ABSTRACT
Participation of masters athletes (>30 years) in sprint running (100-400 m) and sprint track cycling (200 m, team sprint, 1-km) has increased significantly over recent decades. With aging, sprint and endurance performance gradually declines. The present review focuses upon the effects of resistance training on sprint and endurance performance and its physiological determinants in masters athletes. The available research demonstrates that resistance training interventions in masters athletes lead to beneficial adaptations in both sprint and endurance athletes. With inclusion of heavy strength training exercises in sprinters' training regimen, increases muscle mass, size of fast fibres and rapid neural activation capacity along with improvements in maximal, explosive and sprint force production have been observed. In endurance athletes, strength training has been shown to lead to increased maximal and explosive muscle strength levels. The actual event-specific performance changes are typically smaller, but significant (p<0.05), with a 2-4% reduction in sprint running times and 3-6% improvement in endurance cycling and running economy. Taken together, these limited data suggest that resistance training programs produce positive effects on physiological determinants of sprint and endurance performance that result in enhanced sport performance capacity in masters athletes. Further research on these issues is needed to design and deliver optimal training programs to aging athletes.

Keywords: veteran, older athletes, sprint running, cycling, aging, strength training, endurance performance.

INTRODUCTION
Masters athletes are individuals who participate in local, national or international competitive sporting activities specifically designed for middle-aged and older adults. Over recent decades there has been a significant increase in the number of masters athletes continuing to train and compete at high performance levels within both individual sports and multi-sport events. The rising popularity of masters sporting competitions can be seen by the increasing numbers of participation in the World Masters Games. For example, the first World Masters Games in Toronto in 1975 had over 8 000 competitors, while in 2009 over 28 000 athletes took part in World Masters Games in Sydney. Moreover, participation trends in masters track cycling, are also increasing. In 2005, there were 292 entrants from 20 nations who took part in the Union Cycliste...
Internationale (UCI) track cycling masters world championships and in 2013 this number increased to 400 entrants, from 28 countries. Taken together, these data highlight the increasing participation numbers in competitive masters sporting events.

In track-cycling, the 200 m flying start is the qualifying event for sprint competition, which is considered the most explosive effort amongst high-performance track cycling events. Leading international younger male track-cyclists, compete this event in 10 seconds (females in 12 seconds) with cycling cadences between 150-160 rpm and power outputs of 18 to 22 W/kg. Elite younger male sprint runners complete 100 m event in 10 seconds (females in 11 seconds) with running velocities of up to 12 m/s during maximum speed phase. Such performance requires peak power outputs that approach 18 W/kg. Thus, both sprint cycling and sprint running performance impose high demands on maximal speed-power capacities affected by anaerobic ATP-creatine phosphate and glycolytic systems. Therefore, one important challenge for both researchers and strength and conditioning coaches is to find the most effective training methods that might counteract the well documented decrements in sprint and endurance performance in masters athletes.

In light of these findings, it might be suggested that the inclusion of a resistance training program into sprint training programs may enhance sprint performance in aging athletes. Indeed, previous research has demonstrated there is a need for masters athletes to engage in resistance training programs to improve sprint performance for three reasons. Firstly, hypertrophy resistance training may offset the age-related decrease in both muscle fibre size and number commonly observed in aging populations. Secondly, high-intensity resistance training stimulates fast-twitch muscle fibres and motor units. Finally, both explosive power weight training exercises and plyometrics maximise coordinated neuromuscular recruitment and elastic behaviour of muscle-tendon complex. The purpose of this narrative review is to examine the effects of resistance training on sprint and endurance running, and cycling performance in masters athletes.

**METHODS**

A literature search was conducted between November and December 2015 using the electronic databases of Ausport, Cochrane, Embase, Scopus, Sportdiscus and Medline. The following search terms of masters athlete OR veteran AND strength training OR resistance training were used. Studies were included in this review if they satisfied all of the following criteria: male, aged 30 years or older and described as masters athletes or veteran, who participated in a resistance training intervention (figure 1). Further restrictions were applied to only include full-text peer reviewed articles, available in English language. An additional perusal of relevant reference lists was also undertaken to further ensure all relevant data has been identified.

