Does Increasing Maximal Strength Improve Sprint Running Performance?

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Many strength and conditioning professionals are interested in improving speed as it is fundamental to successful performance in many sports. A variety of methods are used to improve speed, one of which is the use of resisted strength training. We assume that strength (force) is essential for most speed athletes and, therefore, some form of resisted strength training is prescribed to improve speed. The rationale for incorporating strength training is based on the contention that increasing the force output (strength) of the major muscles will improve both acceleration and maximum velocity. Of interest is whether such assumptions and contentions are true. The aim of this review is to investigate whether strength training has any effect on speed improvement with reference to running ability.

One approach we can use to quantify the importance of strength to speed is to use correlational analysis. That is, we determine the strength of the relationship between these two variables using correlational statistics. Isokinetic assessment involves the measurement of force/torque and or power through a range of motion with constant angular velocity. Normally isokinetic assessment uses velocities of 60–240 deg/s and has been performed on college-aged subjects or track athletes (2, 11, 12). These strength measures are then related to 40–100 m velocities or times. The results of literature relating isokinetic strength (usually at the knee or the hip) and sprint performance are usually nonsignificant, with low to moderate ($R = –0.52$ to $–0.69$) correlations (2, 10, 12, 16).

Isoinertial refers to contractions where the external load remains constant although muscle tension, length, and velocity continually vary (1). The relationship of isoinertial strength measures to speed are usually found to be similar or slightly stronger ($R = –0.60$ to $–0.79$) in comparison to isokinetic measures. Most isoinertial studies have used weight-training movements, such as the squat or power clean (3, 27, 34) or various types of jumps (19, 28, 30, 35, 37), and reported the correlation of these activities to acceleration or speed measures. Some researchers have instrumented weight training equipment

**Summary**

A strength base is considered critical to speed development and, consequently, a great deal of effort is spent improving the force capability of muscle. Using a correlational approach is one method used to quantify the relationship between strength and speed. However, better insight may be found investigating longitudinal studies that have quantified both strength and speed changes. Such an approach was used in this review to determine the magnitude of strength development necessary for improved running speed.
(e.g., Smith machine) to examine the relationship between muscle force-time characteristics assessed under varying contraction types (isometric, concentric, and eccentric) and sprint performance (33, 37). This type of approach has resulted in the best single predictors ($R = -0.80$ to $-0.86$) of sprint performance. For example, for starting performance (2.5 m time), concentric peak force relative to body weight was found to be the best single predictor ($R = -0.80$). The best single correlate ($R = -0.80$) of maximum running speed was the force applied at 100 ms (relative to body weight) during a concentric jump (37).

Correlational analyses, however, are of limited value in identifying the causal relationship between strength training and speed development. Of interest to strength and conditioning professionals is determining the effect of various programs on the variable of interest, in this case speed or sprint times. To do this, the changes in strength and speed need to be mapped over a longitudinal strength training intervention. Such an approach provides the focus for this review. By adopting such an approach it is hoped that the reader will better understand the importance of strength training to speed development and the program variables of strength training relevant to speed improvement.

**Limitations**

Limitations of the research used in this review do exist. By adopting such an approach, the reader will have a better sense of the quality of the research used in the review. Consequently, you will have a clearer sense of the significance and applications of some of the research.

**Speed**

Speed can be thought of as the product of stride length and stride frequency or the time to complete a specific distance. However, it should be remembered that a sprint can be considered a series of phases, described as the start, acceleration, maximum velocity, and deceleration phases. It may be that developing maximal strength may be more important in the start and acceleration phases than the maximal velocity and deceleration phases, and you need to select exercises and specific loading parameters with this in mind (37).

**Speed Assessment Procedures and Equipment**

Eleven of the studies summarized in Table 1 utilized electronic timing systems to assess speed (4–6, 8, 22–26, 29, 32). Five studies utilized hand-held stopwatches as the sole means of recording speed performance (9, 15, 18, 21, 35). When interpreting the results of the studies, we must be mindful of the measurement error associated with each approach ($\pm 1–2\%$ with timing light systems), given that the measurement error will affect statistical analysis. Furthermore, the protocol used to measure speed will also affect reliability and the accuracy of measurement between studies. Four studies did not publish the procedure used for data collection (4, 17, 24, 25). Six studies documented the average time, based on a various number of recorded trials (8, 9, 29, 32, 34, 35). Eight papers reported the fastest time based on varying number of recorded trials (5, 6, 15, 18, 20–23). We argue that the use of the average speed or time based on a number of trials more reliably maps changes in acceleration and speed performance pre and post training.

**Training Study Participants**

We know that novice and elite athletes respond to strength training at different rates and for the most part are trained differently. Having a sense of the training status of the athletes used in the research reviewed is fundamental to how we interpret findings to shape our programming. For the purpose of this review, novice athletes were classified as students or nonrepresentative sports people. Advanced athletes were defined as representative athletes that had a significant speed component to their sport. Ninety percent of the participants in these studies were novice athletes (males, $n = 582$; females, $n = 25$), with the remaining 10% advanced athletes (males, $n = 57$; females, $n = 14$). We can see that the conclusions drawn in relation to changes in strength and speed after a training intervention is most pertinent to male novice athletes. Novice athletes have greater potential to change in either strength or speed performance, and these changes were observed in shorter training interventions that are typical of most research projects (6–12 weeks duration). However, with elite athletes, an improvement of even as little as 1% may have physiological but not statistical significance and may be the difference in terms of placing in a sprint race.

**Gender Differences**

From the literature summarized in Table 1, it was observed that 95% of the recreational and advanced athletes included in this review were males ($n = 555$) and 5% were females ($n = 39$). For us to extrapolate the findings involving male subjects to females may be unwise, given the paucity of literature utilizing female subjects.

**Age**

Eighty-five percent of the participants reported in these training studies were between 19 and 24 years of age (males, $n = 436$; females, $n = 25$). The remaining 15% had an average age of 16 years (males, $n = 59$; females, $n = 12$). We should be mindful of the limited research on participants below 15 years and above 24 years of age.

