Is velocity-specific strength training important in improving functional performance?

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A variable considered when designing programs to optimize athletic performance is training velocity. It has been suggested that training at a specific velocity improves strength mainly at that velocity and as velocity deviates from the trained velocity, the less effective training will be. However, the research describing velocity-specific adaptation and the transference of these adaptations to other movement velocities is by no means clear. Compounding the problem in this area is the failure of research to detail the relationship between training velocity and actual movement velocity of a given task or athletic pursuit. In most cases there is a great disparity between training velocity and actual movement velocity. Factors that may better develop and explain velocity-specific adaptation in relation to functional performance are discussed. Developing qualities such as strength, power and rate of force development would appear of greater importance than training at the actual movement velocity of a task. It may be that irrespective of load and limb velocity, the repeated intent to move an isoinertial load as rapidly as possible might be an important stimulus for functional high velocity adaptation. The ability of the nervous system to activate and coordinate agonist, synergist and antagonist activity would seem essential. It was suggested training techniques that simulate the velocity and acceleration profiles associated with the desired functional performance, such as throw or jump training, may optimize functional adaptation. Furthermore combination training that incorporates same session sport specific training with either a heavy load or a mixed training load approach might provide an optimal strategy for promoting intramuscular and intermuscular co-ordination and improving functional performance.

KEY WORDS: Exercise - Physical endurance - Exercise test, physiology - Exercise test, methods.

Attempts to improve performance involve a considerable investment of time for most athletes, trainers and coaches. The training methods used to achieve improved performance will depend upon the athlete's skill level and training experience. In novice athletes, improving both control of the movement and muscle strength allow improved performance. For elite athletes, where technique and control are at a high level, improving muscle strength may become the training focus. Given the relative importance of resistance training, there is a need to determine the training stimulus that maximizes functional performance improvement in the athlete's respective discipline. One variable considered when designing programs to optimize athletic performance is training velocity. It has been suggested that training at a specific velocity improves strength mainly at that velocity and as velocity deviates from the trained velocity, the less effective training will be. It has also been suggested that athletes perform resistance training at the velocity encountered during their event. The first section of this article questions the importance of velocity-specificity of strength training in relation to improving functional performance. It is suggested that the relevance of this training princi-
ple in terms of program design should be viewed with scepticism. In the following section it is argued that there may be better methods to explain and develop velocity-specificity for improved functional performance.

Isokinetic research

The basis for velocity-specific adaptation and subsequent transference to performance is that training velocities should simulate the movement velocity of a specific activity. A number of studies have investigated the effects of velocity-specific training using isokinetic dynamometry. Some investigations have found training to produce improvement in performance at or around the training velocities.\textsuperscript{2,4} Furthermore an intermediate training velocity may exist which can enhance performance over a wide range of contraction velocities.\textsuperscript{6,7} Other investigators have reported improvements in muscular force at all velocities of contraction at and below training velocity, after low-load, high-velocity training.\textsuperscript{8,9} Though the results from these studies are conflicting, the majority of isokinetic research would suggest that those subjects undertaking resistance training at fast speeds perform better in tests at fast speed than those subjects who train at slow speeds and vice versa.

Limitations of isokinetic research

The mechanisms underlying velocity-specific adaptation and the transference of these adaptations to other movement velocities is by no means clear. Firstly, the problem is associated with a lack of agreement as to what constitutes fast and slow velocity training.\textsuperscript{10} Classically velocities of 60°-sec\textsuperscript{-1} (slow) are compared to velocities of 240-300°-sec\textsuperscript{-1} (fast).\textsuperscript{2,4} Rather than any rationale behind selection of the aforementioned training velocities, the velocities selected for investigation are for the most part chosen due to constraints that are seemingly set by the velocity limitations of specific dynamometers. That is, the velocity ranges of most isokinetic dynamometers sets the boundaries of the research and as such dictate that which is defined as fast and slow velocity training. For example, MacDougall, Wenger and Green\textsuperscript{11} in reviewing the characteristics of various isokinetic dynamometers found that the concentric velocity range for 80% of the machines was less than 450°-sec\textsuperscript{-1}. Furthermore for the isokinetic eccentric testing mode, no machine had a velocity greater than 220°-sec\textsuperscript{-1}.

