Resistance Training - Part I: Considerations in Maximizing Sport Performance

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Introduction

The need for strength and endurance in sports is accepted by most coaches and athletes. In spite of evidence for direct transfer to performance and injury prevention, the role of strength and endurance is often perceived as indirect or foundational. Indeed, strength is often incorrectly thought to be independent from (or incompatible with) movement velocity, when in fact the latter is a result of force application. Considering that technical precision and speed of execution are fundamental goals of sports, this realization is crucial in order to achieve optimal training effects and performance.

Sports performance is typically determined by the ability to execute skills and assignments at a planned effort level. Training tasks should therefore be selected and prioritized according to their specific relationships to the coordinative, biomechanical and bioenergetic demands of competition. In general, maximum strength and speed-strength training should be conducted with limited work volumes and minimal metabolic stress in order to maximize the quality of learning and training effects (although hypertrophic methods associated with the former are an exception). Likewise, strength-endurance training usually involves fatiguing workloads and greater overall volume. As part of the overall sports preparation process, specialized strength training should be planned and implemented according to sound principles in order to optimize the athlete's performance capabilities.

Movement Mechanics

Effective strength training begins with a working knowledge of basic movement mechanics, especially with regard to: rate of force development (RFD) and impulse; stretch-shortening cycle (SSC) and reactive ability; power; and their roles in "endurance" vs. "power" sports. The operative concept in each case is speed-strength - i.e. the ability to develop forces rapidly and/or at high velocities. Collectively, this section illustrates that evaluation of an athlete's explosive and reactive strength capabilities is the starting point for planning the preparation process. Fortunately, such tests are relatively simple to administer and interpret.

RFD & Impulse

The brief execution times of most athletic tasks require high RFD. Case in point: force is applied for 0.08 - 0.2 sec during the ground support phase of running, whereas peak force production requires up to 0.6 - 0.8 sec in dynamic movements (and up to 3-4 sec in isometric movements). Even in largely non-ballistic locomotion such as cycling, rowing, or swimming, performance is usually determined by the ability to generate force quickly and thereby achieve a critical impulse output (i.e. the change in momentum resulting from a force, measured as the product of force and time; Figure 1).

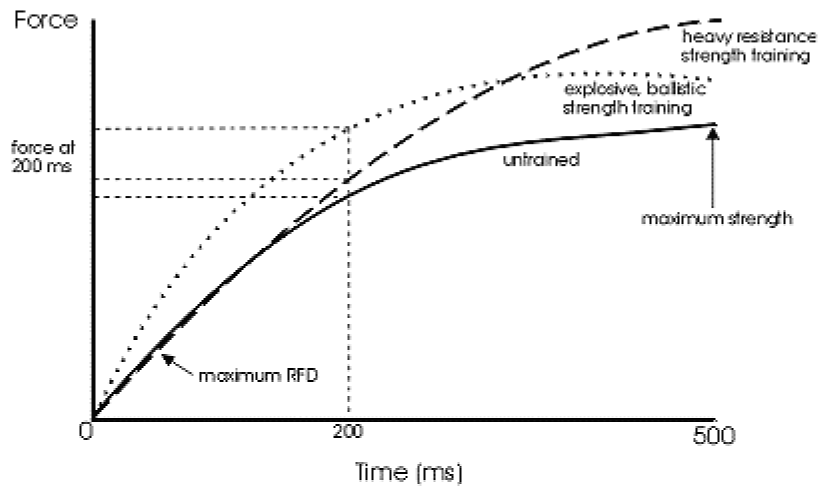

Figure 1. Isometric force as a function of time, indicating maximum strength, rate of force development [RFD], and force at 0.2 sec for untrained [solid line], heavy-resistance trained [dashed line], and explosive-ballistic trained [dotted line] subjects. Impulse is the product of force and time, represented by the area under each curve; and is increased by improving RFD. Source: Newton Kraemer. Adapted from: Häkkinen & Komi Scandinavian Journal of Sports Science 7(2): 55-64 & 65-76, 1985

The practical implication of this is that amplitude, direction and rate of force application are equally significant when performing functional tasks. As will be discussed in more detail in the Exercise Prioritization & Substitution section, the issue is one of specificity to competitive demands. Thus, a basic objective of training is to improve RFD, effectively moving the force-time curve "up and to the left" and thereby generating greater impulse during the limited time (and distance) in which force is applied. Furthermore, the significance of this parameter is not limited to biomechanics: According to the "impulse-timing hypothesis", the force-time relationship is a central component in motor programming and has important implications for motor control and learning.

