and re-utilization of elastic energy.\textsuperscript{40,44,45}\) Rather, the contractile component itself may have been enhanced during SSC; and this mechanism is called “potentiation”.

\textbf{Potentiation of the contractile component of muscle.}

Studies have shown that, when comparing an isometric-shortening vs. stretch-shortening condition in isolated muscles, an additional force production with SSC occurring at the eccentric-concentric phase transition (indicative of the storage and re-utilization of elastic energy) is sustained during the subsequent concentric phase.\textsuperscript{40,52,54}\) This sustained higher force production throughout the concentric phase could indicate an enhancement of the contractile component itself. Bosco et al. (1982)\textsuperscript{44}\) showed that higher force outputs during the concentric phase of maximum countermovement jumps were accompanied by greater EMG amplitudes (myoelectrical potentiation) compared to non-countermovement jumps. Similar to the energy re-utilization mechanism, the potentiation effect has been shown to increase with speed of stretching, and to decrease with the amount of time elapsed at the eccentric-to-concentric phase transition.\textsuperscript{41,50}\) The exact mechanisms underlying the potentiation theory are not clear, but the proposition is that pre-stretching of active muscles alters the properties of the contractile machinery by causing a different overlap or number of cross-bridge bindings of the sliding filaments, leading somehow to higher force production.\textsuperscript{45,50}\) The myoelectrical potentiation may be interpreted as the synchronization of motor unit recruitment, and the firing of additional motor units that were inadvertently not recruited without SSC.\textsuperscript{55-57}\) both of which may result in greater force production.

\textbf{Stretch reflex.}

Pre-stretching can trigger spinal reflexes (stretch reflex) via muscle spindles that could help increase muscle stimulation during the concentric phase.\textsuperscript{45}\) Komi and Gollhofer (1997)\textsuperscript{46}\) suggested that stretch reflex could substantially contribute to force generation during SSC, especially when the pre-stretching is short and rapid, and the transition between stretching and shortening is immediate such as running or hopping. However, the actual contribution of stretch reflex to enhanced performance during SSCs is still debatable.\textsuperscript{50}\)

\textbf{Utilization of SSC effects in training.}

During a countermovement jump, Farley (1997)\textsuperscript{48}\) estimated that 50-70\% of the enhanced power output of the planter flexors was contributed by the elastic component of SSC mechanisms. The elastic energy or stretch reflex mechanism for the planter flexors may be further amplified during repetitive rapid movements such as hopping or running.\textsuperscript{46,48,50}\) Bobbert et al. (1996)\textsuperscript{49}\) argued that, for the thigh muscles, the time elapsed between stretch-shortening is long, and the speeds of pre-stretching and shortening are slow so that the roles of the elastic component and potentiation may be ruled out in a countermovement jump. Instead, a greater active state of the thigh muscles, resulting from the time availability, largely accounted for a greater force at the start of the concentric phase, and consequently a greater jump performance than a squat jump. Accordingly, it is accepted that the relative contribution of each suggested SSC mechanism can vary depending on type of exercise and muscle groups. No matter what mechanism, it is undeniable that SSC does enhance force, power output, work done, and thus overall performance.\textsuperscript{41-44,50}\) The emphasis should be placed on the general findings that the SSC effects are augmented during repetitive movements with: 1) longer muscle length at which SSC occurs, 2) faster stretching and shortening speed, and 3) shorter time elapsed between pre-stretching and shortening phases.\textsuperscript{45,47,50}\) Hence, acquisition of specific skills (e.g., the use of greater range of motion, ability to relax the muscles during the stretching phase, and ability for explosive transition into the concentric phase) may be a goal to achieve in isoinertial resistance training to facilitate the full utilization of SSC effects.