Compounding this problem is the lack of research relating training velocity to actual movement velocity for sport specific tasks. It may be that in many cases training velocity is quite different to the actual movement velocity of sport specific tasks. For example, Mann and Sprague\textsuperscript{12} reported hip angular velocities of up to 500°-sec\textsuperscript{-1} for sprint runners. Thorstenson\textsuperscript{11} reported maximal knee velocities of 700°-sec\textsuperscript{-1} for resisted knee extension. Similar limitations exist for eccentric muscle action as knee flexors can contract eccentrically at about 1,000°-sec\textsuperscript{-1} during sprinting.\textsuperscript{11} Therefore in the context of human movement, the delineation of training velocities into slow (60°-sec\textsuperscript{-1}) and fast (240°-sec\textsuperscript{-1}) would appear somewhat arbitrary and lacking validity. It could be argued that it is inappropriate to compare these peak velocities with isokinetic constant velocities. Conversely it could be argued that this is another limitation of this type of dynamometry attempting to control velocity when most movements start from zero velocity achieve peak velocity and return to zero velocity. As such, much of the research in this area suffers problems with external validity if findings are related to functional performance.

Finally, most of the literature in this area has used isokinetic rather than isoinertial testing and training modalities, the latter of which is more specific to the athlete’s competitive and training environment. As intimated previously, the influences of acceleration and deceleration as well as the coupling of eccentric and concentric muscle action (stretch-shorten cycle) have considerable influence on functional and sporting performance. The ability of isokinetic dynamometry to adequately describe and monitor changes in these parameters would appear totally inadequate. A further problem is the inability of most isokinetic dynamometers to assess multi-joint tasks. Therefore the application of isokinetic training studies to most athletic training appears questionable in terms of external validity.\textsuperscript{13} Research in this area for the most part seems to have investigated velocity-specificity at the expense of contraction mode specificity.

Isoinertial research and functional performance

The training velocities associated with isoinertial loading are not well documented. Figure 1 details the average velocities associated with an isoinertial bench...
press movement recorded in our own lab. As most sports involve the projection of one's own mass or the mass of an implement, Figure 1 represents the velocities attained during a concentric only bench press throw and a rebound bench press throw on a modified Smith machine. Such motion has been reported to more closely simulate the velocity and acceleration profiles associated with throwing. The velocity profiles obtained from these 27 male athletes are similar to those recorded in other research of this kind.

For sports specific motion that uses muscles similar to the bench press the comparison of actual movement velocity to training velocity make for interesting analysis. Ritzdorf details release velocities of 13 m·sec\(^{-1}\) for the shot-put motion. In our own lab we have recorded average release velocities of 11.98 m·sec\(^{-1}\) for the chest pass of semi-elite female netball players. Furthermore Kleindorfer, Neumaier, Loch and Mester as reported by Ritzdorf showed that the segment velocities (shoulder, elbow and hand) combined to produce racquet head velocities of approximately 30 m·sec\(^{-1}\) for the tennis serve. It would seem that there are clear differences between the velocities associated with the most common strength training loading intensities (30-80% 1RM) and the actual movement velocity of a sport specific task even during isoinertial training. There is no doubt that resistance strength training can improve functional performance. However, the significance of attempting to perform velocity-specific strength training would appear questionable, due to the disparity between the actual movement velocities of most athletic tasks and the training velocities achieved during weight training. Other factors may be more important to better develop and explain velocity-specific adaptation in relation to functional performance.

Developing strength and power

Velocity can be influenced significantly by the load to be lifted or propelled. The majority of isoinertial training programs use loading intensities ranging between 30-80% of an individual's repetition maximum (1RM). The lower end of this continuum (30-60% 1RM) represent loading intensities that are thought to offer the optimal compromise between force and velocity for the development of power. The higher loading intensities (>70% 1RM) are thought to develop the maximal strength of muscle.

Almasbakk and Hoff investigated the velocity-specific responses to bench press training of 40 females over six weeks of training. The subjects were divided into four groups, a bench press heavy group (BPH - 80-85% 1RM), bench press light group (BPL - wooden stick = 0.37 kg), an altering group (Alt - increased load by 1.5 kg after each successful set) and a control group. All training groups were instructed to perform each lift with the intent of making a high-speed contraction. Bench press training with a light or heavy load was shown to be equally effective in improving the velocity of the bench press motion. The BPH group was the only group that improved maximal strength.

An experiment in our own lab investigated the change in chest press throw velocity of semi-elite female netball players, after 10 weeks of training. Twenty-one subjects were divided into three homogeneous groups, a heavy group (80% 1RM - average training velocity of 0.308 m·s\(^{-1}\)), a power group (60% 1RM - average training velocity of 398 m·sec\(^{-1}\)) and a control group. Training involved equi-volume (total load lifted per set) bench press training and at the conclusion of each set of bench presses each subject threw 20 chest passes. Both training groups were instructed to perform the bench press and chest pass training as “explosively” as possible for each of their respective repetitions and sets. The heavy load group produced significantly greater velocity, force and power output in the bench press compared to the power-trained and control groups (p<0.05) Both treatment groups how-

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Vol. 42 - No. 3
THE JOURNAL OF SPORTS MEDICINE AND PHYSICAL FITNESS
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ever, produced significant improvement in chest pass throwing velocity (9-12%) compared to the control but were not significantly different to each other.