SSC & Reactive Ability

Many explosive movements can involve the reflex/elastic properties of the muscle-tendon complex and are ballistic in nature, even when initiated from a static position. The action begins with a preparatory countermovement where the involved muscles are rapidly and forcibly lengthened or "stretch loaded", and immediately shortened in a reactive or elastic manner. This eccentric-concentric coupling phenomenon - referred to as the stretch-shortening cycle (SSC) - is often observed in sports, particularly those involving running, jumping and rapid changes in speed and direction. SSC actions exploit motoneural reflexes as well as intrinsic qualities of the muscle-tendon complex. Although the exact relationship of reflex/elastic properties of the muscle-tendon complex to maximum strength is not completely understood there does appear to be a degree of independence, thus training for maximum strength will not optimally train these properties. Training for such sports should therefore progressively include "plyometric" methods in addition to basic "heavy resistance" movements.

It is important to distinguish the concept of reactive ability from that of reaction time. The former is a characteristic of speed-strength exhibited in stretch-shortening cycle (SSC) actions which can be improved through reactive-explosive training (graphically, this can be illustrated as a rapid and efficient transition from eccentric muscle action in the lower quadrant of Figure 2 to concentric muscle action in the upper quadrant). In contrast, the latter is a relatively un-trainable quality which correlates poorly with movement action time or performance in many brief explosive events. For example, an elite sprinter's auditory reaction time typically ranges from 0.12 - 0.18sec, but is not significantly related to his/her 100 m results. Other factors such as acceleration, speed-endurance and (to a lesser extent) maximum speed are more closely associated with overall sprint times. Reaction time is, however, an important determinant of performance in quick timing tasks (e.g., a batter hitting a baseball) and defensive types of stimulus-response actions (e.g., a goaltender making a save).

Power

The peak levels of force and power (energy) absorbed by the tissues while actively lengthening are often greater than those produced while shortening (Figure 2). If not adequately addressed in training, this can be the mechanism of so-called non-contact injury, technical inefficiency or outright non-athleticism. Thus, in addition to improving concentric power production capability, the demands of SSC movements dictate two more training objectives: to develop the eccentric strength needed to tolerate extreme power absorption while explosively braking during the initial lengthening action, as well as the reactive strength needed to rapidly recoil into the subsequent shortening action.

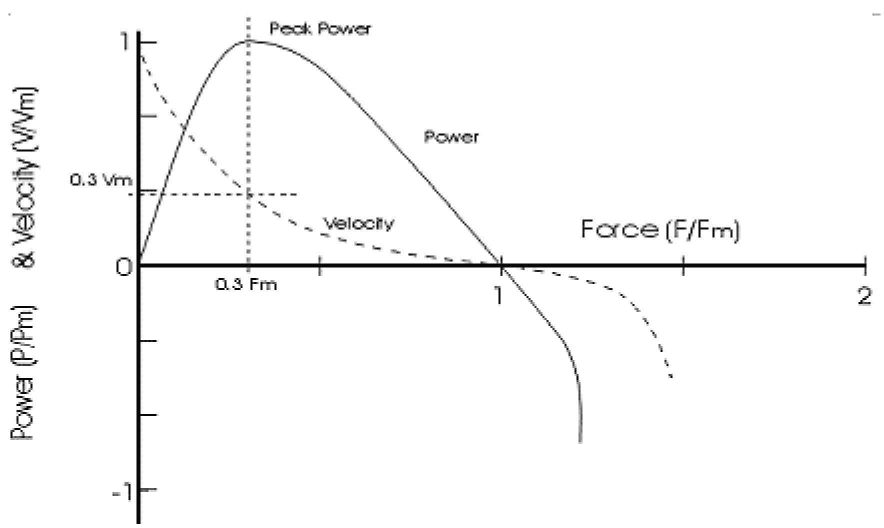

Figure 2: Power production/absorption [solid line] as a function of force and velocity [dashed line] in concentric and eccentric muscle actions. Maximum concentric power [Pm] occurs at ~30% of maximum force [Fm] and velocity [Vm]. Note that the greatest force and power is produced during explosive eccentric (lengthening) muscle actions. Source: Newton & Kraemer. Adapted from: Faulkner et al. In: Human Muscle Power, N.L. Jones, N. McCartney & A.J. McComas (Editors). Champaign IL: Human Kinetics Publishers, 1986; pp. 81-94

Figure 2 also illustrates that achievable movement speed also depends on the load to be overcome. Simply put, as resistance increases in any task, so does the role of strength in determining velocity or acceleration. In terrestrial movement this resistance usually includes the athlete's own body mass, and possibly his/her equipment or opponent (in comparison, despite the fact that aquatic locomotion is not "weight bearing", consider the challenge presented by hydraulic resistance - i.e. energy cost as a function of drag). Indeed, it is difficult to find examples of sports where power and high-speed force output are not required to rapidly accelerate, decelerate or achieve high velocities. Primarily the athlete's percentage of type II motor units, and the ability to optimally activate them determine these capabilities. In contrast, isometric or low-velocity maximum strength is a function of muscle cross-sectional area (i.e. the number of active sarcomeres in parallel). Once the upper limit for specific muscle tension can be achieved (40 - 45 N/cm2 in trained athletes), hypertrophy is required - especially in type II fibers - in order to further increase force and speed production.