![Figure 1: Narrative review flow chart](image-url)
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Training protocol</th>
<th>Outcome Measures</th>
<th>Finding</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piacentini et al. (2013)</td>
<td>16 TMER</td>
<td>MST group: 44.2 ± 3.9 years</td>
<td>MST Group: 4 x M 2 x F</td>
<td>6-wk CERS RT: two times per week,, 3x10, 70% 1RM, bench press, lat pulldown, seated row, cable shoulder press, triceps extension, bicep curl. ½ squat, calf press, lunges, eccentric leg extensions on leg press MST: 4 x 3-4, 85-90% 1RM, same exercises</td>
<td>1RM LP, CMJ, SJ, RE</td>
<td>Significant increase in 1RM LP and RE in the MST group only.</td>
<td>16.3% increase in leg press 1RM LP in MST group. 6.1% increase in RE in MST group</td>
</tr>
<tr>
<td>Louis et al. (2012)</td>
<td>9 TMEC</td>
<td>51.5 ± 5.5 years</td>
<td>Gender not specified.</td>
<td>3-wk CER RT: three times per week, 10 x 10 knee extension 70% 1RM.</td>
<td>KE-MVC, Tmean, CE</td>
<td>Significant increase in KE-MVC, Tmean and CE.</td>
<td>17.8% increase KE MVC in TMEC. 5.9% increase in KE MVC in TYEC. 6.9% increase in Tmean in TMEC. 3% increase in CE in TMEC.</td>
</tr>
<tr>
<td>Cristea et al (2008)</td>
<td>9 TMS</td>
<td>54.7 ± 5.5 years</td>
<td>males</td>
<td>20-wk CSR RT: two times per week, periodised sets and reps scheme. ST: two s·wk, 20-60 m track sprint training</td>
<td>10m SV, 60 m ST, 1RM SQ, SJ, TJ</td>
<td>Significant increase in SV60 mST, 1RM SQ, SJ and TJ performance</td>
<td>4% increase in 10 m SV. 2% increase in 60 m ST. 27% increase in 1RM SQ. 10% in SJ. 4% increase in TJ.</td>
</tr>
<tr>
<td>Reaburn and Mackinnon (1996)</td>
<td>12 TMS</td>
<td>54.7 ± 5.5 years</td>
<td>males</td>
<td>8-wk CSR RT: two times per week, 3 x 8-12RM leg extension, leg curl, leg press, half-squat. ST: 8-wk, two times per week, 100 &amp; 300 meter track sprint training.</td>
<td>100 m ST, 300 m sprint time, QS MVC, HS MVC, TC</td>
<td>Significant improvement in 100 m sprint performance, TC, QS and HS PT</td>
<td>4% improvement in 100 m sprint time. 1.1% increase in QS PT and HS PT. 1% increase in TC.</td>
</tr>
</tbody>
</table>

TMER = Trained Masters Endurance Runners; MST = Maximum Strength Training; RT = Resistance Training, C = Control Group; 1RM = 1 Repetition Maximum; LP = Leg Press; CMJ = Countermovement Jump; SQ = Squat, SJ = Squat Jump, RE = Running Economy; TMEC = Trained Masters Endurance Cyclists; TYEC = Trained Younger Endurance Cyclists; CER = Concurrent Endurance and Resistance Training Program; CE = Cycling Economy; KE = Knee Extension; MVC = Maximum Voluntary Contraction; Tmean = mean torque development; TMS = Trained Masters Sprinters; CSR = Concurrent Sprint and Resistance Training Program; SV = Sprint Velocity; ST = Sprint Time; TJ = Triple Jump, QS = Quadriceps, HS = Hamstrings, PT = Peak Torque, TC = Thigh Circumference, 30WT = 30 Second Wingate Test, CSA = Cross Sectional Area, IHSMF = Isometric Half Squat Maximal Force.
RESULTS

A total of four studies met the inclusion criteria and were subsequently included in this review. Of the four articles reviewed, a total of 46 trained masters athletes (37 males and 9 females), with a mean age of 52.2 ± 8.8 years, participated in a resistance training intervention. Intervention components such as the frequency of sessions, the duration of interventions varied. Specifically, duration of interventions ranged from 3 – 20 weeks, while the frequency of interventions ranged from 2-3 sessions per week. Results suggest significant improvements (p<0.05) in 60 m and 100 m sprint time, running economy, cycling economy, knee extension peak torque and 1RM squat and leg press strength. Further details are provided in table 1.