**Making Sense of the Findings: Effect Sizes**

The results of each strength and speed measurement have been presented in terms of $p$ values ($< 0.5$) for statistical significance, percent change, and effect sizes (ES). Percent changes in strength and speed are commonly reported in the literature. However, calculation of percent change does not take into consideration...
<table>
<thead>
<tr>
<th>Authors</th>
<th>Study participants</th>
<th>Exercises used, training and duration frequency, intensity, and sets and repetitions</th>
<th>Strength and speed variables assessed</th>
<th>% Change in performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blazevich et al. (2002)</td>
<td>Nationally ranked male junior sprinters (n = 10; mean age 19 yr)</td>
<td>HV group (n = 5) LV group (n = 4) Squat, hip extension, hip flexion + 2 others</td>
<td>HV group 30–50% 1RM LV group 70–90% 1RM</td>
<td>1–4 sets of 3–10 reps</td>
</tr>
<tr>
<td>Coutts et al. (2004)</td>
<td>Healthy young rugby league players (n = 42; mean age 16.7 yr)</td>
<td>Supervised group (n = 21) Unsupervised group (n = 21)</td>
<td>4–10RM</td>
<td>3–4 sets of 4–10RM</td>
</tr>
<tr>
<td>Deane et al. (2005)</td>
<td>Physically active college volunteers (n = 48; mean age 22.2 yr) (24 men &amp; 24 women)</td>
<td>Treatment group (24 men &amp; women) Control group (24 men &amp; women)</td>
<td>20RM</td>
<td>3 sets of 20RM</td>
</tr>
<tr>
<td>Delecluse et al. (1995)</td>
<td>Male physical education students (n = 78; mean age 20 yr)</td>
<td>HR group (n = 22) Leg extension, leg press, 1/2 squat + 5 others</td>
<td>3–10RM</td>
<td>Periodized 3–4 sets of 3–10RM</td>
</tr>
<tr>
<td>Dintiman (1964)</td>
<td>Male physical education students (n = 145; mean age 7?)</td>
<td>WS group (n = 29) FWS group (n = 29) 3/4 squat + 3 others S group (n = 29)</td>
<td>8 weeks 3 x per wk</td>
<td>8–12RM</td>
</tr>
<tr>
<td>Fry et al. (1991)</td>
<td>Division 1 female volleyball players (n = 14; mean age 20 yr)</td>
<td>Full-body workout squats + 9–10 others</td>
<td>12 weeks 4 x per wk</td>
<td>1–15RM (depending on exercise &amp; training phase)</td>
</tr>
<tr>
<td>Authors</td>
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</tr>
<tr>
<td>Hammett and Hey (2003)</td>
<td>High school student athletes Male football players (n = 26); Female softball players (n = 12); mean age 16 yr</td>
<td>Experimental group (male, (n = 13); female, (n = 6)) Ballistic single hip &amp; knee extension</td>
<td>4 weeks (3 \times ) per wk 110% efforts for 10s (over-speed) 3 (\times) 10s (max 20 reps)</td>
<td>Strength Speed No change 36.6 m</td>
</tr>
<tr>
<td>Harris et al. (2000)</td>
<td>Male football players (n = 51); mean age 19 yr</td>
<td>Full-body workout squats &amp;/or 1/4 squats + 4 others</td>
<td>9 weeks (4 \times ) per wk HF group (&gt; 80% 1RM) HP group (30–45% 1RM) COM group weeks 1–5 Mon &amp; Thur (&gt; 80% 1RM) &amp; 60% 1RM weeks 6–9 (30–80% 1RM)</td>
<td>5–7 sets of 5 reps Strength Speed 1RM squat 1RM 1/4 squat 30 m</td>
</tr>
<tr>
<td>Hoffman et al. (1991)</td>
<td>Division 1 male basketball players (n = 9); mean age 19 yr</td>
<td>Full-body workout squats + 9 others (i.e., leg extension, leg curl etc.)</td>
<td>5 weeks (3 \times ) per wk 2 day/wk 5RM 1 day/wk 10RM</td>
<td>3–4 sets of 5–10 reps Strength Speed 1RM squat Isokinetic knee extension at 60 deg/s at 180 deg/s at 300 deg/s 27 m</td>
</tr>
<tr>
<td>Hoffman et al. (2004)</td>
<td>Division 1 male football players (n = 20); mean age 19.3 yr</td>
<td>OL group (n = 10) PL group (n = 10)</td>
<td>15 weeks (4 \times ) per wk 3–10RM</td>
<td>3–5 sets of 3–10RM Strength Speed 1RM squat 40 yd dash</td>
</tr>
<tr>
<td>Kotzamanidis et al. (2005)</td>
<td>Healthy male volunteers (n = 35); mean age 17.5 yr</td>
<td>COM resistance and jumping (n = 12) STR resistance only (n = 11) Control (n = 12)</td>
<td>13 weeks (3 \times ) per wk 3–8RM</td>
<td>4 sets of 3–8RM Strength Speed 1RM squat 30-m sprinting</td>
</tr>
<tr>
<td>Kraemer et al. (2000)</td>
<td>Male recreational athletes (n = 17); mean age 21 yr</td>
<td>AS control group (n = 8) MS experimental group (n = 9) Full-body workout Squat + 4 others</td>
<td>8 weeks (2 \times ) per wk 5–10RM</td>
<td>Periodized multiset 3 sets of 5–10 reps Strength Speed 1RM Squat 1RM 30% Jump Squat peak force 40 yd 60 yd</td>
</tr>
</tbody>
</table>
the variance of strength and speed improvements (31). By including the effect size (pretest minus posttest divided by the standard deviation of the pretest), the variance of each measurement is included, thus making it a standardized and more accurate description of the treatment effect (31). The ES allows us to compare the magnitude of the treatment (strength program) on speed between studies. We describe the effects as “trivial,” “small,” “moderate,” and “large”

**Table 1 (cont.) Summary of Training Studies**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Study participants</th>
<th>Exercises used, training and duration frequency, intensity, and sets and repetitions</th>
<th>Strength and speed variables assessed</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Lyttle et al. (1996)</td>
<td>Male recreational athletes (n = 39; mean age 23 yr)</td>
<td>COM group (n = 11) Weight/plyo LB: squats &amp; depth jumps MP group (n = 11) Squat jumps &amp; BP throws</td>
<td>COM 6–10RM WT 20–60cm drop height Plyo MP 30% 1RM</td>
<td>COM = 14.8% MP = 14.7%</td>
</tr>
<tr>
<td>McBride et al. (2002)</td>
<td>Male athletes (n = 26; mean age 23 yr)</td>
<td>JS JS30 group (n = 9) JS80 group (n = 10)</td>
<td>JS30 group 30% 1RM JS80 group 80% 1RM</td>
<td>JS30 group = 7.6% JS80 group = 9.2% JS30 group = 3.4% JS80 group = 4.6% JS30 group = 5.3% JS80 group = 6.7% JS30 group = –0.9% JS80 group = 6.0% JS30 group = –1.6% JS80 group = 4.7% JS30 group = –0.9% JS80 group = –1.5%</td>
</tr>
<tr>
<td>Murphy and Wilson (1997)</td>
<td>Male recreational athletes (n = 30; mean age 22 yr)</td>
<td>WT group (n = 14) Parallel squats</td>
<td>Periodized 3–6 sets of 6–10 reps</td>
<td>*20.9% Concentric (10kg) = 4.2% Eccentric (200%BM) = 8% 4.8% 4.6% *–2.3%</td>
</tr>
<tr>
<td>Tricoli et al. (2005)</td>
<td>College physical education students (n = 32; mean age = 22 yrs)</td>
<td>WL group (n = 7) Jumping group (n = 8) Control (n = 7)</td>
<td>4–6RM</td>
<td>WL group = 44% increase PL group = 34% increase Control = no change</td>
</tr>
<tr>
<td>Wilson et al. (1996)</td>
<td>Male exercise science students (n = 30; mean age 22 yr)</td>
<td>WT group (n = 14) Squat</td>
<td>Periodized 4–6 sets of 6–10 reps</td>
<td>1RM Squat Isokinetic knee extension at 60 deg/s at 270 deg/s 40 m</td>
</tr>
</tbody>
</table>
based on the description of effects for untrained, recreationally trained, and highly trained athletes (31). Such classification means that ES is not described in a uniform manner throughout the different populations. For example, an ES of 1.2 is described as “large” for an elite population, such as nationally ranked soccer players (4), whereas an ES of 1.3 is described as “moderate” for recreationally active subjects (23).

**Strength Training and Speed Development**

Considering the popularity of strength training, there are surprisingly few studies examining the effectiveness of resistance training to improve speed. We use the term speed broadly in this article to describe either the change in time or velocity over distances ranging from 5 m to 100 m. The changes in strength and speed can be observed in Table 1.

**Isokinetic Assessment and Speed Performance**

Training studies that utilized isokinetic measures of leg strength have used a variety of joint movements and angular velocities, including leg extension (14, 35), hip extension/flexion (4), and knee extension/flexion (21, 29, 34). Angular velocities ranged from 60 to 480 deg/s (depending on the joint movement). The most commonly used isokinetic strength measure was knee extension at 60 deg/s (9, 21, 29, 34). As can be observed from Tables 1, and 2, any increase in isokinetic knee and leg extension strength, at angular velocities of 60, 180 and 300 deg/s, did not result in any significant improvements in speed following resistance training interventions of 5–12 weeks (14, 21, 29, 34).

Only 2 studies using isokinetic measures were found to improve sprint ability. Blazevich and Jenkins (4) found that after 7 weeks of resistance training involving exercises such as the squat, hip extension, and hip flexion, the low-velocity group significantly improved hip extensor strength at isokinetic speeds of 60 deg/s and decreased 20 m acceleration time by −15.4% and −2.9% respectively. The high-velocity group significantly increased hip extensor strength at low velocities (60 deg/s) and significantly decreased 20 m acceleration time by −15.6% and −4.3% respectively. Wilson et al. (35) found that after 10 weeks of training, the maximal power weight-training group significantly improved leg extensor strength (6.5%) and decreased 30 m times (−1.5%; p < 0.1). Note that the speed assessments in this study involved averaging 2 trials recorded using a stopwatch, which no doubt affected measurement error.

Based on these findings (4, 35) it might be tempting to conclude that low-velocity, high-intensity (70–90% one repetition maximum [1RM]) and high-velocity, low-intensity (30–50% 1RM) resistance training involving squat, hip extension, and hip flexion type movements improve isokinetic leg strength and speed performance. However, we note that other authors using different joint actions and velocities (14, 21, 29, 34) found no significant improvements in either isokinetic leg strength or running speed following 5–12 weeks of re-

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</tr>
</thead>
<tbody>
<tr>
<td>Wilson et al. (1993)</td>
<td>Recreational athletes (n = 64; mean age 23 yr) gender unknown</td>
<td>WT group (n = 15) MP WT group (n = 13) Squat 10 weeks 2 × per wk</td>
<td>WT group 6–10RM MP WT group 30% maximum isometric force</td>
<td>Periodized 3–6 sets of 6–10 reps</td>
</tr>
</tbody>
</table>

* p < 0.05
HV = high velocity, LV = low velocity, FWS = flexibility/weight/sprint, HR = high resistance, WS = weight/sprint, S = sprint, RM = repetition maximum, HF = high force, HP = high power, COM = combined, OL = Olympic lifting, PL = power lifting, WL = weightlifting, AS = athletic shoe, MS = intervention shoe, MP = maximum power, JS = jump squats, JS30 = JS at 30% RM, JS80 = JS at 80% RM, WT = weight training, LB = lower body, PP = peak power.
Resistance training. Given the status of the literature, a definitive finding cannot be stated in relation to the efficacy of isokinetic training, assessment, and predication of speed improvement.