\textbf{Power training}

\textbf{Speed-oriented and strength-oriented methods.}\n
In traditional resistance training, aiming for improved maximum strength or muscle hypertrophy, trainees are instructed to perform lifting at controlled slow speed (4-7 seconds for each repetition) through a full range of motion.\textsuperscript{60}\) This is to ensure a consistent application of force, longer total muscle tension (or time-under-tension), and greater muscle fiber activation by minimizing the momentum before the end of the concentric phase. Slower speed may also reduce the risk of tissue trauma or injury.\textsuperscript{60}\) These training tips may apply to novices or individuals with potential medical problems. The effectiveness of traditional resistance training is commonly evaluated by the change in 1RM or peak torque value of isometric maximum voluntary contraction (MVC), neither of which concerns the amount of time spent in lifting work. However, for sport dynamics, the ability to produce greater force at faster speed, or a faster rate of force production is essential. The development of power, therefore, should be of paramount importance. An ideal training effect may be described as a parallel upward shift of the length-tension-velocity curve depicted in Fig. 1. Although isoinertial resistance training is comprised of variable contraction speeds compared to isokinetic training, it is still, however, not feasible to train under all possible speed × intensity conditions at the same time. In practice, therefore, power training is usually divided into “speed-oriented” and “strength-oriented” methods. Intensity for the speed-oriented method has been suggested to be less than 30\% 1RM (typically accomplished by plyometrics) in order to achieve a high velocity of movement without compromis-
ing force exertion so that the coordination of rapid movements can be improved$^{31}$. The strength-oriented method involves heavy resistance weightlifting, with the recommended intensities ranging 75-90% 1RM$^1$. For any intensity schemes, power training is performed with “maximum speed” in order to train under the maximal power output at the given load$^{1,25,62,63}$. The target repetitions for each training set are usually fewer than the maximum repetitions predicted from the repetition-intensity relationship. This is because the quality of technique or speed of movement declines in later repetitions as muscles become fatigued, reducing the effectiveness of power development$^3$. Moreover, when the lifting is continued until substantial fatigue or lifting failure, a significantly long time is needed between exercise sets to regain the ability of high power output, which may prolong the training duration, or else the total volume of high-power repetitions may be compromised.

To help distinguish which is more important (a speed-oriented or strength-oriented method), trainees need to know which component of their power (force or speed) is weakest and needs the most development$^{64}$. However, one method cannot replace the other, one is not better than the other; and application of both methods is fundamental for effective power improvement$^{64}$.

**Maximal mechanical power output training (Pmax training).** A third method to develop power is called “maximal mechanical power output training” (Pmax training)$^{63}$. The speed-oriented and strength-oriented methods aim to improve the individual components of power separately, and thus the two methods need to be combined. However, Pmax training utilizes the load that elicits one’s maximum mechanical power output of a given exercise. This alternative method has proven to be effective and time-efficient, with an equivalent or better power improvement compared to the combination of both speed-oriented and strength-oriented methods$^{1,63}$. Kaneko et al. (1983)$^{25}$ studied the effect of isoinertial training under four different intensities on the torque-velocity relationship of the elbow flexors. The intensity was either no load, a load equivalent to 30% of maximal isometric contraction (MIC), 60% of MIC, or 100% of MIC (isometric); and subjects performed the contractions at maximum effort 10 repetitions a day, 3 days a week for 12 weeks. While no-load and 100% MVC groups produced the greatest improvements in maximum contraction speed and isometric strength, respectively, the intensity of 30% MIC elicited the greatest power output (Pmax) and resulted in all-round improvement in torque over the widest velocity range. That is, the torque-velocity relationship shifted in parallel with the pre-training curve. Lyttle et al. (1996)$^3$ found that after 8 weeks of 2 sessions/week training, a combination of heavy training and plyometric training (squat and bench press at 6-10RM, depth jump and medicine ball throw), and Pmax training (jump squat and bench press throw at Pmax intensity, approximately 30% 1RM) were equally effective in improving dynamic sporting performance (jumping, cycling, throwing and lifting). Wilson et al. (1993)$^{31}$ has shown that the Pmax training group (jump squat at 30% 1RM, load based on Kaneko et al. [1983]) resulted in significantly better results in most tested performances (sprinting, jumping, cycling, and isokinetic and isometric strength) than either the traditional weightlifting group (heavy squat at 80-90% 1RM), or the plyometric training group (depth jump). The concept of Pmax training well resembles the training adaptation observed after isokinetic exercise, where “the transfer of strength gain” (strength gains at and near the velocity of training) tends to occur over a wider speed range after intermediate-velocity training than very slow- or very fast-velocity training$^{64}$. Perhaps, the intermediate-velocity used during the isokinetic training coincided with or fell within the Pmax range. Despite the greater efficacy of Pmax training, there are, however, large variations in Pmax intensity among studies; ranging from 30 to 70% 1RM depending on training experience, equipment, muscles involved and/ or type of exercise$^{22,25,62,65}$. The determination of Pmax intensity, therefore, warrants individual assessment for each exercise. Thus, there is no guarantee that the intensities prescribed in previous research truly represents the Pmax intensities of all training populations or situations.