Moss et al.24 investigated the effect of maximal effort strength training with different loads on many variables including velocity. Subjects were matched into three groups and trained using loads of 90% 1RM (G90), 35% 1RM (G35) and 15% 1RM (G15). Maximal power and velocity were tested at 2.5 kg, 15%, 25%, 35%, 50%, 70% and 90% of pretraining 1RM. Training loads were equated according to time under tension (EMG) and subjects were encouraged to perform each lift as fast as possible. After nine weeks of training of the elbow flexors, angular velocity increased significantly for all loads for G90 and G35. G15 had increases in angular velocity at 15%, 35% and 50% 1RM. No significant differences in angular velocity were found between the groups at 15%, 35% and 50% 1RM, but at 25%, 70% and 90% 1RM the increase in angular velocity was larger for G90 and G35 than G15. No significant difference was found between G90 and G35.

Comparing and evaluating the data between strength and power programs and between studies is always difficult due to the different manner in which researchers equate training load. In each of these studies however, it would be expected that the lighter load, higher velocity training would produce greater high-velocity adaptation. However, this was not the case. It would seem that loading intensities associated with strength (>80% 1RM) and power training (30-60% 1RM) and development of these two qualities are equally effective in improving movement velocity. It may be that the development of these two qualities or qualities such as stretch-shorten cycle capability or maximum rate of force development are more important than benefits gained from velocity-specific training. The results described previously may also indicate that even though weight training may differ significantly in terms of load (% 1RM) the actual velocities associated with strength and power training are not that disparate in relation to the actual movement velocity of a functional task.

Neural intent

Another mechanism that might account for the findings described in the previous section is the neural intent that an athlete uses to initiate a movement. In each of these studies subjects were asked to move the mass as explosively as possible. It may be that irrespective of load and limb velocity, the repeated intent to move “explosively” is an important stimulus for high velocity adaptation. The findings of Behm and Sale25 support such a notion, as they found that regardless of the actual velocity of movement (isometric versus isokinetic), it was the intention to execute a high-velocity movement, which resulted in a high velocity-specific training effect. In another study, Yue and Cole26 found that strength increased regardless of whether maximal voluntary contractions or imagined contractions were used. Behm27 stated that a limitation of research into strength and power development is the narrow focus into hypertrophic or neural adaptation. He concluded that skill and strength might be more closely related than typically thought. As such the use of imagery may be important for the development of strength and power. These findings indicate the importance of training instructions given to subjects/athletes as to mental approach as well as tempo of their resistance training.

Coordination

Another possible explanation for the adaptations reported above is that the training programs reflect the acquisition of skill. Rutherford and Jones28 trained a group of subjects for 12 weeks with a bilateral knee extension task. They found a large increase in the training load (about 200%) associated with a smaller increase (15-20%) in isometric force. Because strength was measured with an isometric contraction and the training involved dynamic contractions, they concluded that the greater increase in training load must have been due to an improvement in the coordination associated with the knee extension task. The equivalent effects for the BPH and BPL groups of the Almasbakk and Hoff3 research support Rutherford and Jones28 findings, indicating co-ordination as being the determining factor in early velocity-specific strength gains.

It would seem that during the initial phase of a training program at least, an improvement in the ability to activate and coordinate the contraction of the involved muscles is the important factor. During this phase there is a rapid progress in the ability to improve the training exercise such as lifting the weights, which is the result of a learning process.29 The learning process
appears to be very specific in that lifting weights makes better weight lifters but does not necessarily mean improved performance in other tasks. As such, it would seem prudent to implement training methods that promote the transference and tuning of strength improvements to task-related performance.

One such training method that may lead to the development of more efficient coordination and activation patterns within the nervous system is throw or jump training. It may be speculated that the importance of velocity maybe secondary to the influence of the time course and magnitude of acceleration/deceleration. For example, velocity and acceleration profiles will differ according to the load and type of strength training techniques used. During light load resistance training, large accelerations are achieved at the beginning of the concentric phase of the contraction and consequently large amounts of time are spent in deceleration over the final stages of the contraction. Hence when using light loads, high force levels are achieved only through a very small range of movement. Some training techniques aim at decreasing the deceleration phase by allowing the load to be projected as in a throw or a jump. Greater average velocity, peak velocity, peak acceleration, average force, mean power output and peak power output have been recorded for this type of training. Furthermore, as intimated earlier this type of training closely simulates the velocity and acceleration profiles and therefore contraction dynamics associated with most functional performance.