1RM Strength and Speed Performance

All the training studies reported in Table 2 (8 studies) reported significant ($p < 0.05$) improvements in maximal strength (9.0 to 44.0%) and sprint time (–0.9 to –4.3%) decreases and speed (3.7%) increases. Of the 8 studies, 7 used the squat as their measure of maximal strength. Sprint distances ranged between 10 m and 60 yards. Wilson and Murphy (29, 34) studied weight-trained males (average age, 22 years) who trained 2 times a week for 8 weeks and performed 3–6 sets of 6–10 reps of squats. Both studies (29, 34) resulted in significant increases in the subject’s 1RM squat (20.9%; ES = 1.2) and significant decreases in 40 m sprint times (–2.3%; ES = 0.36). Coutts et al. (5) found a small but significant decrease in 10 m (–0.9%; ES = 0.22) and 20 m (–0.9%; ES = 0.4) sprint times, and significant increases in 1RM squat strength (37%; ES = 1.7) after training 3 times a week for 12 weeks.

Kraemer et al. (23) investigated the effectiveness of the Meridian shoe on vertical jump and sprint performances following short-term combined plyometric/sprint and resistance training. After the training intervention, the only significant increases were observed in the Meridian shoe group. The 1RM squat (24%; ES = 1.3), 30% 1RM jump squat (2.6%; ES = 0.15) and 60-yd dash times (–3.4%; ES = unable to be calculated) improved over the course of the training intervention. Feedback at the completion of the study via questionnaires also indicated that participants thought increases in strength and speed were due to the training program as opposed to the type of shoe worn.

Kotzamanidis et al. (22) compared the effects of strength straining and sprint training on 3 groups (2 experimental and 1 control) and found that the combined group (resistance training and sprint training) produced significant improvements in strength (9%; ES = 0.7), and significant decreases in sprint times (–3.6%; ES = 0.9). Tricoli et al. (32) found similar improvements in speed (3.7%; ES = 0.95), but had much greater improvements in maximal squat strength (44%; ES = 2.0). In this study, recreationally active college students participated and received strength training (hang cleans, clean and jerk, squats, and high pulls). The only study to use well-trained athletes found significant changes in 1RM squat and 20 m sprint times in elite junior sprinters (4). The low-velocity group significantly improved their 1RM squat and decreased their 20 m acceleration time by 11.8% (ES = 0.71) and –2.9% (ES = 0.94), respectively. Significant increases in the high velocity group were also observed in their 1RM squat (12.4%; ES = 1.2) and 20 m acceleration times decreased significantly by –4.3% (ES = 0.74).

In summary, for the only study that found significant changes in highly trained athletes (nationally ranked junior sprinters), it would seem that moderate to large (ES = 0.71 to 1.2) squat strength changes (~12%) are needed for moderate (ES = 0.74 to 0.94) changes (~2%) in sprint times (4). For recreationally trained athletes it would seem that small to large (ES = 0.7 to 2.0; average ES = 1.19) squat strength changes (~23%) are needed for trivial to moderate (ES = 0.22 to 0.95) changes (~2.4%) in sprint times (22, 23, 29, 32, 34). However, these studies utilized male elite and novice athletes ranging in age from 19–22 years. Fry et al. (14) investigated changes in strength (1RM squat) and running speed (9.1 m and 36.6 m dash times) in 14 female elite volleyball players. Although there were significant improvements in 1RM squat strength (20.5%; ES = 1.2), they found no significant changes to 36.6 m time (~0.9%) and 9.1 m time (8.2%). Whether gender differences exist in terms of strength and speed improvements is difficult to discern given the paucity of literature in this area.

Program Design

In this section we attempt to summarize common variables reported in each study that resulted in significant increases in strength and speed.

Progression and Periodization

Several studies used a periodization model (4–6, 8, 9, 15, 21–24, 26, 29, 32, 34, 35) during their prescribed resistance training programs. Periodization implies a prescribed overload progression (e.g., percent improvement or increased load, sets, and/or reps) per week or session of training (e.g., alternating low and high overload sessions). According to Fleck (13) periodized programs can result in greater strength (1RM) gains than nonperiodized multi-set and single-set programs. The 9 studies that produced performance improvements in both strength and speed (4, 5, 9, 22, 23, 29, 32, 34, 35) all used a periodized resistance-training model.

Program Duration and Frequency

The prescribed resistance training programs reviewed ranged from 4 to 15 weeks in duration with 2–4 sessions per week. As can be observed from Tables 1 and 2, studies with well-defined assessment procedures that involved 2–3 sessions per week for 7 (4) to 13 weeks (5, 9, 22, 23, 29, 32, 34) produced significant performance improvements in both lower body strength and running speed. We conclude significant improvements in strength and running speed can occur when 2–3 training sessions per week are maintained for a period of 7–13 weeks.

Exercise Selection

It has been argued that speed may need to be analyzed over 2 separate distances. Short sprints that take place over 10–20 m reflect acceleration capabilities of the athlete (3). Conversely, maximum speed sprints are typically executed over 40–70 m, which requires high force pro-
duction over short time periods (<250 milliseconds). A needs analysis of speed requirements in sports found that short sprints and maximum speed sprints have different strength requirements, which should be reflected in different exercise selection (36). The reader needs to be cognizant of this when selecting exercises specific to acceleration and maximum speed development.

The majority of the studies reviewed utilized a squat exercise (3–5, 8, 9, 15, 18, 21–24, 29, 32, 34) and subsequent variations, such as the jump squat (25, 26), split squat, and side squat (16). Other frequently prescribed exercises included calf raises (8, 9, 15, 21, 23) leg extension, and leg curls (4, 7, 15, 21). Only 1 study prescribed the leg press (8). Deanne et al. (6) used elastic tubing as resistance for hip flexion strength training. Significant performance improvements in leg strength and running speed were most frequently reported in studies that prescribed the squat and/or jump squat (4, 5, 22, 23, 29, 32, 34). The squat and/or jump squat appear to be specific exercises associated with improvements in lower body strength and ultimately running speed.

### Training Intensity

Blazevich and Jenkins (4) investigated changes in 20 m acceleration and flying 20 m dash times in groups utilizing resistance training exercises such as the squat, hip extension and hip flexion at high intensity-low velocity (70–90% 1RM) and low-intensity, high-velocity (30–50% 1RM) loads. The low-velocity group decreased their 20 m acceleration sprint time by –2.9% (ES = 0.94), while the high-velocity group experienced a –4.3% (ES = 0.74) decrease. The low-velocity group significantly decreased flying 20 m dash times by –2.4%, while the high-velocity group only exhibited a –1.9% decrease in sprint times.

Harris et al. (18) studied the effects of 3 different training velocity methods on a variety of strength measures and 30 m sprint times. This study also utilized the squat exercise at a similar intensity velocity to Blazevich and Jenkins (4), high force (>80% 1RM) and high power (30–45% 1RM), with an extra group using a combination of high force and high power. In contrast to Blazevich and Jenkins (4), no significant differences in sprint times (30 m) were found between any of the 3 groups.

McBride et al. (25) investigated changes in a variety of strength measures and 5, 10, and 20 m sprints utilizing the jump squat at high-intensity, low-velocity (jump squat 80% 1RM [JS80]) versus low-intensity, high-velocity (jump squat 30% 1RM [JS30]) loads. The low-velocity JS80 groups 5, 10, and 20 m sprint times all increased by 6%, 4.7%, and 1.5%, respectively. Non-significant decreases in running times posttraining were observed in the high-velocity JS30 groups 5 m (0.9%), 10 m (1.6%), and 20 m (0.9%) sprint times.