**Effort rather than intensity**

Varying loading intensities alters the amount of effort required, and therefore the number of motor units recruited. Naturally, heavier loads require more effort per repetition. Until recently, research has extensively focused on the training structure such as the number of sets, resting period and intensity to seek effective or optimum prescriptions$^5$. More recent studies, however, revealed that there are alternative effective approaches, other than intensity, to manipulating effort$^{65}$. During isoinertial resistance training, the amount of effort is determined by complex interactions of many variables (i.e., contraction velocity, momentum, SSC effects, joint angle, and perpendicular component of external loading to the bone) even under a given load.

For example, movement speed affects both eccentric and concentric effort; with faster speed reducing the eccentric effort, but increasing the concentric effort; and slower speed having the opposite effects$^{66}$. In the context of momentum, a faster speed may increase eccentric effort and decrease concentric effort at the end of their respective phases$^{67,68}$. According to the torque-velocity relationship, faster speed may increase effort due to reduced maximum torque ability$^{29}$. Based on the SSC effects, however, faster speed may reduce effort due to enhanced torque or power ability$^{60,65}$. Further, the contraction speed changes even within a repetition under a given lifting tempo, composed of acceleration and deceleration$^{69}$.
Joint angles also affect effort. For example, suppose a standing dumbbell arm-curl exercise is performed. According to the angle-torque relationship, the torque generating ability of the muscles is weakest near the full extension or flexion of the elbow, but is greatest near 90° flexion\(^{29}\). Meanwhile, the perpendicular component of the dumbbell loading to the forearm is very small when the elbow is extended or flexed, while it is largest near 90° flexion. Hence, the lifting effort may depend on the difference between the torque ability and the amount of perpendicular component of the external loading, both of which vary through the range of motion.

For the above reasons, the prescribed intensity represents merely the gross effort. For example, 70% 1RM does not imply that all the involved muscles are exerting 70% effort at all times, but the weight of effort changes every moment. To demonstrate part of the complex interactions on effort, Sakamoto and Sinclair (2012)\(^{66}\) compared muscle activation (EMG amplitudes of the pectoralis major, deltoid and triceps) while undertaking Smith machine bench presses under varying intensities (40-80% 1RM) and lifting velocities (slow: 2.8-s down and 2.8-s up, medium: 1.4-s down and 1.4-s up, fast: 1.0-s down and 1.0-s up, and ballistic: maximum velocity by performing bench press throws). As has been well established, muscle activation was greater for heavier intensities. The lifting velocities also affected muscle activation with faster speeds producing greater EMG amplitudes averaged across the entire concentric phase. The concentric bar displacement phase (or the joint angles) was a further factor influencing EMG amplitudes. Under slower speeds, muscle activation was more stable throughout the concentric phase. By contrast, faster speeds produced greater activation at the start of the concentric phase, followed by a gradual reduction in activation towards the end of the concentric phase. The ballistic condition resulted in the greatest muscle activation of all, with activation being near maximum regardless of the intensity or bar displacement phase (a fall in the EMG amplitude in the final concentric phase was due to bar release from the hands).

In the meantime, other researchers investigated whether the manipulation of effort (concentric speed) would actually influence training effectiveness, despite the same loading intensity. In a study by Yong and Bilby (1993)\(^{69}\), subjects underwent barbell squat training (4 sets of 8-12 RM 3 times a week for 7.5 weeks). The control (slow) group performed squat in a slow controlled manner with minimum acceleration. The experimental (Vmax) group was instructed to lower the weight in a slow controlled manner, but upon reaching the bottom, there was to be an explosive concentric contraction at maximum effort. They found similar improvements in all tested measures between the groups (strength, power and hypertrophy); despite a trend that the Vmax group induced a greater improvement in maximum rate of force production (68.7 % vs. 23.5 %), but a smaller improvement in isometric strength (12.4 % vs. 31.0 %) than the slow group. The authors noted that greater time-under-tension using the slow speed had a compensating effect for the reduced effort.