'Endurance' vs 'Power' Sports

It is generally accepted that these speed-strength capabilities are important in "power" sports involving explosive running, jumping and changes in speed or direction. There is a common misconception, however, that their role in "endurance" types of activities is minor. The ability to apply force rapidly and accelerate one's body mass is the rule rather than the exception in athletics. While prolonged activities certainly require specialized metabolic capacity, they often involve a series of brief, explosive "spikes" in power output. Thus, the simplistic classification of endurance events as sub-maximal or non-strength related should be reconsidered. The task-specific importance of speed-strength should be critically evaluated on a mechanical basis, rather than categorically dismissed for physiological reasons.

Systems vs Components

In general, structural movements (e.g. multi-joint, weight-bearing exercises) have a systemic effect which reaches far beyond the muscle fibers used in their execution. Muscles act - and must be targeted - in functional task groups rather than in isolation. This is one reason why athletes are well advised to emphasize powerlifting and weightlifting-style movements, and compound exercises in general, in their training. Furthermore, such movements are also a potent means by which the neuromuscular and neuroendocrine systems are activated, in turn up-regulating every system in the body. Thus, there are several reasons why strength training programs should be based on free-weight movements rather than isolated muscles:

Power The greater the effort - and acceleration - with a given weight, the greater the power development and subsequent training effect. Peak power output during weightlifting movements (snatch and clean & jerk) is the highest ever documented, and is comparable to the maximum theoretically possible for a human. For example, the explosive "jump and pull" or "dip and drive" actions of these movements are executed in 0.2 - 0.3sec; and peak power production is:

* 4-5 times that of the deadlift or squat

* 11-15 times that of the bench press

Motor Coordination Skillful movements have a motor control / learning effect which carries over to the athlete's "coordinative abilities":

* orientation
* differentiation
* reactive ability
* rhythm
* balance
* combinatory ability
* adaptive ability

Systemic Effect To a point the greater the exertion, especially in multi-joint lifts, the higher the production of most endogenous hormones. Some evidence indicates that an increased blood concentration of anabolic hormones, such as somatotrophin or testosterone, in response to resistance exercises are involved in stimulating overall changes in muscle mass and strength. The following guidelines are not definitive, and there probably is no ideal workload protocol for either effect. However, a sound training strategy must account for and exploit such basic adaptive mechanisms:

* Moderate weights for higher reps (8-10/set), and high-intensity endurance activities in general, maximize the somatotropin and testosterone response.

* Large muscle mass exercises (i.e. multi-joint) performed for multiple sets result in greater hormonal respsonses compared to small muscle mass exercises.

There is nothing magical about the sound of iron clanking, and in fact certain machines such as a hip sled or cable-pulley system can serve useful roles. But there is an inherent advantage to multi-joint free weight training which cams, levers or linear bearings cannot match: It requires - and develops - functional strength, and has excellent transfer to athleticism and explosiveness.

Exercise Prioritization

In terms of specificity, training tasks should be selected and prioritized according to their dynamic correspondence with the demands of the activity (also referred to as specificity or transfer of training effect): Their basic biomechanics - but not necessarily outward appearance - should be specific to those occurring in competition. The rate of force development and time of force production (impulse; Figure 1) and dynamics of effort (power; Figure 2) are especially important criteria in explosive athletic movements. Other practical considerations include amplitude and direction of movement, accentuated region of force application, and regime of muscular work.

This concept is analogous to the motor learning principle of practice specificity with respect to sensorimotor, processing and contextual effects on acquisition, retention and transfer. While these may appear to be statements of common sense, it is difficult to overstate their importance because failure to address them in training can result in limited transfer to competitive performance.

Program Design

In order to maximize the athlete's performance capabilities, the sports preparation process must be planned and implemented according to sound principles. With regard to specialized strength development, the following variables must be rationally manipulated:

* Action speed the intent to accelerate and/or achieve high velocity with a given load as a means of manipulating power or impulse production

* Exercise order the sequence in which a set of exercises is performed

* Density the amount of work performed in a set or training session

* Frequency the number of training sessions performed in a given time period (e.g., day or week)

* Intensity the effort with which a repetition is executed (usually characterized by resistance, but more accurately associated with impulse or power output)

* Recovery the time interval between sets

* Repetition the execution of a specific workload assignment or movement technique

* Series a group of sets and recovery intervals

* Set a group of repetitions

* Volume he amount of work performed in a given training session or time period (usually characterized by the volume load (repetitions x mass lifted), but more accurately associated with the product of resistance and distance moved per repetition)

These parameters are useful in quantifying training, and in most cases can also be adapted or directly applied to speed, agility and speed-endurance development. In order to be useful in practice, however, they must be accompanied by qualitative guidelines regarding movement mechanics and planned variation in training objectives.