### Table 2

#### Summary of Training Studies That Found Significant Strength and Speed Improvements Represented as Percent Changes and Effect Sizes

<table>
<thead>
<tr>
<th>Reference</th>
<th>Performance % change in speed times and (effect size)</th>
<th>Speed variable assessed</th>
<th>Performance % change in strength and (effect size)</th>
<th>Strength variable assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blazevich et al. (2002)</td>
<td>*HV group –4.3% (0.74) *LV group –2.9% (0.94)</td>
<td>20 m time</td>
<td>*HV group 12.4% (1.2) *LV group 11.8% (0.71)</td>
<td>1RM squat</td>
</tr>
<tr>
<td>Coutts et al. (2004)</td>
<td>*SUP group –0.9% (0.22) *UN group –0.9% (0.4)</td>
<td>10 m time 20 m time</td>
<td>*SUP group 37% (1.7)</td>
<td>1RM squat</td>
</tr>
<tr>
<td>Dintiman (1964)</td>
<td>*WS group 8% (0.94) *FWS group 9% (1.0)</td>
<td>“Flying” 50-yard</td>
<td>*WS group 19% (0.9) *FWS group 21% (0.93)</td>
<td>Leg dynamometer</td>
</tr>
<tr>
<td>Kotzamanidis et al. (2005)</td>
<td>*COM group –3.6% (0.9)</td>
<td>30 m time</td>
<td>*COM group 9% (0.7)</td>
<td>1RM squat</td>
</tr>
<tr>
<td>Kraemer et al. (2000)</td>
<td>*MS group –3.4%</td>
<td>60-yd time</td>
<td>*MS group 24% (1.3)</td>
<td>1RM squat</td>
</tr>
<tr>
<td>Murphy &amp; Wilson (1997)</td>
<td>*WT group –2.3% (0.36)</td>
<td>40 m time</td>
<td>*WT group 20.9% (1.2)</td>
<td>1RM squat</td>
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<td>Tricoli et al. (2005)</td>
<td>*WT group 3.7% (0.95)</td>
<td>10 m speed</td>
<td>*WT group 44% (2.0)</td>
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<td>Wilson et al. (1996)</td>
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<td>*WT group 20.9% (1.2)</td>
<td>1RM squat</td>
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* Significant (p < 0.05)
LV = low velocity, HV = high velocity, WS = weight and sprint, FWS = flexibility/weight/sprint, MP = maximum power, SUP = supervised, UN = unsupervised, COM = combined resistance training and running, WT = weight training, MS = meridian shoe
Based on these findings we cannot conclude that low-intensity, high-velocity or high-intensity, slow-velocity squat training is superior at improving running speed.

Summary and Practical Applications

The purpose of this brief review was to evaluate if training maximum strength improves maximum speed. From the 18 studies reviewed that mapped strength and speed changes over the course of a training intervention, only 8 studies reported significant changes in both measures. That is, the bulk of the literature has found significant strength gains without significant improvement in speed, and the following findings should be read with this in mind. For highly trained athletes, it is difficult to arrive at a consensus about the importance of improving strength for improving sprint performance, given the paucity of literature in this area. For recreationally trained athletes it would seem that ≥23% increases in squat 1RM are necessary for significant changes in sprint times (≥2%). Periodization of the strength program over a training period of 7–13 weeks, performed a minimum of 2–3 times per week is necessary to improve strength and subsequent sprint performance. There is no clear consensus as to which loading intensities are most beneficial for decreasing sprint times, so a mixed method approach would seem most prudent given the status of research in this area. Our findings are specific to male recreational athletes between 19–24 years of age, emphasizing the need for further research utilizing other populations groups, such as female subjects and elite athletes.

References


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Resisted Sprint Training for the Acceleration Phase of Sprinting

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Summary
First, the biomechanical differences between the acceleration phase and the maximum velocity phase of sprinting are considered. Second, research on the various resisted sprinting techniques is examined, linking these techniques to the biomechanics of the acceleration phase. Some suggestions are made regarding the application of these findings to the training of athletes.

Sprinting has previously been described as consisting of a series of phases: an acceleration phase from 0 to 10 m, a transition phase, and then a maximum velocity phase from 36 to 100 m during a 100-m sprint (7). Mero et al. (34) described the acceleration phase as being in the first 30–50 m, followed by a maximum velocity phase and a phase of deceleration. However, for many sporting activities such as soccer, rugby, football, netball, and basketball, maximum velocity is not always attained, and repeated short sprints are more common. As such, the ability to develop velocity in as short a time as possible (acceleration) may be of most importance to performance in many sporting activities. Furthermore, it is thought that acceleration and maximum velocity are relatively separate and specific qualities (9, 44). Therefore, it is the development of the acceleration phase of sprinting that would seem to be of greatest benefit to many sports people and is the subsequent focus of this article.

An athlete’s ability to accelerate his or her body mass during sprinting is dependent upon a number of factors. These factors include technique and the force production capability of the body, in particular the lower limb musculature. However, technical considerations may have less importance for acceleration phase performance than for a typical sprint event. That is, in many sports the athletes have to accelerate from lying prone or a crouch, from moving sideways or backwards, from landing on 1 leg and pivoting sideways, from catching a ball to chasing a kick and so on. Therefore, the force capability of muscle may be the more important consideration in developing sports speed. This contention that muscular force is important to acceleration phase performance was supported by Mann et al. (29), who stated that the ability to perform well in sprints over short distances is dependent on the ability to produce large amounts of force at crucial times.

Methods used to enhance force output for improving acceleration phase performance include various forms of weight training, plyometric training, and assisted and resisted sprinting techniques. This article will focus on resisted sprinting, which involves the athlete sprinting with added load, or utilizing other forms of resistance such as hills and stairs. In an attempt to provide velocity and movement pattern specificity during power training for the acceleration phase of sprinting, a variety of methods are used to provide resistance while sprinting. These methods include limb loading, uphill running, weighted vests, and resisted towing (13). The use of these resisted sprinting techniques is common both in athletics and in a variety of sports. However, there is very little experimental evidence that describes the merits of resisted sprinting or the different adaptations that may occur
with the utilization of different resisted techniques. That is, it could be that limb loading, uphill running, weighted vests, and resisted towing provide different training stimuli and hence produce different adaptations. Therefore, each technique may need to be linked to the specific needs of an athlete in relation to the requirements of the athlete’s sport. This paper addresses this premise through a review of the literature. First, the biomechanical differences between the acceleration phase and the maximum velocity phase of sprinting are considered. Second, research on the various resisted sprinting techniques is examined, linking these techniques to the biomechanics of the acceleration phase. Thereafter, loading parameters are discussed and recommendations are made regarding the application of these findings to the training of athletes.

**Biomechanics of the Acceleration Phase**

A brief comparison of biomechanical research associated with the acceleration and maximum velocity phases of sprinting would provide a useful introduction to an examination of the effects of resisted training techniques. A full treatise of this area is outside the scope of this article, but if interested the reader is directed to articles by Mero et al. (34) and Williams (43). This section will focus on kinematic aspects of the stance phase of sprinting during the acceleration and maximum speed phases. Thereafter, kinetic and electromyographic (EMG) characteristics of sprinting will be briefly introduced. The discussion is limited to the stance phase of sprinting.

**Kinematics**

Sprint velocity is a product of step length and step frequency (11, 19, 27, 34). Step length and step frequency are both increased to enhance velocity during the acceleration phase (see Figure 1) of sprinting (34). Each step comprises a stance phase and a swing phase. The time that the foot is in contact with the ground during the stride cycle is termed the stance phase, and the swing phase is from ipsilateral foot strike to ipsilateral toe-off (12). The acceleration phase of sprinting is characterized by a relatively long stance phase as the runner endeavors to generate velocity (27). The stance phase comprises 2 distinct components, braking and propulsion. The relative contributions of braking and propulsion to the stance phase differ during the acceleration phase of sprinting compared to the maximum velocity phase. During the acceleration phase, the stance phase is largely made up of a propulsive component, with minimal braking forces at foot strike. However, in the maximum velocity phase, braking constitutes up to 43% of the stance phase (33). Mero (31) found that when the athlete was accelerating, the braking phase constituted only 12.9% of the stance phase, and the remainder was associated with propulsion.

With respect to sprinting technique, the acceleration phase has been found to differ significantly from the maximum velocity phase of sprinting. Mero and colleagues (34) reported that during the first few strides in sprinting, the body’s center of gravity undergoes a posterior shift, from an anterior position at foot strike to a position posterior to the point of foot strike. Seagrave (39), based on coaching observations, has suggested that during the initial stages of the acceleration phase the body should be at an angle of approximately 45° to the surface of the ground. As the sprinter’s velocity increases, the body becomes more upright (16).

An athlete’s sprinting technique is determined by the angles of the trunk, thigh, knee, and ankle. There is considerable variation in the literature regarding thigh angle (angle between the thigh segment and a vertical line from the ground) during sprint running. Frischberg (16) reported a foot strike thigh angle of 29.9° at 50 m from a sprint start. In contrast, Letzelter and colleagues (25) reported a mean thigh angle of 22.6° at 30 m from a sprint start. The literature is inconclusive as to whether thigh angle varies considerably between the acceleration and maximum velocity phases of sprinting. Williams (43) in reviewing the literature reported foot-strike thigh angles ranging from 20.8° to 30° and stated that thigh angle did not seem to change appreciably with increasing running speed. There is also
variation in the literature regarding optimal thigh angle at toe-off. Mann and Herman (27) stated that more efficient sprinters terminated the nonproductive latter part of the stance phase and began recovery more quickly, whereas Hay (19) believed that the thigh should move through as great a range as possible and that failure of the thigh to do so was a common fault in sprinting.