Recent findings are, however, more favorable to the use of maximum speed\(^{4,5,70}\). Padulo et al. (2012)\(^{70}\) investigated the effect of 2 sessions/week × 3 weeks of bench press training on 1RM value and the maximum speed attained during 1RM lift of resistance-trained subjects, with one group performing the concentric phase at maximum speed (Vmax), and the other performing the lift at a self-selected (slower) speed. In both groups, the training intensity was set at 85% 1RM, with each set continued until the speed dropped by 20% for the Vmax group, and until exhaustion for the slow group. Each session ended when the minimum velocity required (above 80% of maximum) was no longer sustained for the Vmax group, and when unable to lift an 85% 1RM load for the slower group. As a result, the Vmax group produced significant improvements in 1RM (by 10.2%) and the maximum speed during 1RM lift (2.22%); but these measures were unchanged (< 1.0%) after the slower training. Gonzalez-Badillo et al. (2014)\(^{6}\) showed that maximal intended velocity (Vmax) bench press training was superior to intentionally slower training (half-maximum velocity, 1/2Vmax) in the gains of 1RM (18.2 vs. 9.7%), and the maximum velocity attained under both light loading (11.5 vs. 4.5%) and heavy loading (36.2 vs. 17.3%); despite both conditions having the same controlled eccentric speed (0.30–0.50 m/s), training intensity (weekly incremental from 60% 1RM to 80% 1RM) and volume (3 sets/day, 3 sessions/week for 6 weeks). A similar study was conducted using squat exercises by Pareja-Blanco et al. (2014)\(^{6}\), where greater improvements were found for the Vmax training group than the 1/2Vmax group in 1RM (18.0 vs. 9.7%), the maximum velocity attained under light loading (10.9 vs. 5.0%) and under heavy loading (17.6 vs. 13.1%) (eccentric speed was 0.50–0.65 m/s for both groups). Moreover, they evaluated power performance tasks of countermovement jump (CMJ) and 20-m sprint time before and after the training, and reported a greater improvement in CMJ for the Vmax group (8.9 vs. 2.4%), but similar improvements in 20-m sprint time (1.6% improvement) between the two groups. The consistent findings among recent studies demonstrating the superiority of Vmax training may be attributed to the use of a Smith machine (allows a stable vertical pushing) and a linear position or velocity transducer (allows the quantification of velocity and immediate feedback), thus the maximum velocity effort is assured. According to Argus et al. (2011)\(^{71}\), providing feedback on peak velocity during bench press throws was effective in increasing the peak power output compared to non-feedback trials. This suggests that, without the provision of certain training equipment or the related scientific knowledge, it may be difficult to elicit the true maximum effort even though instructed to do so. Hence, trainees and coaches need to be well educated and familiarized to
facilitate the understandings of the context of maximum effort.

**Importance of projectile motion and SSC utilization**

The studies of Vmax vs. intentionally slow training may be further improved by adopting projectile motion, and by maximally utilizing the SSC properties (the eccentric phase was performed in a slow controlled manner even for the Vmax groups of previous studies). These techniques are known to be important\(^\text{65,67}\), but not always accomplished in training or by experiment. During the speed-oriented or Pmax training, relatively light loads are used compared to the strength-oriented method. Thus, large accelerations are achieved at the beginning, but large amounts of time are spent in deceleration over the final stage of the concentric phase\(^\text{65,67,68}\). Consequently, high forces are generated only through a very small range of movement. The deceleration phase is evident even during 1RM lifts, accounting for 24% of the concentric phase of a bench press, and increasing to 52% of the concentric phase when the load is reduced to 81% of 1RM\(^\text{65}\). The deceleration phase is also accompanied by a reduction in agonist EMG activity\(^\text{66,68}\). Accordingly, projectile motion such as bench press throws or jump squats has been widely adopted as an important technique to decrease or minimize the deceleration, so that greater velocity, force and power output can be achieved. Newton et al. (1996)\(^\text{67}\) compared throwing and conventional (non-throwing) bench press techniques at 45% 1RM. They revealed that the bar velocity was significantly higher for the press throws at 10% of the concentric bar displacement, with a continuous increase in velocity and minimal deceleration phase thereafter. The conventional press, however, resulted in a clear deceleration after 60-70% of the concentric phase (Fig. 2). Similarly, the force applied to the bar was significantly greater in press throws from the 10% concentric displacement onwards (Fig. 3). The greater force and bar velocity were accompanied by greater EMG activity of the pectoralis major, anterior deltoid, and triceps brachii during press throws, especially during the later concentric phase\(^\text{67}\).

The study of Newton et al. (1996)\(^\text{67}\) further reported that the average power output was 70% greater, and the peak power output was 67% greater with the press throws than bench presses without throws. As described earlier, Sakamoto and Sinclair (2012)\(^\text{66}\) also reported significant reductions in EMG amplitudes later in the concentric phase during bench presses without throws. With a maximum effort of bench press throws, however, the reduction in EMG amplitudes were minimized. The most notable finding of the study was that, with a maximum effort projectile motion, muscle activation under light loading intensities became close to that recorded under heavy loading intensities\(^\text{66}\).