DISCUSSION

The effects of aging on sprint running and sprint cycling performance

This first section reviews research that has investigated the age-related decline in the energetically similar events of 100 m sprint running and 200 m sprint cycling performance.

A number of studies have investigated the decline in sprint running performance with age. For example, Suominen (2011) examined world 100 m sprint running records and reported that running speed declined quite linearly by 6% per decade in men between 20 and 80 years, and in females by 7% per decade between 20 and 75 years. After age 75-80 years, reductions in 100 m record performances become more evident. In a study conducted in European Veterans Athletics Championships, Korhonen et al. (2003) observed that in 100 m finalists, maximum speed declined by 4.1% in males) (4.9% in females) and increase in contact time (44% to 61% in males) (45% to 71% in females) while stride rate showed minor reduction (2.2% in males) (2.1% in females). The age-related reductions in braking and propulsive ground reaction forces and their rate of development may be primarily responsible for the changes in stride length, contact time, and consequently, speed. In another study, researchers investigated the blood lactate concentrations in a group of male and female masters sprint runners (40-88 years) following competitive 100 m, 200 m and 400 m sprint running. The researchers reported blood lactate concentrations were significantly lower in the sprinters aged between 70-88 years. This implies that decreased ability to generate energy from anaerobic glycolysis may be additional factor in the age-related decrease in sprinting ability after 70 years.

Similar age-related declines in metabolic power appear to occur in sprint performance in both veteran runners and veteran cyclists. Metabolic power represents the rate at which energy is generated and it is commonly expressed in relation to body mass (watts/kg). The relative metabolic power in 100 m sprint running performance has been reported to decline by 30% (approximately 10% per decade) from 40 to 70 years in competitive male sprinters. In veteran cyclists, Balmer et al. (2005) reported in a cross-sectional study of competitive male cyclists aged 30 to 73 years, ramped minute power (watts) measured via air-braked cycle ergometry declines by 2.4 watts per year. More recently, Ampratzis et al. (2011) compared absolute values of both 100 m sprint running and inertial cycle ergometry power in male masters endurance cyclists and 100 m sprint runners aged 40 to 65 years. Their findings suggest a similar decline in both sprint cycling power (25.3% per decade) and 100 m sprint running power (25.4% per decade) between the ages 40 and 65 years.

To date, few studies have examined the age-related decline in sprint cycling performance. Martin et al. (2000) reported that maximal cycling sprint power, as measured during 3-4-s all-out effort using inertial load cycle ergometry, declined by 7.5% per decade in competitive male cyclists aged 30-70 years. The researchers reported the decline in maximal power was reduced to 5% per
decade when scaled to lean thigh volume, suggesting a decrease in muscle mass commonly observed in older athletes\textsuperscript{9,26,27} may be a major contributor to age-related declines in track cycling performance. It was also found that with age the pedalling rate at which peak power was attained decreased from 124 to 114 rpm and this was thought to reflect age-related reduction in cross-sectional area occupied by fast type 2 fibres. In addition, Gent & Norton (2012)\textsuperscript{28} reported anaerobic peak power measured by 10-s all-out effort using wind-resisted cycle ergometry declined by 8\% in both male (n=156) and female (n=17) masters cyclists aged 35-64 years. Taken together, these data suggest cycling peak power declines by 5-8\% in masters-cyclists.

We recently examined the current masters 200 m track cycling world records for age-related changes in track cycling performance (see Figure 1). The results suggest 200 m track sprint cycling performance declines by 2.8\% and 11.2\% per decade in males and female track cyclists, respectively. The data in figure 1 appears to suggest a linear decline in flying 200 m performance with increasing age in both male and female masters cyclists. Interestingly, cycling times in the 40-44 year category for males and 45-49 year category for females are slightly faster than the male 35-39 year and female 40-44 categories, faster times in these slightly older cohorts may be a result of improved training practices, track-cycling experience or simply, a more athletic group. Taken together, these competition results are in agreement with previous laboratory-based research which reported that in trained cyclists, the decline in anaerobic performance is magnified from 60 years.\textsuperscript{25}

The effect of resistance training on sprint running and sprint cycling performance