Knee flexion at foot strike has been reported to range between 10° (4) and 30° (20, 28). Following foot strike, the knee flexes further to absorb the energy associated with the ground reaction forces generated at foot strike. This flexion following foot strike was reported by Jacobs and colleagues (20) to be on average approximately 15°. Mann and Herman (27) reported a mean foot strike knee angle of 13° 180 m into a 200-m race. This is in contrast to Jacobs and colleagues (20) and Paradis and Cooke (36) who reported mean foot-strike knee angles of 30° and 35° respectively during the acceleration phase. This suggests that knee flexion at foot strike is greater during the acceleration phase when compared to maximum velocity sprinting. A lack of literature regarding ankle kinematics during sprinting makes comparisons between the acceleration and maximum-velocity phases difficult.

Researchers comparing slow and fast field sport athletes over the first 3 steps of a 15-m sprint found that the fast group had significantly (p < 0.05) lower (approximately 11–13%) left and right foot contact times, increased stride frequency (approximately 9%), and lower knee extension angles (approximately 11°; 35). It was concluded that those players who were relatively fast during the acceleration phase achieved this by reduced knee extension angles and ground contact times, which increased stride frequency.

Kinetics

Larger propulsive forces (526 N horizontally and 431 N vertically) are exerted during the longer stance phase while accelerating (31). Horizontal propulsive forces during the first ground contact have been reported to be 46% greater than those observed once maximum velocity is achieved. Vertical propulsive forces have been shown to be similar during the acceleration phase and the maximum velocity phase of sprinting (31). Braking forces during the acceleration phase have been reported to be relatively small, –153 N horizontally, and a net force of 148 N vertically (31), compared with –445 N horizontally and 1,707 N vertically during the maximum velocity phase of sprinting (34). Plamondon and Roy (37) found that vertical braking forces decreased between steps 1 and 12, whereas horizontal braking forces increased up to the 12th stride, where they started to plateau.

EMG Activity

Limited research has been undertaken on the sequencing and degree of muscle activation across the acceleration and maximum speed phases of sprinting. It has been suggested that the hamstrings play an important role during the propulsive phase of stance, extending the thigh (22, 32, 42). Mero and Komi (32) suggested that knee extensor activity during the propulsive phase of stance during maximum velocity sprinting was limited. However, the propulsive role of the knee extensors during the acceleration phase may be greater (15). Wieman and Tidow (42) found that during the first few steps of sprinting, the vastus lateralis showed significantly greater activation during the stance phase compared to activity observed at maximum velocity. This increase in vastus lateralis activation was accompanied by a significant decrease in hamstring activation during the stance phase. Harland and Steele (18) also reported an increase in EMG activity of the vastus medialis during the sprint start. These findings suggest that the quadriceps are relatively more important for the acceleration phase as compared to the maximum velocity phase. Delecluse and colleagues (8) stated that although there was still a significant body lean during the acceleration phase, there was less reliance on the stretch-shorten cycle (SSC) and the knee extensors were the main accelerators.

Resisted Sprinting

The preceding literature review has suggested some significant differences between the acceleration and maximum speed phases of sprinting. During the acceleration phase, there is a longer stance phase, greater knee and trunk flexion at foot strike, greater propulsive forces, and possibly greater EMG activity in the knee extensors. It follows that these factors should be taken into consideration when choosing the mode of training for the acceleration phase of sprinting. As such, resisted sprint training has become a popular training method, with many sports teams and track athletes to develop acceleration. It is thought that such techniques increase neural activation and hence muscular force output of the leg, resulting in an increase in stride length over time (5, 6, 14) However, whether this is actually the case has not been empirically proven. It may be that each of these resisted techniques provides a different training stimulus and therefore each may be better suited for training different phases of sprinting. This contention is discussed in the ensuing sections.

Limb Loading

Limb loading involves the attachment of weights to the extremities of the athlete in order to provide overload while sprinting. The loads are typically placed at the ends of the distal segments and thus are likely to increase the moment of inertia considerably (19) and subsequently increase the muscle activity required during motion. Two studies have examined the effects of limb loading. Ropret et al. (38) studied the effect of arm and leg loading on sprinting velocity, step length, and step frequency. Arm loading up to a maximum of 0.66 kg did not have a significant effect on the athlete’s sprinting velocity, step length, or...
step frequency. In contrast, leg loading at 0.6, 1.2, and 1.8 kg had a significant effect on performance. A load of 1.8 kg significantly reduced sprinting velocity. Step length remained the same, so the decrease in velocity was attributed to a decrease in step frequency.

Similar findings were reported by Martin (30), who compared the effects of loading the foot by adding lead to specially developed running shoes and loading the thighs by wearing lead-weighted bike pants during treadmill running. It was found that foot loading and thigh loading lengthened step length, increased recovery time of the contralateral limb, and increased swing phase duration. However, this effect was statistically significant with ankle joint loading only. Therefore, this study illustrated how the increased inertial forces associated with distal loading resulted in a greater effect on running technique, especially in terms of decreasing step frequency.

From these studies it would seem that loading of the distal segment of the lower limb at the ankle joints decreased velocity and that the mechanism of velocity decrease was likely to have been through a decrease in step frequency, whereas step length remained relatively unaffected. To the authors’ knowledge, there are to date no training studies examining the long-term adaptations using this training technique.

**Uphill Running**

Some practitioners have suggested that uphill running will place increased load on the thigh extensor muscles as athletes try to maximize step length (13). Because thigh extensor activity is thought to be important in the propulsive phase of sprinting, the associated gain in strength is thought to increase the athlete’s step length when sprinting on a flat surface. Dintiman et al. (10), based on observations, suggested that the hill incline should be at a grade that does not compromise running form. They suggested, based on their training experience, the use of steeper inclines to improve the start and acceleration phases of sprinting (8–10° in 2.5–3.5 seconds) and progressively reduced inclines for longer sprint training.

Kunz and Kaufman (24) examined the biomechanics of uphill running. They compared running on a 3° grade as opposed to running on a flat surface. The inclined run resulted in a decrease in velocity of 1 m·s⁻¹, no change in step frequency, a decrease in step length, and an increase in trunk-thigh angle. Kunz and Kaufman (24) concluded that uphill running might result in longitudinal adaptations, increasing step length, and shortening the stance phase during sprinting on a flat surface.

Paradisis and Cooke (36) also compared the kinematics and kinetics of sprinting on a flat surface to sprinting up a 3° slope. It was found that velocity was significantly decreased (3%) when sprinting uphill compared to sprinting on a flat surface. The researchers observed that the decrease in velocity was primarily attributable to a decrease in step length, which decreased by 5.2% (p < 0.05). These researchers also found significant changes in body position between sprinting uphill and on a flat surface. Trunk flexion was significantly increased, and the shank angle (the angle between the lower leg and the running surface) was reduced at both foot strike and toe-off. Thigh-to-thigh angle (the angle between the right and left thigh segments) was significantly decreased at foot strike and knee angle was significantly decreased at toe-off. A significant decrease in landing distance (the distance between a vertical line through the athlete’s center of gravity and the point of foot strike) was also noted. Paradisis and Cooke (36) suggested that these kinematic changes resulted in an increase in the contribution of the propulsive phase to the stance phase during uphill sprinting. Once more, the long-term application of such training has not been investigated.

**Weighted Vests**

The use of weighted vests while sprinting is another method of providing resistance during training (see Figure 2). Vest sprinting with loads of 15 and 20% of body mass has increased sprint times at 10 m (7.5 and 10%, respectively) and at 30 m (9.3 and 11.7%, respectively) (17). It was suggested that the athletes had less additional force to overcome in the early stages of the sprint during vest sprinting, but that as they developed velocity, the need to control the additional mass around the trunk resulted in decreased performance. The increase in sprint times was attributed to decreased step length and step frequency and to increased stance times. However, the joint kinematics was similar between loaded and unloaded conditions.

A series of longitudinal studies have investigated the practice of applying extra mass to the body of elite athletes for prolonged periods of time (1–3). The first in this series of investigations (3) attempted to create a “hypergravity” situation by loading the athlete for a 3-week period with a vest that equated to 13% of the athlete’s body mass. The load was worn from morning to evening, including training sessions. Training included jump training and weight training that did not deviate from normal training for the 3-week trial period other than by the additional load of the weighted vest. Following training, a significant increase in lower limb explosive power measured during squat jumps and drop jumps (approximately 10%) was found. Furthermore, a significant right shift of the force-velocity curve measured during squat jumping was observed. It was concluded that the high-gravity conditions influenced the muscle mechanics of even well-trained athletes.

Bosco (1) examined the force-velocity relationship of the lower limb musculature in 5 international-level male...
jumpers over a 13-month period. During the first 12 months of training, in which the athletes did not wear vests, no improvements in the measured variables were found. However, after 3 weeks of a simulated hypergravity situation in which the athlete wore 11% of his body mass, a significant shift of the force-velocity curve to the right was observed during loaded squat jump assessment. The utilization of the weighted vest also resulted in an increase in average drop jump performance from 0.48 m to 0.55 m ($p < 0.001$). Bosco (1) did not examine whether the mechanisms behind the improvements found were neural or muscular. However, it was noted that after the high-gravity conditioning, execution time for the SSC during drop jumping and 15-second jumps was decreased, and force development was improved. Both of these tests assessed fast SSC movements as found during sprint running. Bosco suggested that this improvement in fast SSC performance might be a result of increased stiffness of the leg extensor musculature (1).

Another study by Bosco and colleagues (2) further investigated the effects of vest training by using sprinters performing jump and sprint training with a load of 7–8% of their body mass. As in previous studies, the athletes wore the extra load for 3 weeks from morning until evening, including during training times. Normal training volumes were otherwise unchanged. As found in previous studies, the force-velocity curve was observed to shift to the right. Therefore, the ability of those subjects who wore vests to produce greater force at higher velocities dramatically improved with this form of conditioning. No significant changes were found in the control group.

Bosco and colleagues (2) did not study factors related to sprint mechanics or sprint performance. However, it is possible that a vest worn during sprinting might increase the vertical force at each ground contact, thereby increasing the
eccentric load on the extensor muscles during the braking phase. This effect may serve to increase the muscles’ capacity to store elastic energy and improve power output (13, 39).

**Resisted Towing**

The towing of weighted devices such as sleds (Figure 3) and tires is the most common method of providing towing resistance for the enhancement of sprint performance, although the use of parachutes has also been documented (40). Faccioni (13), again based on coaching observations, suggested that using towing as a form of resistance may increase the load on the athlete’s torso and therefore may require more stabilization. This training stimulus may increase pelvic stabilization, which may have a positive effect on sprint performance.

Letzelter et al. (25) studied the acute effect that different loads had on performance variables with a group of female sprinters during sled towing. They found that a 2.5-kg load resulted in an 8% decrease in performance over 30 m, and 10 kg resulted in a 22% decrease in sprint performance. Step length was affected to a far greater extent than step frequency by the increased resistance. As the load increased, decreasing step length accounted for a greater proportion of decreasing velocity. The variable affected most by increasing resistance was stance phase duration, which increased significantly with all loads. Increased loads also caused increased upper-body lean and increased thigh angle at both the beginning and the end of the stance phase. This increased thigh angle reflects the increased need for force production during the prolonged stance phase. Unfortunately, this study did not quantify towing loads relative to body mass or provide anthropometric data on the subjects. It is therefore difficult to relate the results found to previously recommended loading guidelines.

Lockie et al. (26) studied the effect of sled towing on acceleration-phase sprinting kinematics in field-sport athletes. Athletes towed weighted sleds with loads equaling 12.6 and 32.2% of their body mass over a 15-m distance. Sled towing resulted in a decrease in stride length of 10 and 24% for the 12.6 and 32.2% loads respectively. Stride frequency was significantly decreased compared to baseline with both towing loads, but there was no significant difference between the 2 towing loads. The duration of the stance phase was also significantly increased during the towing conditions. Trunk flexion and hip range of motion were also significantly increased compared to baseline with both towing loads. Knee joint range of motion was increased for load 1 only on stride 1 of the sprint. The authors concluded that the heavier load led to a greater disruption of running kinematics, and recommended training with lighter loads.

Kafer and colleagues (23) studied the effects of resisted and assisted training on sprint times over 20-, 40-, and 60-m distances. A weighted sled was used to provide resistance, and a bungee cord (rubber rope) to provide assistance. The training groups included an assisted group, a resisted group, a group combining the 2 techniques, and a control group performing unloaded sprint training. The resisted group recorded an average improvement of 0.08 seconds ($p < 0.01$) and 0.35 seconds ($p < 0.01$) in sprint times over 20- and 60-m distances respectively. The combined group was significantly faster posttraining over both 40 m (0.19 seconds) and 60 m (0.34 seconds). The control group and the assisted group displayed significant improvements between pretraining and posttraining only over 60 m (0.08 and 0.27 seconds, respectively). It was suggested that the generic improvements in 60-m sprint performance were attributable to the subjects’ being rugby union players, who were unfamiliar with running the longer distances that are required only occasionally in their sport. Between group comparisons showed that only the combined resisted-assisted group was significantly faster ($p < 0.05$) than the control group posttraining. The mechanisms behind improvements in performance were not investigated. It was suggested, however, that a possible reason for the improvement was that the increased resistance from the sled resulted in increased force production to develop and maintain velocity. The researchers specu-
lated that this effect would increase the load associated with the SSC, increasing muscle stiffness and vertical force at each ground contact. Further research examining mechanical adaptations with resisted towing is required in order to examine mechanisms behind any improvements in sprinting performance.

In terms of the loading parameters, towing loads of less than 10% of body mass have been recommended, but this is based on practical observations rather than research (5, 25, 39). Kafer and colleagues (23) suggested that a load less than 15% of the athlete’s body mass will not affect the sprinter’s technique, but they also stated that the evidence was anecdotal and not scientifically substantiated. Seagrave (39) believed that the load should be determined by the extent to which performance is affected. If performance variables decrease by more than 10%, the load being used is too great and will have a detrimental effect on sprinting technique (5, 39).

<table>
<thead>
<tr>
<th>(A) Biomechanical characteristics</th>
<th>Muscles</th>
<th>Exercises</th>
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<tbody>
<tr>
<td>Trunk position</td>
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<td>Thigh angle at footstrike</td>
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<td>Quadriceps****</td>
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<td>Knee angle at footstrike</td>
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<td>Propulsion</td>
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<td>Swing phase</td>
<td>Shorter</td>
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<table>
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<tr>
<th>(B) Biomechanical characteristics</th>
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<th>Exercises</th>
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<tr>
<td>Stride length</td>
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<td>Stride frequency</td>
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<td>Braking</td>
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<tr>
<td>Propulsion</td>
<td>Shorter</td>
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<tr>
<td>Swing phase</td>
<td>Longer</td>
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* denotes the relative importance of that muscle group during each phase of sprinting. The greater the number of stars, the more important that muscle group is to that phase.
Frictional forces contribute to the resistance experienced by the athlete when towing a sled. It is difficult to quantify these frictional forces. The magnitude of the frictional force (coefficient of friction) is dependent on the mass on the sled and on the characteristics of the ground surface and the sled. It is relatively independent of the total surface area and is also independent at velocities between 0.01 and several m·s⁻¹ (21, 41). For training purposes, the load on the sled and the surface over which it is moving will be the variables that can be most easily manipulated to change the frictional force and hence the resistance against which the athlete is working. Therefore, when assigning load during sled towing, coaches not only must be conscious of how much mass they are adding to the sled, but also must be aware of the characteristics of the surface on which they are towing. For example, towing on grass is likely to result in a different coefficient of kinetic friction from towing on a track. Furthermore, James (21) has shown that the coefficient of kinetic friction was less for wet steel than for dry steel. The same is likely to be the case for a track surface with a decrease in frictional force when towing on a wet track.

It is possible that during resisted sprinting, different loads could be used for training the different phases of the sprint. It has been suggested that greater resistance should be used for training the acceleration phase and light loads for increasing the maximum velocity phase (7, 10, 40). Increased loads that increase forward body lean and increase stance phase duration may be beneficial to the acceleration phase of sprinting. However, there is a lack of information on the kinematic, kinetic, and EMG differences between loading parameters and their effects. Therefore, these thoughts are also based on anecdotal evidence.

Practical Applications for Resisted Sprinting

As described previously, different phases of the sprint generate different kinematic, kinetic, and EMG responses. The acceleration phase, for example, is characterized by a longer stance phase, a large proportion of which is propulsion. During the acceleration phase, there is greater trunk flexion, greater knee flexion at foot strike, and greater recruitment of the knee extensor musculature. Taking into consideration the principle of specificity in strength and power training, it follows that those modes of training that replicate these characteristics should be utilized. It is clear that different resistance training methods overload the body in a different manner, and therefore the training effect provided by each of the resisted training techniques results in a specific adaptation.