Cronin et al. (2001)\(^\text{65}\) studied the effect of a throwing motion and rebound motion (with or without eccentric pre-stretching) on bench press kinetics (Table 3). They found that the throwing motion was most influential in boosting peak velocity and peak power, while having no effect on peak force and peak acceleration. Throwing also resulted in a small but significant increase in mean power output. The enhancement of peak velocity with the throwing motion was greater for light loading intensities, but not as effective for heavier loads. On the contrary, rebound motion led to the most gains in peak acceleration, peak force, and mean power output, while having negligible effects on peak velocity and peak power output (Table 3). A simple interpretation of Cronin et al. (2001) could be that the throwing motion enhances power output.
in the later concentric phase through a prolonged acceleration, whereas the rebound motion enhances power output both at the start of the concentric phase and the remaining concentric phase through the utilization of SSC. Ultimately, using both the throwing and rebound conditions can produce combined effects, with power output or effort further augmented throughout the entire concentric phase (Table 3).

In a very recent study by Kuroda and Sakamoto (2016)⁶, well-trained competitive shot-put athletes underwent 12 weeks of Vmax bench press training (50→40→30% 1RM, 20-s × 2 sets for each intensity, 2 sessions/week) in addition to their normal training routines, with or without projectile motions (press throws). Their normal training was conventional power training, i.e., a combination of very heavy intensities (70-100% 1RM) and plyometric training. Subjects were instructed to perform as many repetitions within 20-s through a full range of motion as possible, with the SSC effects fully utilized, and the joint angular velocity at the elbow monitored and recorded by a wireless electrogoniometer. After 12 weeks, only the throwing Vmax group showed significantly improved

### Table 3. Mean % increase due to the effect of throwing and rebound motions in testing variables relative to non-throw concentric only technique (control)⁶.

|       | PV (m/s) | PA (m/s²) | PF (N) | MP (W) | PP (W) |
|-------|----------|-----------|--------|--------|--------|
| **Throw** |          |           |        |        |        |
| 8.8% (30-50% 1RM) | N.S.     | N.S.     | 5.8%   | 6.7%   |
| 4.5% (60-80% 1RM) |          |           |        |        |        |
| **Rebound** |          |           |        |        |        |
| 2.6% (30-50% 1RM) | 38.5%    | 14.1%    | 11.7%  | N.S.   |
| N.S. (60-80% 1RM) |          |           |        |        |        |
| **Throw + Rebound** |          |           |        |        |        |
| 11.8% (60-80% 1RM) | 38.5%    | 14.1%    | 21.2%  | 6.7%   |
| 3.6% (60-80% 1RM) |          |           |        |        |        |

PV: peak velocity, PA: peak acceleration, PF: peak force, MP: mean power output, PP: peak power output, N.S.: no significant change from the control technique. The % changes is shown separately when condition × intensity interaction was present. Unless labeled in a bracket, the values represent mean % changes across all testing intensities (30-80% 1RM).

![Fig. 3 Mean (±SD) vertical force at each concentric phase (% total concentric bar displacement) for the conventional press (□) and throw (■) conditions. **p < 0.01; ***p < 0.001, significantly different from the conventional press within respective phase. The Figure is reprinted from Newton et al. (1996)⁶.](image-url)
1RM (10.0%) and shot-put distance (3.0%), whereas these performance measures remained unchanged after non-throw Vmax training. This study implied that 1) normal training merely maintained the level of performance, with non-throw Vmax training at light loads adding no further improvement, 2) projectile motions not only rendered the training speed closer to the event-specific speed resulting in improved shot-put distance, but also enabled light intensities to improve 1RM strength.