A further benefit of throw or jump training is that there may be greater benefit to not only the concentric phase of a contraction. For example, repeated throw training within a Smith machine would load the eccentric phase of the contraction to a greater extent if the bar were not braked during the downward phase. The effect of such training therefore would be potentiation of both the eccentric (greater eccentric load) and concentric (throw) phases.

**Combination training**

An issue related to that of velocity-specificity is whether one exercise speed is optimal for improving functional performance. Realizing that high load and high velocity resistance training affect different parts of the force-velocity curve, some authors have suggested combining both slow and fast movements to optimize neuromuscular adaptation. The effects of combined training have been investigated in programs that combined: isometrics and isotonic muscle action, isoinertial and plyometric training and periodised slow and fast resistance training. Most of this research however, investigated velocity-specific adaptation and changes to various kinematic and kinetic variables without examining changes in performance during functional tasks.

Some research has investigated combinations of isoinertial and sport specific motion training. Mayhew et al. reported no transfer of strength and power to seated shot-put performance after a 12-week isoinertial-training program. The seated shot put however, was only used for assessment purposes. Voight and Klausen showed that maximal heavy load training enhanced the speed of an unloaded movement, but only when combined with specific training of that movement. Other researchers have reported that heavy load resistance training that was combined with sport specific throw training produced greater throw velocity than sport specific training only, for both handball and baseball. A limitation of most of the above research however, is the absence of control and/or other treatment groups, making the application of research findings to training methodology somewhat tenuous.

A further area of interest is the magnitude of the load used in training. Most research has utilized heavy load intensities (74-88% 1RM) in their programs. The utilization of loads that maximize power output (30-60% 1RM) or mixed load training in combination with sport specific motion training may be more effective. Recent research by Newton, Kraemer and Hakkonen would seem to support such a notion. Newton et al. investigated whether ballistic resistance strength training would increase vertical jump performance of elite volleyball players. All subjects completed preseason on-court training combined with a resistance strength-training program. One group completed eight weeks of ballistic squat jump training at 30, 60 and 80% 1RM while the control group completed squat and leg press exercises at a 6RM load. The group that incorporated the ballistic squat jump training produced a significant increase in both standing vertical jump (5.9±3.1%) and three step vertical jump (6.3±5.1%). The pre- to postchanges produced by the control group were not significant for either jump.
Intramuscular and intermuscular coordination and functional performance

The effectiveness of combination training in improving functional performance may be attributed to the isoinertial training methods used and their effects on intramuscular and intermuscular coordination. Intramuscular coordination refers to the interaction between excitatory and inhibitory mechanisms between motor units within the same muscle.\textsuperscript{44, 45} Maximizing excitation (recruitment, firing frequency and synchronization) and minimizing inhibition (Golgi tendon organ activity) of a specific muscle facilitates intramuscular coordination.\textsuperscript{44} Maximal ballistic contractions and lifting maximal loads result in maximal number of motor units being activated, the fastest motor units being recruited and the discharge frequency of motoneurons being at their highest frequency.\textsuperscript{44-48} Furthermore, by exposing the neuromuscular system to relatively heavy loads the sensitivity of inhibitory mechanisms such as the Golgi tendon organs may be reduced through a process known as disinhibition, which in turn produces greater force output.\textsuperscript{2, 5, 49} It is also documented that such training can improve muscle stiffness. Komi\textsuperscript{50} proposed that the facilitatory stretch reflex from the muscle spindles can be enhanced. This would allow greater stiffness, which in turn allows greater stretch-load tolerance and improved power and mechanical efficiency. Research from Wilson, Murphy and Pryor\textsuperscript{51} supports this contention with the stiffest subjects producing superior average force and rate of force development to their more compliant counterparts.

Intermuscular coordination refers to the interaction of the agonistic, synergistic and antagonistic muscles, during the performance of movement.\textsuperscript{44} Supplementing the slow-velocity, heavy-load training with sport-specific, high-velocity training also allows intermuscular coordination to be developed. Repeatedly simulating movement pattern, velocity, contraction type and contraction force during training has been shown to increase activation and coordination of these muscles, resulting in enhanced sports performance.\textsuperscript{7, 52} Co-activation of antagonists impairs agonist activation by reciprocal inhibition, therefore reducing motor unit firing and force production. This co-activation is especially prevalent in high velocity explosive tasks.\textsuperscript{25, 52, 53} Some research\textsuperscript{26, 54} has indicated that the role of co-contracting antagonists can be altered due to neural adaptations to strength training. This relationship needs clarification but it is believed that practice and training may facilitate the reduction of co-activation of antagonists, thereby allowing greater force output. Improvement of this type is movement specific and best facilitated by coordination training using sport-specific actions.\textsuperscript{44, 47, 52, 53}

References