One method of providing this specificity in resistance training is to add load to the athlete while sprinting. The adjustments in sprinting technique made during towing and uphill running seem to replicate the acceleration phase more closely than do other resisted techniques. Both these techniques increase trunk lean, stance duration, and the need for horizontal force production during the propulsive phase of stance. Hill sprinting will also increase the need for horizontal propulsive forces, although the need to counter the grade may also result in an increased need for vertical propulsion. The specific need for increased propulsive forces may make modes of resistance such as resisted towing and hill sprinting more appropriate for training the acceleration phase of sprinting, in which propulsive force production comprises a large proportion of the stance phase.

Weighted vests provide overload in a different manner, by increasing the vertical load during foot strike, increasing the braking forces, and perhaps overloading the SSC to better effect. As such, weighted-vest training may have better applications for maximum velocity adaptation. Nonetheless, such training may also have an application to the training of the acceleration phase of sprinting by increasing eccentric strength and muscle stiffness and therefore decreasing the duration of the stance phase. It is not clear whether this type of overload or the greater horizontal overload provided by resisted towing results in greater increases in acceleration phase performance. Likewise, the optimal load to be used during resisted sprinting has not been determined. That is, it may be that greater resistance should be used for training the acceleration phase and light loads for increasing the maximum velocity phase. However, the practitioner should be aware that there is a risk that too much load may result in technique adjustments that could compromise the athlete’s sprinting technique.

Resisted sprinting provides a highly specific and convenient method of training muscular power for the acceleration phase of sprinting. Table 1 attempts to summarize some of the information into a format that may assist the training of athletes. However, the reader needs to be mindful that most evidence in this area is anecdotal, with very few randomized controlled designs validating the most desirable mode of resistance training, the mechanisms behind improvements in the acceleration phase, the possible negative effect on technique, and the optimal training loads. Answers to these questions are necessary if resisted sprinting is to be utilized effectively by coaches and athletes.

References


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Specificity of Sprint and Agility Training Methods

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ABSTRACT

The purpose of this study was to determine if straight sprint training transferred to agility performance tests that involved various change-of-direction complexities and if agility training transferred to straight sprinting speed. Thirty-six males were tested on a 30-m straight sprint and 6 agility tests with 2–5 changes of direction at various angles. The subjects participated in 2 training sessions per week for 6 weeks using 20–40-m straight sprints (speed) or 20–40-m change-of-direction sprints (3–5 changes of 100°) (agility). After the training period, the subjects were retested, and the speed training resulted in significant improvements (\(p < 0.05\)) in straight sprinting speed but limited gains in the agility tests. Generally, the more complex the agility task, the less the transfer from the speed training to the agility task. Conversely, the agility training resulted in significant improvements in the change-of-direction tests (\(p < 0.05\)) but no significant improvement (\(p > 0.05\)) in straight sprint performance. We concluded that straight speed and agility training methods are specific and produce limited transfer to the other. These findings have implications for the design of speed and agility training and testing protocols.

Key Words: transfer of training, change of direction, sprinting


Introduction

Straight sprinting speed and agility are considered important qualities in many sports. Sprinting in a straight line is a relatively closed skill involving predictable and planned movements and is used in sports such as track and field and gymnastics. Agility is difficult to define, but is often described as a quality possessing the ability to change direction and start and stop quickly (1, 9, 13, 14). In a sporting situation, changes of direction may be initiated to either pursue or evade an opponent or react to a moving ball. Therefore, it has been recognized that a component of agility performance is the response to a stimulus (3). It has been shown that up-and-back sprint time of 2.4 m increased as a light stimulus became less predictable in terms of timing and location, presumably because of increased information processing (5). Further, Chelladurai and Yuhasz (4) demonstrated that a change-of-direction task with a simple stimulus shared only 31% common variance with a more complex task in which the timing and location of the stimulus were not known. This suggests that having to react to a stimulus such as an opponent’s movement on the field may significantly influence the nature of the change-of-direction movement task.

Several studies have reported correlations between straight sprint tests and various agility tests. When a correlation coefficient (\(r\)) is less than 0.71, the shared or common variance between the 2 variables is less than 50%, indicating that they are specific or somewhat independent in nature (15). For example, Hortobagyi et al. (11) used this statistical approach to demonstrate that various modes of strength testing indicated more generality (\(r > 0.71\)) of strength than specificity (\(r < 0.71\)). Common variances of 11% and 22% have been reported, respectively, for straight sprints and a soccer agility test (2) and the Illinois agility test (7). Mayhew et al. (12) reported a common variance of 21% for 40-yd time and an agility test containing 5 changes of direction and forward, sideways, and backward running. Further, these investigators conducted a factor analysis on several fitness test results and found the speed and agility tests to be represented by different factors. This meant that speed and agility had little in common statistically, leading the authors to conclude that they were relatively independent qualities.

A common variance of only 7% was reported for a straight 20-m sprint and a 20-m sprint involving 3 changes of direction of 90° in Australian footballers (16). When the players were required to bounce a football twice while performing these changes of direction, the correlation with the straight sprint dropped to nearly 0. Corvo (6) suggested that speed training has limited benefit for improving agility in rugby league players, and Gambetta (8) suggested that because of the need to change direction in American football, the
importance of straight sprinting speed is diminished. Collectively, these findings and views indicate that straight sprinting and relatively complex agility maneuvers have little in common and are independent or specific qualities.

It would therefore follow that the training of straight sprinting speed would have little transfer to agility performance and vice versa. In 1969, a study was conducted (10) that compared the effects of speed and agility training on various fitness parameters. The study reported that agility training was superior to speed training for performance in the Illinois agility run and a “zig-zag run,” but the speed training was not significantly better for improving 50- yard sprint time. Unfortunately, the authors failed to describe the training that was implemented, making it difficult to evaluate the effects. Since the potential specificity of speed and agility training has not yet been clearly established, the purpose of the present study was to determine if straight sprint training transferred to change-of-direction tests of varying complexities. Another objective was to determine if agility training could enhance straight sprinting speed.

**Methods**

**Subjects**

Thirty-six men volunteered to participate in the study and provided informed consent. The project was approved by the Human Research Ethics Committee of the University of Ballarat. The subjects had a mean ± SD age, height, and body mass of 24.0 ± 5.7 years, 180.1 ± 4.4-cm, and 81.1 ± 8.4-kg, respectively. To be eligible for participation, the subjects were required to have prior experience of at least one season participating in activities involving sprinting and/or change-of-direction maneuvers, such as the activities performed in many team sports. During the study some of the subjects wanted to continue participating in various physical activities of a noncompetitive recreational nature. These individuals were allowed to participate in one such session per week because this represented their baseline level of activity. However, people who wanted to perform more than one additional training session per week were not selected as subjects because of the potential to mask the effects of the imposed training.

**Testing**

All subjects were assessed on 7 different 30-m tests. Test 1 was a straight sprint, and tests 2–7 involved multiple changes of direction (Figure 1). Tests 2–7 were designed to involve progressively greater change-of-direction complexity by increasing either the angle of directional change and/or the number of changes of direction. Therefore, test 2 was considered the simplest and test 7 the most complex change-of-direction task. Poles about 1-m high were placed on the floor to indicate the change of direction. The subjects were not permitted to touch these as they sprinted around them. When this did occur (fewer than 5 occasions), the trial was repeated after a complete recovery of at least 3 minutes.

Performance in the 7 tests was assessed by the time to cover the 30-m distance as measured by a dual-beam infrared timing system (Swift Performance Equipment, Lismore, Australia). The system requires both beams to be broken simultaneously to trigger the start or finish of timing and is designed to capture the trunk movement rather than a false trigger from a limb. All times were recorded to a resolution of 0.01 second.

The participants were tested in small groups (3–4), with half the subjects performing the 7 tests in ascending order and half in descending order. A randomized order was not used because of the time required to precisely set the 7 tests. Two trials were allowed for each test, with the best one being retained. A rest of at least 3 minutes between trials and tests was administered to minimize the effects of fatigue. Before testing, each subject performed a warm-up consisting of 3 minutes of jogging, stretching of the muscles of the lower extremity, and 3–4 submaximum efforts of the test about to be conducted.

The sprints were performed from a standing start with the toe of the preferred foot 0.3-m behind the starting gate. This was intended to allow some forward lean and cause triggering of the timing system as soon as the subject moved. The subjects were not permitted to use a “rolling” start and were instructed to sprint with maximum effort when they were ready. The sprint tests were performed in an indoor stadium on a wooden floor, and the subjects wore running shoes, which they were instructed to wear for both pretesting and posttesting occasions.
Table 1. Summary of the training programs for the speed and agility groups.