**Summary and implications**

During natural human dynamics, isoinertial resistance is imposed on the body, where the joint angle, joint velocity and external loading vary at every moment. Therefore, increased power ability under any conceivable angle × load × velocity is an ideal training goal. Consequently, trainees should undergo several loading intensities, comprised of strength-oriented (>70% 1RM), Pmax (30-70% 1RM) and speed-oriented (<30% 1RM) methods, all of which are equally important. However, because of the difficulty of exactly reproducing a prescribed intensity, knowing the intensity being performed, and because of variability in the optimum intensity required (e.g., Pmax), some leniency or approximation may be accepted. Instructions for training such as very heavy (strength-oriented), intermediate (Pmax), or very light (speed-oriented) may be a sufficient prescription, rather than aiming for precise intensity values. A recent study by Hernandez-Davo et al. (2015) demonstrated that lifting of unknown loads resulted in more rapid force production and greater EMG activity than those of lifting the same loads with load knowledge, despite an instruction to elicit maximum effort. It was suggested that an over-estimation of the load resulting from no-load knowledge increased the pre-programmed muscle activation (or activation preparation). This finding further underpins the notion that discerning the exact training intensity may be unnecessary. It is more important, no matter what the intensity, to undergo each repetition at maximum effort with an attempt to maximize the acceleration duration (or velocity) and the SSC effects. Thus, intensity is no longer an effort-determinant, but a peak velocity-determinant in power training. Until today, successful movements in training have often been determined by kinematic information, such as form or smooth repetitiveness. Once the correct technique has been established, the kinetic parameters, such as greater acceleration, faster peak speed and greater projectile displacement should be the main focus. However, exerting maximum effort for every repetition at all times is never an easy challenge, and is sometimes not feasible (e.g., through lack of motivation, recovery from injury or illness, or the presence of pain or discomfort). In such cases, slower velocities may be applied.

Projectile motions are important to minimize the deceleration duration, particularly when undergoing Pmax or speed-oriented training. While the use of plyometric training (e.g., drop jump, bounding, medicine ball throw, projectile push-up) is a solution, the use of a Smith machine may be necessary; helping to keep balance and assure a stable bar path for explosive successive movements, but restricting the types of resistance exercise. Vmax training without projectile motion, however, is still effective in enlarging training effectiveness when relatively heavy intensities are used (60-80% 1RM). When a Smith machine is not available or not applicable to the chosen exercise, instructing trainees to “exert maximum force all the way through the concentric phase with an attempt to minimize deceleration” may be a practical alternative. For lighter intensities to better simulate event-specific speeds, projectile motions were found to be essential for improved event performance and maximum strength. Given that projectile motions using a Smith machine can only be applied to pushing exercises, the invention of new training equipment, which can minimize or eliminate the need for deceleration, may be warranted for a wider variety of exercises to be ideally performed.

The SSC effects should also be fully utilized to maximize training effort. The benefits of a SSC are greater with longer muscle length when pre-stretching occurs, with faster stretch-shortening speed, and with a shorter elapsing of time at the eccentric-to-concentric phase transition. Consequently, the eccentric speed may need to be fast with as large a counter-motion as possible. The projection of the bar, greater eccentric displacement and faster eccentric speed, however, increase the kinetic energy of the loading mass at the end of the eccentric phase. If the kinetic energy is too large and exceeds the force ability for abrupt phase transition into concentric action, the shortening speed is reduced and more time elapses at the transition from eccentric to concentric phase, and the SSC effects may be reduced. For example, drop jump performance decreases when landing from a platform higher than the optimum height. This negative effect may be exaggerated when using relatively heavy loads. Thus, the acquisition of complex SSC skills should include recognition of optimum eccentric speed.

In power training, each set is not necessarily continued until failure. Instead, it is advocated to end each set before a significant reduction in speed or power occurs to assure the production of maximum or near maximum power output with a correct technique; and to avoid a prolonged recovery time before the subsequent set. Nonetheless, competitive athletes may make each training set a fatigue-challenge. In many race- and match-sports, high power output is required not only instantaneously in a fresh condition, but repetitively against both peripheral and central fatigue, particularly near the finish line or when competing closely with other contenders. Moreover, it is well understood that not only mechanical stress, but also metabolic stress plays an essential role in muscle adaptation, with accelerated strength gains and hypertrophy (reviewed...
in detail by Ozaki et al. (2015))⁷⁹. Hence, we suggest that early training sets aim for maximum power output of the given load, followed by fatigue-challenge sets later on. Alternatively, adopting super-set or circuit training may allow for recovery time without prolonging the total training duration, where fatigued muscles are rested while other muscle groups are trained. With relatively light Pmax intensities or a speed-oriented method, it would be better to pre-establish when to end each exercise set so as to maximize motivation. Setting a specific number of target repetitions, however, may not be a good idea because the repetition-intensity relationship lacks accuracy at light loads. Instead, event specific time durations (e.g., 20-s, 40-s or 60-s) may be an alternative prescription. Improved fatigue tolerance, an anticipated training effect from fatigue-challenge trials, may ultimately increase training efficacy via an increased number of high-speed repetitions, a slower rate of power decrement, and/or through shorter recovery time being required between sets.

**Conflict of Interests**

The authors declare that there is no conflict of interests regarding the publication of this article.

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