In athletes of any age, resistance training programs aim to increase muscular strength, neuromuscular power and sprint performance.\textsuperscript{29} For masters athletes, to minimise the age-related decline in physiological function, muscle morphology, and neuromuscular function, resistance training programs should include hypertrophy, strength and power training components for the following three reasons.\textsuperscript{30} Firstly, muscle force production capacity is proportional to muscle size and hypertrophy resistance training is required to offset the age-related decrease in overall muscle size, strength and power.\textsuperscript{13} Secondly, heavier resistance training is required to stimulate fast twitch muscle fibres and

![Figure 2: Male and female masters flying 200 m track cycling records](image-url)
motor units, necessary for the improvement of rapid force production.\textsuperscript{12} Thirdly, explosive power resistance training exercises and plyometric exercises are required to maximise neuromuscular stimulation and the utilisation of muscle-tendon elasticity.\textsuperscript{11} However, limited research has investigated the effectiveness of resistance training programs in masters athletes. Indeed, no data are currently available on the effect of either resistance training in masters track-cyclists. Nevertheless, it could be hypothesised, that optimal training in middle- and older-aged sprint cyclists, should follow the guidelines of younger athletes and emphasise resistance training along with sport specific sprint cycle training. The aim of the following section is to review the effectiveness of resistance training programs, in improving sprint performance in masters sprint runners, masters endurance cyclists and masters endurance runners.

**Resistance training programs improves sprint performance in masters sprint runners**

To date, only two studies have investigated the effects of resistance training on sprint running performance.\textsuperscript{13,11} Reaburn & Mackinnon (1994)\textsuperscript{13} examined the effect of an eight-week hypertrophy training program on 100 m and 300 m sprint run performance, muscular strength and thigh girth (measured anthropometrically) in eight male sprint-trained runners (54.7 ± 5.5 years). Resistance training took place three times per week under the supervision of an experienced and qualified trainer. The participants performed three sets of 12, 10 then 8 repetitions at 80\% of 1RM with one minute rest between sets. Exercises selected included leg extensions, leg curls, leg press, half squats, bench press, upright row, bicep curl, triceps push down and abdominal crunches. 1RM capacity was measured every two weeks to adjust training loads appropriately. Subjects were instructed to maintain their normal sprint training regime over the period of the study. At the conclusion of the eight-week study, significant improvements were observed in both 100 m (4\%) and 300 m (2\%) sprint running performance, quadriceps peak torque (10.3\%), hamstring peak torque (12\%) and thigh circumference (3.4\%).

More recently, Cristea et al (2008)\textsuperscript{11} investigated the effect of a 20-week combined sprint, strength and power training program on sprint running performance, morphological and neural adaptations in seven sprint-trained masters track athletes (66.0 ± 3.0 years) who had no previous resistance training experience. The resistance strength and power training program was designed to increase explosive power, strength and muscle hypertrophy, while the sprint training was designed to improve acceleration and maximal running speed. Both resistance training and sprint training sessions were performed twice per week on non-consecutive days. The training program was divided into three cycles. The first cycle involved muscular hypertrophy training protocols (3-4 sets, 8-12 repetitions at 50-70\% 1RM). The second and third cycles involved combined plyometric, maximal strength and explosive weight training strength exercises used 4-6 repetitions at 70-85\% 1RM, explosive exercises (high-load speed strength used 2-3 sets of 4-6 repetitions at 35-60\% 1RM), the plyometric exercises (low-load speed strength used 2-3 sets of 3-10 repetitions). Cycle two used similar exercises and repetition ranges as used in cycle one, but with a general increase in intensity through an increase in load and the addition of plyometric and explosive exercises. In cycle 3, reductions in training volume across both sprint running and resistance training exercises occurred to prevent overtraining.

During the first cycle, the sprint runners performed five times 200-250 m runs at 75-85\% of maximum sprint running speed. The field sprint sessions were purposefully designed to develop speed endurance with low volumes to accommodate the resistance training program. To develop acceleration, the athletes performed four times 30 m sprints at 80\% of maximal effort. During the second and third training cycles, sprint intensity was gradually increased until near maximal speeds were reached. Workouts included two to three repetitions of 30-80 m sprints at 90-98\% effort. At the conclusion of the 20-week
training period, significant increases were observed in maximum sprint velocity (4%), ground reaction force in the propulsive phase of contact (8%), 1RM squat strength (27%), squat jump (10%), triple jump (4%) and power of reactive jump test (29%), while 60 m sprint run time was significantly decreased (2%). Significant increases were also noted in the size of fast twitch muscle fibres (20%) and electromyographic activity of leg extensor muscles in squat jump performance (9%).