<table>
<thead>
<tr>
<th>Week</th>
<th>Repetition number × distance (m)</th>
<th>Rest between repetitions</th>
<th>Intensity (% of maximum)</th>
<th>Angle of directional change (°)*</th>
<th>No. of changes of direction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 × 40</td>
<td>Complete</td>
<td>95</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>8 × 30</td>
<td>Complete</td>
<td>98</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>8 × 20</td>
<td>Complete</td>
<td>100</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>5 × 40</td>
<td>Complete</td>
<td>100</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6 × 30</td>
<td>Complete</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>5 × 30</td>
<td>Complete</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
</tbody>
</table>

* Applies to agility group only.

Training

Following the testing, the subjects were randomly divided into 1 of 3 groups: a speed training group (n = 13), an agility training group (n = 13), and a control group (n = 10). The control group was instructed to continue with daily activities but not to undertake any new training. Both training groups were required to participate in 2 training sessions per week, 3–4 days apart, for a 6-week period. All training sessions were supervised by one of the investigators, and all sprint efforts were timed with a stopwatch with feedback given to enhance motivation. A minimum of 10 sessions needed to be completed during the training period for the data to be retained. The speed and agility training programs were designed to be equivalent with respect to the distances run, the total training volume, and the intensity of the efforts. The only difference between the programs was that the speed group performed only straight sprints, whereas the agility group performed only change-of-direction sprints (Table 1). The agility training consisted of 3–5 changes of direction of 100° (similar to tests 5–7) and was intended to be relatively complex to differentiate it from the speed training.

The subjects were instructed to use a “complete” recovery between sprints (typically 2–4 minutes) and to avoid any worsening of times as the session progressed. The length of each interval varied from 20–40 m to provide variety and allow a slightly different training emphasis. For example, 20-m efforts emphasized acceleration, whereas 40-m efforts allowed greater speeds to be attained. The intensity was slightly below maximum speed for the first 2 weeks to allow progression and to reduce the risk of injury (Table 1). The intensity of the submaximum efforts was monitored by providing feedback to each subject on how his interval time (recorded by stopwatch) compared with the times achieved during the pretesting. Within 2–3 days of completion of the training program, the subjects were again assessed on the 7 tests, using the same order as the pretests.

Statistical Analyses

An analysis of variance (ANOVA) with repeated measures was conducted to determine if the training responses for the experimental groups differed significantly from each other and the control group for each test. Pearson correlation coefficients were also computed to determine the interrelationships among the tests. The level of significance for both statistical tests was set at $p \leq 0.05$.

Results

Nine subjects did not complete the study because of illness, injury, or failure to complete all the tests or the minimum number of training sessions. One subject was required to withdraw because of a slight hamstring muscle strain during an agility training session. The number of subjects in each group who completed the entire study were 11 (speed), 9 (agility), and 7 (control).

Descriptive data are shown in Table 2, and the mean times for each test for all subjects are illustrated in Figure 2. The ANOVAs revealed significant ($p < 0.05$) group-by-time interactions for tests 1, 3, 5, 6, and 7. These results indicate that the changes over time (before to after training) were significantly different between the groups for these tests. To clarify the within-group changes, paired $t$-tests were conducted for each group on each test. The mean changes for all groups and tests are indicated in Figure 3.

There were no significant improvements in any of the tests for the control group. The speed group improved significantly in test 1 (straight sprint) and test 2 only. The agility group improved significantly in tests 2–7 (change-of-direction tasks) but not test 1. Generally, the speed group improved most in the straight sprint, and the gains in performance decayed from test 2–7 as the change-in-direction task became more complex. The reverse trend was apparent for the agility group; that is, the gains were greatest for the tests that were similar to the training (5–7) and dimin-
Table 2. Mean ± SD times (in seconds) for all groups before and after training.

<table>
<thead>
<tr>
<th>Week</th>
<th>Speed</th>
<th></th>
<th>Agility</th>
<th></th>
<th>Control</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>4.47 ± 0.18</td>
<td>4.34 ± 0.18</td>
<td>4.74 ± 0.30</td>
<td>4.72 ± 0.24</td>
<td>4.52 ± 0.21</td>
<td>4.53 ± 0.16</td>
</tr>
<tr>
<td>2</td>
<td>4.76 ± 0.19</td>
<td>4.65 ± 0.23</td>
<td>5.04 ± 0.23</td>
<td>4.93 ± 0.24</td>
<td>4.82 ± 0.24</td>
<td>4.77 ± 0.18</td>
</tr>
<tr>
<td>3</td>
<td>5.79 ± 0.26</td>
<td>5.71 ± 0.25</td>
<td>6.00 ± 0.28</td>
<td>5.78 ± 0.24</td>
<td>5.74 ± 0.26</td>
<td>5.82 ± 0.20</td>
</tr>
<tr>
<td>4</td>
<td>6.67 ± 0.32</td>
<td>6.59 ± 0.29</td>
<td>6.91 ± 0.27</td>
<td>6.73 ± 0.23</td>
<td>6.71 ± 0.27</td>
<td>6.70 ± 0.27</td>
</tr>
<tr>
<td>5</td>
<td>7.65 ± 0.40</td>
<td>7.65 ± 0.42</td>
<td>7.93 ± 0.37</td>
<td>7.68 ± 0.29</td>
<td>7.83 ± 0.42</td>
<td>7.83 ± 0.40</td>
</tr>
<tr>
<td>6</td>
<td>8.60 ± 0.41</td>
<td>8.63 ± 0.43</td>
<td>8.83 ± 0.35</td>
<td>8.55 ± 0.37</td>
<td>8.83 ± 0.53</td>
<td>8.78 ± 0.52</td>
</tr>
<tr>
<td>7</td>
<td>9.51 ± 0.52</td>
<td>9.51 ± 0.52</td>
<td>9.78 ± 0.31</td>
<td>9.52 ± 0.30</td>
<td>9.68 ± 0.67</td>
<td>9.78 ± 0.66</td>
</tr>
</tbody>
</table>

Figure 2. Mean times for each test from pretraining data (n = 36).

Figure 3. Mean changes for all groups in each test. Asterisk denotes significant change (p < 0.05) before and after training.

Discussion

The progressively increasing sprint times from tests 1–7 (Figure 2) support the notion that systematically increasing the angle of directional change and the number of changes of direction increased the complexity of the agility tasks. The longer times are likely to be due to the need to apply greater lateral forces and to produce more decelerations and accelerations.

An important finding from this research was that straight sprint training enhanced speed in a straight line (test 1) with limited transfer to the agility tasks. Although there was a significant improvement in test 2, this test only involved 2 changes of direction with a relatively small directional change (20° deviation). The correlation between tests 1 and 2 was relatively high before the training (r = 0.92, p < 0.01), indicating the tests had much in common. However, the speed training resulted in no improvement in the most complex agility task (test 7) and only minor, nonsignificant gains in tests 3–6. The correlation between tests 1 and 7 was 0.64 (pretraining data) and 0.47 (posttraining data), which indicate respective common variances of 41% and 22%. This relatively small common variance indicates that the speed and agility tests assessed specific qualities, a finding that is consistent with previous research (2, 7, 12, 16). The 5 relatively sharp changes of direction in test 7 required the subjects to adopt a sideways leaning posture in an effort to apply enough lateral force to the ground to successfully change direction at high speed. They also required significant adjustments to the stride pattern to decelerate and then accelerate around each marker. The complexity of this task made the running motion dissimilar to the mechanics of straight running. Therefore, the lack of transfer from the speed training to the more complex agility maneuvers was expected.
The agility training induced significant gains in all agility tests but produced little change (nonsignificant) in straight sprinting speed. In general, both training groups experienced the biggest gains in the tests related to their training, and the training-induced improvements diminished as the tests became more different to the training. Therefore, the results of this research strongly support the specificity of training. In summary, sprinting in a straight line and sprinting with changes of direction are specific tasks that do not readily transfer to the other.

**Practical Applications**

The findings of this research indicate that straight sprint training has limited ability to transfer to agility performance involving fast changes of direction. Therefore, the interval training and supplementary exercises that are typically performed to enhance straight sprinting speed (for example, in track and field) can be expected to be of limited value for the agility component of many sports. Coaches are advised to implement specific agility drills to develop this component. Since running mechanics are likely to vary according to the sporting situation, analysis of movement patterns typically used at high speed should be conducted. These patterns can then be incorporated into any training or testing protocols to enhance specificity.

The present research also suggests that agility training may not improve straight sprinting speed, and therefore speed and agility methods should be included in a training program according to the needs of each sport. Although this study focused on the running component of agility performance, the role of perceptual skills, such as reacting to surrounding players and decision making, should also be considered in the design and testing of agility.

**References**