Summary

There is tremendous potential to improve an athlete's performance capability and minimize the risk of injury through specialized strength training. Principle-based planning and implementation of the preparation process is the key. This requires a working knowledge of physiological and biomechanical bases of maximum strength, speed-strength and strength-endurance development.

In conclusion, the following practical implications can be recommended:

* Explosive force application is the basis of strength training for sports Functional strength is expressed in terms of acceleration, execution time or velocity - especially in athletics. Training tactics which disregard this fact are fundamentally unsound. Moving through an acceleration path, and applying rapid and/or high-speed force, is the name of the game.

* Emphasize big basic movements which have the greatest training effects; and use equipment which challenges the athlete to control, direct and/or stabilize it Muscles act in functional task groups, and must be targeted via force transmission through (rather than isolation within) the body's "kinetic chain". Multi-joint free weight movements are superior in this regard.

* Distinguish between specificity and simulation Training tasks should be selected and prioritized according to the coordinative, biomechanical and bioenergetic demands of competition.

* Balance the need for specificity vs. variability Maintain stability in the program by sticking with a basic exercise menu rather than trying to include every possible movement. Variation can be achieved by cycling workloads on a "periodic" 3-4 week basis in order to summate their training effects and avoid accommodation problems.

* Quality, not quantity, of effort is the bottom line While it is necessary to do enough work to get a training effect, there is likely a threshold of diminishing returns above which the athlete's effort is diluted - and recoverability / adaptability are compromised. Fitness and fatigue are a trade-off beyond a certain point. Generally, the best results are achieved by maximizing the quality of effort within a prescribed amount of work.

* Effort and recovery are interdependent The interrelation of workload, intensity, frequency and volume cannot be changed arbitrarily. They must be adjusted together, which occurs automatically with a sound plan. A training program is only as good as the athlete's ability to recover from and adapt to it!

* Fitness qualities are means toward an end, not ends in themselves: to develop the athlete's performance capabilities and skills, and thereby couple effort with execution Power, flexibility, agility, speed and endurance - combined with motor coordination - are the elements of athleticism. Each part can be trained, but they must be trained collectively because they are parts of a larger whole. None is a separate entity, nor more important than another. Train athletes, not muscles!

* Most importantly, skillful tasks are the basis of sports training, and require the services of a qualified Strength & Conditioning coach If simply counting reps and sets were the answer, anyone could do it. As is the case in all aspects of coaching or teaching, attention must be directed toward what the athlete is doing as well as how they are doing it - not just how much they do. Skilled training requires skilled coaching, and without it the program isn't worth the paper it's written on.

Key Terms

Dynamic Correspondence A principle stating that the basic biomechanics - but not necessarily outward appearance - of training tasks should be specific to those occurring in competition (analogous to the practice specificity concept).

Impulse The change in momentum resulting from a force, measured as the product of force and time; an important criterion of speed-strength.

Strength The ability to apply force in brief maximal efforts or repeated submaximal efforts.

Plyometrics Explosive-reactive training comprised of stretch-shortening cycle actions; aimed at improving explosive-reactive qualities of strength. Acute responses include increased mechanical efficiency and working effect (e.g., power, rate of force development), while chronic responses involve up-regulated muscle stiffness and motoneural activation.

Power The rate of doing work, or product of force and velocity; an important criterion of speed-strength.

Practice Specificity A motor learning principle stating that the contextual, processing and sensorimotor effects of training tasks on acquisition, retention and transfer should be specific to those occurring in competition (analogous to the dynamic correspondence concept).

Reactive Ability A characteristic of speed-strength (e.g., in stretch-shortening cycle actions) which can be improved through plyometric training aimed at improving explosive-reactive strength.

Speed-Strength The ability to apply force rapidly and/or at high velocities, i.e. in submaximal accelerative efforts or reactive-ballistic efforts; usually expressed as impulse or power.

Strength-Endurance The ability to maintain force in extensive/intensive interval workloads or repeated submaximal efforts.

Stretch-Shortening Cycle Muscle actions characterized by impulsive eccentric-concentric coupling (i.e. rapid deceleration/lengthening immediately followed by acceleration/shortening in the opposite direction) which exploit reflex potentiation and elastic energy recovery phenomena. Such actions are intrinsic to functional - and especially athletic - movement, and are the basis of plyometric training aimed at improving explosive-reactive strength

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