Examining the effect of resistance training on sprint performance in masters sprinters is limited by very few recent studies, small samples sizes and short intervention periods. Therefore, based on the available literature, these results suggest that resistance training increases muscle mass, fast twitch muscle fibre size and rapid neural activation, thus positively affecting strength, power and sprint performance in masters sprint runners. However, the effects of resistance training on track-cycling performance in masters track-cyclists is not yet known.

**Resistance training programs improve running and cycling performance in masters endurance runners and cyclists**

Limited research has examined resistance training effects in endurance-trained masters runners and cyclists. Previously, Louis et al. (2010) investigated the effect of a 3-week resistance training program on cycling efficiency in nine endurance-trained male masters cyclists (51.5 ± 5.5 years) and eight endurance-trained younger (25.6 ± 5.9 years) cyclists. Before and after the program, participants performed a 15 minute cycling efficiency test that measured the ratio between external power output and energy expenditure. Following the initial testing protocols, participants performed 10 sets of 10 repetitions at approximately 70% of 1RM load three times per week on a pin-loaded knee extension machine with three minutes rest between each set, whilst maintaining their usual endurance training (7 hours per week). Upon completion of the three-week resistance training program, the endurance-trained masters athletes significantly increased both knee extensor maximal voluntary contraction torque (17.8%) and cycling efficiency (3.0%).

Resistance training may also benefit masters endurance runners, by increasing running economy. In their study, Piacentinni et al. (2013) investigated the effects of a 6-week resistance training program on running economy in 16 male and female masters endurance runners. Participants were randomly divided into one of three experimental groups, a maximal strength training group (n=6, 4 male and 2 female, 44.2 ± 3.9 years) who performed 4 sets of 3-4 repetitions at 85-90% of 1RM, two times per week, a resistance training group (n=5, 3 male and 2 female, 44.2 ± 3.9 years) who performed 3 sets of 10 repetitions, at 70% of 1RM, two times per week and a control group (n=5, 5 males, 43.2 ± 7.9 years) who continued with their normal endurance training. Upon completion of the six-week training program, only the maximum strength training group made a significant improvement in running economy at marathon pace (6.1%) and dynamic leg strength (16.3%).

Thus, this limited data suggests resistance training programs may produce positive effects on both running and cycling performance in masters endurance runners and masters endurance cyclists. However, research has not yet examined the effects of resistance training on track-cycling performance in masters track cyclists. Therefore we can only speculate that improvements in track cycling performance may result from additional resistance training, which limits the age-related decline in muscle mass, muscle strength and neuromuscular power.

**CONCLUSION**

The present review suggests the addition of a resistance training program to sprint running, endurance running or endurance cycling, may lead to additional benefits in performance for masters athletes. However, no research to date, has examined the effect of resistance training on track cycling performance in masters track cyclists. Therefore, future research examining the effect of resistance training on track-cycling performance in masters track-cyclists is needed.
PRACTICAL APPLICATIONS

• Resistance training may benefit sprint running performance, endurance running and endurance cycling performance in masters athletes.
• The effect of resistance training on track-cycling performance in masters track-cyclists is currently unknown.
• The volume of sprint training may need to be reduced, in order to accommodate for the inclusion of additional resistance training.
• Resistance training programs that incorporate power development, strength development and hypertrophy are recommended.
• Hypertrophy training may be maximised by prescribing loads of 70% of 1RM for 3 sets x 10 repetitions, 2-3 times per week. Strength training may be maximised by prescribing loads of 85-90% of 1RM for 2-4 sets x 4-6 repetitions, for two-sessions per week and finally power training may be maximised by prescribing loads of 35-60% of 1RM for 2-3 sets x 3-10 repetitions, for two-sessions per week.
• Participation in vigorous physical activity such as organised sport or resistance and sprint training poses greater cardiovascular risks to the masters athlete than lower intensity competitive sports, such as golf, billiards and lawn bowling. Therefore strength and conditioning coaches should be aware of the contraindications to exercise before prescribing a resistance and/or sprint training program for a masters athlete.

REFERENCES:


