Author(s): Del Vecchio, Luke; Stanton, Robert; Reaburn, Peter; Macgregor, Campbell; Meerkin, Jarrod; Villegas, Jerome; Korhonen, Marko

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Effects of Combined Strength and Sprint Training on Lean Mass, Strength, Power and Sprint Performance in Masters Road Cyclists

Luke Del Vecchio[1], Robert Stanton[1], Peter Reaburn[1], Campbell Macgregor[1], Jarrod Meerkin[2], Jerome Villegas[3] and Marko T. Korhonen[4]

[1]School of Medical and Applied Sciences, Central Queensland University, Rockhampton, Australia

[2]Measureup, Sydney, Australia

[3] Sports Performance and Athletic Development Consultant, Canberra, Australia

[4]Gerontology Research Centre, Department of Health Sciences, University of Jyvaskyla, Finland

All Correspondence to:

Luke Del Vecchio

School of Medical and Applied Sciences

Central Queensland University

Building 81/1.16, Bruce Highway

Rockhampton QLD 4700

Australia

Email: l.delvecchio@cqu.edu.au

Telephone Number: +61 0749232427

Abstract

Strength and sprint training exercises are integral part of training in many younger endurance cyclists to improve cycling efficiency and sprinting ability. This study was undertaken to examine whether muscle and performance characteristics could be improved in endurance-trained masters cyclist by adding strength and sprint training stimuli into their training regimen. Twenty five masters road cyclists were assigned to a combined strength and sprint training group (CT; n=9, 53.5 ± 9.3 years), a sprint training group (ST, n=7, 49.4 ± 4.8 years) or a control group (CG, n=9, 56.9 ± 8.6 years). Before and after the 12 week intervention, whole body lean mass (WBLM), total lower limb lean mass (LLLM), countermovement jump height (CMJ), peak isometric torque of quadriceps (QPT) and hamstring (HPT) muscles were examined. For evaluation of sport-specific performance, 10 second sprint cycling peak power (PP10), total 30 second work (TW), peak power output (PPO) and flying 200 meter time trial performance (TT) were assessed. No pre-training differences were observed between CT, ST and CG groups for any of the dependant variables. After training, a significant ($p<0.05$) between group difference was observed in TW between CT and CG groups. A significant effect of time ($p<0.05$) was observed for LLLM in CT and ST groups, and for TT in the CT group. These results suggest including strength and sprint exercises in training can increase lower limb lean mass and sprint performance in endurance trained masters road cyclists. Further research is warranted to find out an ideal pattern of training to maintain aerobic capabilities along with sprint performance in aging road cyclists.

Key Words: Masters Cyclists, Muscle Mass, Combined, Strength Training, Sprint Training

Introduction

Masters athletes are typically older than 35 years of age and systematically train for, and compete in, organized forms of sport (32). Over recent years there has been a significant increase in the number of masters athletes continuing to train and compete at high performance levels within individual and multi-sport (duathlon, triathlon) endurance events designed for masters athletes (38,22). Of the individual events, particularly road cycling is becoming increasingly popular among masters athletes. For example, the number of competitive masters road cyclists in Australia has grown from about 4,000 in 2013 to 10,000 in 2015 (4).

In younger cyclists, maximal strength and hypertrophy exercises (4-10 RM) has been shown to increase cycling efficiency and power output at VO_{2max} (34, 42). There is also evidence that various explosive strength training exercises are used in high-level road cyclists in order to improve sprinting ability that is decisive factor in the finish and breaks in road cycling (30). Although training-induced muscular hypertrophy and strength gains may slightly decrease with age, due to factors such hormonal changes, the adaptive capacity could be maintained up to very old age (20). Only few studies have addressed the effects of strength training on cycling performance in masters endurance cyclists and older individuals (11, 23, 35). For instance, Louis (23) reported an improvement in cycling efficiency, following 3 weeks of hypertrophy training (70% of 1RM) in a group of masters road cyclists. In older non-athletes, strength training (~80% of 1RM) has been shown to improve cycling peak power output (11).

Previous research has shown that an age-related decline in lean mass contributes to the age-related declines in aerobic and anaerobic performance in both untrained older adults (12) and masters athletes (32). Importantly, high-volume endurance training has been shown to lead reduced muscle fiber size, muscle mass and reduced absolute power and force production in both single fiber and whole-muscle level in masters long-distance runners (7, 20, 41). In contrast, strength training has proved to be an effective countermeasure to maintain or increase muscle mass and functional characteristics of masters endurance runners (31) and masters sprint runners (10,33). However, the effectiveness of strength training to increase lean mass in endurance-trained masters cyclists is currently unknown.

Recently, there has been growing interest in the effects of sprint training and it's specific form, high intensity interval training (HIIT) as an alternative modality for increasing physical performance and muscle mass in older adults (3,28). HIIT regimes are characterised by brief repeated intense bursts of activity (e.g. 4-6 x 30s), at maximal intensities. In healthy older men HIIT has been shown to increase lean muscle mass (28). In younger cyclists, HIIT improves cycling performance including sprint performance (9). However, to the best of our knowledge, limited studies to date have investigated the effect of HIIT on cycling performance and lean mass in masters endurance cyclists.

Based on the available studies, it might be suggested that replacing a portion of endurance training with a combination of strength and sprint training, may be beneficial to limit the age-related decline in lean mass, strength, power and sprint performance. In terms of overall cycling performance, sprint and / or strength training is important for a number of reasons. First, increase in muscle strength can improve cycling efficiency. Second, leg power is needed to accelerate rapidly during a breakaway attack and the sprint to the finish typical in road racing. Third, leg strength and power are needed during hill climbing. The purpose of this study was to examine the effect of a 12 week concurrent strength and sprint training program on muscle and performance characteristics in male masters road cyclists. We hypothesised that 12 weeks of concurrent strength and sprint cycling training, would significantly increase lean mass, strength, power and sprint performance in already endurance-trained cyclists

Methods

Experimental approach to the problem

It was hypothesised that concurrent strength and sprint cycling training added to regular endurance cycling training would lead to a significant increase in lean body mass, muscular strength and power, and sprint performance in master road cyclists. A parallel, three-group, intervention (pre-post-test) experimental design was used. To investigate the possible effects of CT on strength, power and sprint performance in master endurance cyclists, Dual Energy X-Ray Absorptiometry (DXA) measures of WBLM, LLLM, CMJ, QPT and HPT were examined. For evaluation of sport-specific performance, PP10, TW, PPO and TT were measured before and after a 12 week intervention period. All subjects performed familiarization trials before the testing days. We used as the independent variable, the group, whereas the dependent variables were WBLM, LLLM, CMJ, QPT, HPT, PP10, TW, PPO and TT.

Participants

The study was approved by the Central Queensland University Human Research Ethics Committee. Twenty-five healthy male masters cyclists aged between 41 and 76 years with no background of strength training were recruited and provided written informed consent. The subjects were required to be involved in regular cycling training and/or road cycling competition for a minimum of two years and to be achieving a minimum of eight hours of endurance cycling training per week. All subjects underwent pre-exercise screening to ensure they had no established cardiovascular, metabolic or respiratory disease nor signs or symptoms of disease (29).

Random allocation of participants into training groups was not possible as the majority of participants had both work and family commitments that limited their availability to participate in the ST or CT programs. As a result, subjects were allocated to either a control group (CG, n=10), sprint cycling group (ST, n=7) or concurrent strength and sprint cycling training group (CT, n=10). For personal reasons, one participant from the CT group and one subject from the CG group withdrew from the study, subsequently reducing the CT group to nine participants (CT, n=9) and the control group to nine participants (CG, n=9). Subjects were instructed not to change their diet or lifestyle over the experimental period. The physical characteristics of each group are shown in Table 1.

Table 1 about here.

Procedures

Subjects attended the laboratory (22ºC, 60% RH) following an overnight fast and did not consume caffeine the morning of the test. All tests were carried out between 0700 and 0900 hours. Pre- and post-intervention testing included measures of anthropometry, DXA, jumping performance on force-plate, peak isometric torque of quadriceps and hamstring muscle groups, ten second sprint cycling peak power, total 30 second work and maximal aerobic power on a cycle ergometer. The flying 200 meter time trial performance test was performed at a local, outdoor cycling velodrome. Twenty-five masters road cyclists, engaged in the same endurance training program were assigned to one of the following three groups: concurrent strength and sprint cycling training group (CT), sprint cycling training group (ST) and a control group (CG). The CT group replaced four (50%) of their usual endurance cycling sessions (table 3) with two strength training sessions and two sprint training sessions, the ST group replaced two of their usual endurance cycling sessions with two sprint training sessions; and the CG group maintained their normal endurance training.

1. Body composition

Stature (m) and body mass (kg) were measured with a stadiometer and medical scales (Seca, Birmingham, UK) with participant's unshod and wearing cycling apparel. Dual Energy X-

Ray Absorptiometry (DXA) (Hologic Discovery-W, Bedford, MA.) was used to measure WBLM and LLLM. A Certified Clinical Densitometrist (CM) performed all DXA data collection and analysis procedures. Prior to each measurement session an automatic calibration procedure was performed to assess and maintain the measurement precision and accuracy of the DXA. During the procedure, subjects lay motionless in a supine position on a table for eight minutes, while an X-ray fan array passed above the table. WBLM and LLLM were determined using manufacturer-supplied software (APEX version 4.0, Hologic Discovery).

2. Warm up

Following the DXA scan, and prior to all performance measures, a 15-minute warm up consisting of 5 minutes of cycling at 50 watts on a cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, WA, USA). Followed by 10 body weight squats, 10 heel raises, 10 countermovement jumps (CMJ). All were undertaken at moderate intensity. Participants then completed each of the following performance measures.

3. Muscular power

Muscular power was assessed using a CMJ test. CMJ trials were performed three times on an AMTI force plate (Advanced Medical Technology Inc., Watertown, USA). The analogue signal sampled at 1000Hz was converted to a digital signal using a Powerlab 30 series data acquisition system (AD Instruments, Sydney, Australia), and data were collected using custom-written LabView software Version 2011 (National Instruments, Texas, USA). The vertical force-time data were filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 17 Hz. Participants were instructed to perform a fast downward movement (to 90º knee flexion) immediately followed by a fast upward movement, and to jump as high as possible. Hands were kept on the hips to minimize any influence of the arm swing. Each trial was followed by 2 minutes of passive rest, and the mean of three jumps (cm) was used for further analysis.

4. Muscular strength

Quadriceps and hamstring peak isometric torque (QPT and HPT) of the dominant leg was measured using a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA). Subjects performed three x 10-second maximal isometric knee extensions (QPT) and three 10-second maximal isometric knee flexions with strong verbal encouragement. The effort with the highest peak torque ($Nm \cdot kg^{-1}$) was used for subsequent data analysis (24).

5. Anaerobic performance

Sprint cycling performance was measured using 10 and 30 second sprint tests on a Velotron ergocycle (Racermate, Seattle, USA) with a 5-minute passive rest period between tests. Following familiarisation of the protocol and a warm-up consisting of pedalling at a self-selected cadence at a set resistance of 50 W for five minutes interspersed with three practice maximal accelerations over 2-3 seconds, the resistance of the ergocycle was adjusted at 75 $g \cdot kg^{-1}$ of body mass (39). Peak power ($W \cdot kg^{-1}$) in the 10-second test and total 30 second work ($kJ \cdot kg^{-1}$) was used for subsequent data analysis.

7. Peak power output

A graded maximal exercise test to measure peak power output (PPO) was completed on an electrically-braked, computer controlled cycle ergometer (Velotron Dynafit Pro, RaceMate, Seattle, USA). Gas analysis was undertaken using a Fitmate Pro (Cosmed, Rome, Italy) following a 5-minute warm-up at 30 W cycling and a pedalling cadence of 90 rpm throughout the test. The work increments for each 1-minute stage were 15 W. The test ceased when two or more criteria for attainment of VO_{2peak} were achieved. These criteria included no significant increase in O_2 uptake with an increase in work rate, attainment of the age-predicted maximum heart rate, and/or volitional exhaustion (36). Peak power output (PPO) was calculated from the last completed work rate, plus the fraction of time spent in the final non-completed work rate multiplied by 25 watts (16).

8. Flying 200 meter time sprint time

Forty-eight hours after the laboratory tests, flying 200 meter sprint time was assessed at a local concrete and banked (31 degrees), 333 meter cycling velodrome with participants using their own road bikes to perform a total of three flying 200 meter attempts. Following a ten lap warm up, participants then performed two familiarisation attempts of the flying 200 meter time trial before ten minutes of passive seated rest. The flying 200 meter time trial commenced by each participant cycling around the velodrome two times in attempt to build up speed, and on the third lap, participants were instructed to come down the bank of the velodrome at maximal speed when crossing the starting line. Flying 200 meter sprint time was recorded by three, experienced observers using hand-held stopwatches (Hart sports timer 898, Hart Sport, Aspley, Australia). Observers were instructed to start the stopwatches when the participant crossed the start line with the front end of the front wheel and stop the stopwatches when the participant crossed the finish line with the front wheel. The mean of three trails was recorded for subsequent analysis.

Sprint cycling training Program

The sprint cycling training program was designed in consultation with an accredited track cycling coach and supervised by the same coach for each of the twice weekly sessions. Both CT and ST groups performed two 60-90 minute sprint cycling training sessions per week, separated by 48 hours. Sprint cycling sessions consisted of a five to ten minute warm-up (10-15 x 333 meter laps at a self-selected pace) after which subjects performed 1-3 sets x 1-3 repetitions of maximal effort sprints ranging in distance from 65 meters to 333 meters with 2-3 mins of active then passive recovery between repetitions and 10 minutes passive rest between sets. At the completion of the track training session, subjects performed a five to ten minute cool down (10-15 laps of the velodrome at a self-selected pace). Using an undulating periodization program; participants commenced the track program using a 92 inch gear and throughout the 12-week period, progressed to a 104 inch gear (table 2). As a result, the ST group reduced their usual weekly endurance cycling training by three hours per week. The overall training adherence rate calculated as a percentage of the total sprint cycling training sessions successfully completed was 82 ± 5.1% for ST group across the 12-week study period.

Table 2 about here

Table 3 about here

Strength training program

The CT group replaced four of their usual weekly endurance cycling training sessions with two evening group track sprint-cycling training sessions as described above, and two morning group gym-based strength training sessions per week. As a result the CT group reduced their usual weekly endurance cycling training by six hours per week. Participants were advised to perform two 60 minute recovery rides (50-70% MHR, 90-110rpm) and not undertake other cycling training sessions throughout the training week to avoid overtraining and excessive fatigue. All four training sessions were supervised by an accredited strength and conditioning coach. Strength training sessions were conducted on alternate days to the track sprint training days. The strength training program and relative volumes of the different modes of strength during the course of the study are summarized in Table 4. During each training session, subjects performed the following exercises in order [1] Plyometric and explosive strength exercises: double leg vertical and horizontal hops or jumps, single leg alternating box jumps, leg press throws. [2] Strength training exercises: single-leg leg presses, seated hip flexions.

[3] Hypertrophy exercises: leg curls, leg extensions, seated calf-raises, supine hip extensions, chest press, bench rows, abdominal curl ups and lower back extensions. Recovery time of two minutes between sets and exercises was strictly controlled, and each strength training session lasted approximately 90 minutes. The strength training program incorporated an undulating periodization approach, to reduce the potential for overtraining and to optimise adaptation. Subjects completed electronic training logs (Accelaware, Sports Performance Systems, Brisbane, Australia) describing all their training parameters (number of repetitions, sets, loads, distances, track sprint cycling times) to monitor progress and to provide motivation for maximal effort during the training program. The overall strength training adherence rate, calculated as a percentage of training sessions successfully completed, was 85 ± 3.8% for CT group across the 12-week study period.

Table 4 about here

Control group

The CON group were asked to maintain eight-hours per week, of their current endurance cycling training program (table 3). In comparison to the CON group, the CT undertook two hours per week of endurance training for 12-weeks, whilst the ST group undertook five hours per week of endurance training for 12-weeks (table 5).

Table 5 about here

Data analysis

The training related effects were measured using a three (group) x two (time) repeated measures analysis of variance (ANOVA). If a main effect was observed, a Tukey post-hoc test was undertaken to identify the source of the differences. A p value of <0.05 was considered statistically significant. Twenty-three of the twenty-four dependant variables were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), although one variable did not meet the assumption of normality (Post_PP10; $p = 0.033$). For this variable, data were log transformed and the equivalent non-parametric statistic used. This did not change the outcome for this variable, and thus for ease of interpretation, we report findings from parametric statistics only. Cohen's conventions for effect size (ES) were used for interpretation for no effect (ES<0.2), small effect (0.2-0.49), moderate effect (0.5-0.79), and large effect (>0.8) (5). SPSS Version 20 (IBM, Corp, New York) software was used for all statistical analyses.

Results

Pre and post-test values for each dependant variable for each of the intervention groups are shown in Table 6. No pre-training differences were observed between CT group, ST group and the CG group for any of the dependant variables.

Lean mass

No changes in WBLM occurred during the intervention in all groups ($F(2, 22) = 2.4$, $p = 0.11$) (Table 6). There were no significant between group effects for LLLM ($F(2,22) = 2.7$, $p = 0.89$). However there was a significant effect of time ($F(1, 22) = 10.61$, $p = 0.04$). LLLM increased in CT group ($p = 0.01$, 4.5%, ES = 0.35), and in the ST group ($p = 0.03$, 3.5%, ES = 0.45).

Muscular power

No changes in CMJ occurred during the intervention in all groups ($F(1, 24) = 0.48$, $p = 0.69$). (table 6).

Muscular strength

No changes in either QPT or HPT occurred during the intervention in all groups. ($F(2, 22) = 2.61$, $p = 0.96$); ($F(2, 22) = 2.32$, $p = 0.14$) (table 6).

Sprint cycling performance

A significant group x time interaction was observed for PP10 ($F(2, 22) = 3.50$, $p = 0.48$), however subsequent post hoc analysis revealed no differences between groups (table 6). A significant group x time interaction was also observed for TW ($F(2, 22) = 5.59$, $p = 0.01$, 6.9%, ES = -0.59), subsequent a Tukey post hoc analysis revealed a difference in TW between ST and CG groups ($p = 0.02$).

Peak power output

No changes in PPO occurred during the intervention in all groups ($F(2, 22) = 1.61$, $p = 0.22$) (table 6).

Flying 200 meter sprint time trial

A significant group x time interaction was observed for TT (F, (2, 22) = 11.70, $p = 0.00$) however subsequent post hoc analysis revealed no differences between groups. There was also a significant effect of time ($F(1, 22) = 7.21$, $p = 0.01$). TT decreased in the CT group ($p < 0.01$, -7.7%, ES = 0.85). In the CON group, TT increased ($p = 0.07$, -8.8%, ES = 0.85).

Table 6 about here

Discussion

The success in many endurance events such as road cycling and running could be dependent not only good aerobic capabilities but also muscle characteristics and related sprint performance. The purpose of this study was to examine whether lean mass, strength, power and sprint performance could be in improved by short term concurrent training in a group of masters road cyclists who had no previous experience in strength and sprint training. The major finding was that 12 weeks of concurrent strength and sprint training increased LLLM and improved TT performance in masters road cyclists.

There are very few training studies on aging athletes and we are not aware of any previous interventions on road cyclists. Our findings of training induced change in LLLM are in agreement with previous research, which has reported increases in muscle mass or fibre area in response to concurrent strength training in masters sprint and endurance runners (10,31,33). For example, Piacentini et al. (31) reported a non-significant 2% increase in lean mass in a group (n=6, 44.2 ± 3.9 years) of male and female masters endurance runners following six weeks of concurrent endurance running and strength training. However the duration of the latter study (six weeks), may not have been long enough to observe significant changes in lean mass, as it is generally understood that muscle hypertrophy requires greater than eight weeks of strength training (37). The ST group in the current study demonstrated a 3.5% increase in LLLM which is surprisingly higher than the increases in lean mass reported in younger cohorts who have undergone sprint interval training programs lasting between eight weeks to eight months (18,27). These differences may be explained by the use of heavy gearing in the present study with the ST gearing progressively increased over the 12 week training program, thus providing a form of progressive overload that may have stimulated an increase LLLM. Taken together, the results of the current study suggest ST positively affects lean mass in masters cyclists. These findings support the use of ST as an alternative exercise intervention to increase lower limb lean mass in masters road cyclists.

In the present study, CMJ did not significantly increase following 12 weeks of CT. These results are in contrast to the findings of Cristea et al. (10) who reported a significant improvement in squat jump height in a group of male masters sprint runners (n=7, 71.0 ± 5.0 years) who completed a 20 week progressive strength training program. However, the previous researchers used a squat jump test which does not utilize the stretch-shortening cycle, making a true comparison of the present results difficult. In contrast, the lack of a significant increase in CMJ following 12 weeks of concurrent resistance and sprint training observed in the current study are in agreement with the findings of Piacentini et al. (29) who reported six weeks of concurrent endurance running and strength training did not significantly improve CMJ in a group (n=6, 44.2 ± 3.9 years) of male and female masters endurance runners. Despite not reaching significance, the participants in the Piacentini et al. (29) study improved countermovement jump height by 3.2% which is similar to the 2.7% increase in CMJ observed in the CT group. A lack of a significant improvement in CMJ in the current study, may also be attributed to a possible interference effect known to affect explosive strength when strength training is combined with endurance training (14). Despite reducing their endurance training volume, the CT group still performed more than two scheduled endurance sessions a week throughout the whole study period. Taken together, these results suggest 12 weeks of CT or ST may not significantly improve muscular power in masters road cyclists.

In the present study 12 weeks of CT did not significantly improve QPT or HPT in the CT group. Age-related declines in muscular strength is commonly associated with the age-related loss of lean mass observed in masters runners, swimmers and cyclists (1). These age-related declines in muscular strength and muscle mass may contribute to the observed reduction in cycling performance with age. It has been shown that strength improvements are lower when endurance training is combined with a strength training program (17) as a result of conflicting cellular stimuli (26). In the current study, participants in the CT group performed more than the prescribed limit of endurance cycling training sessions throughout the 12 week CT program, which could explain why no changes were observed in QPT and HPT observed in the CT group. Similarly, 12 weeks of ST did not significantly improve QPT or HPT. To the best of our knowledge, no studies to date, have investigated the effects of ST on muscle strength in masters cyclists. However, in younger cohorts, repeat sprint training has been shown to increase lower limb strength (8, 15). For example, Harridge et al. (15) reported a significant increase in maximal isometric knee extensor torque (7%) following six weeks of sprint cycling training, performed four times per week, in a group of recreationally active, younger males (n=7, 22 ± 2 years). Taken as a whole, the results of the present study showed 12 weeks of CT or ST does not significantly increase knee flexion or knee extension strength in masters road cyclists.

The ability to generate brief, high powered outputs is an important component of competitive cycling performance (2). In the present study 12 weeks of CT did not significantly increase PP10 or TW in the CT group. No research to date, has investigated the effects of CT on PP10 or TW in healthy older adults or masters cyclists. However, in a cross sectional analysis of highly trained masters cyclists (n= 173, 35-64 years). Gent and Norton (13) reported PP10 and TW declined by 8.1% and 8.0% per decade. In contrast, 12 weeks of ST did not significantly improve PP10 or TW in the ST group. These results are in contrast to similar studies in younger cohorts (9), which have reported significant improvements in TW. For example Creer et al. (9) reported 4 weeks of sprint cycling training, performed two times per week, significantly increased total 30 second work (6.0%) as measured by cycle ergometry, in a group of younger, trained cyclists (n=10, 25.1 ± 2.3 years). The lack of improvement in PP10 & TW in the CT group may be a consequence of insufficient recovery between exercise training and testing. In particular, subjects in all groups continued their endurance training at the completion of the 12 week program up until the date of testing. Future research is warranted to better understand the effect of CT and ST on anaerobic performance in masters road cyclists.

In the current study, PPO was unaffected by 12 weeks of either CT or ST. To date, the effects of CT or ST on PPO in masters cyclists is unknown. However, the use of strength training to improve endurance cycling performance in healthy, younger and older adults is well supported (6, 19, 25, 34, 42). For example Loveless et al. (25) reported 8 weeks of maximal leg-strength training significantly improved cycling peak aerobic power, in a group of healthy, younger males (n=7, 25.0 ± 2.0 years). Additionally, Izquierdo et al. (19) reported 16 weeks of progressive strength-training significantly increased cycling peak aerobic power in a group of healthy, older males (n=11, 64-74 years). In the present study the ST group did not significantly improve PPO. These results are in contrast to the findings from studies in younger cyclists, which have reported significant increases in PPO following sprint cycling training (21, 39). For example, Laursen et al. (21) reported a significant improvement in peak aerobic power following two weeks of sprint cycling training in a group of trained, younger cyclists (n=14, 23.5 ± 3.5 years). Unsurprisingly, the current study observed no significant change in PPO following the 12 week training period. These results suggest, reducing cycling endurance training volume and replacing it with either CT or ST, does not negatively affect a primary marker of endurance performance in masters road cyclists.

In the present study 12 weeks of CT significantly improved TT (8.1%) in the CT group. Typical for road cycling competition is that a large group of riders are often together until the end of the race and the ability to sprint to the finish line determines the place in the race. Thus, sprinting speed is of particular importance to cycling performance. To date, no studies have investigated the effects of CT on sprint cycling TT performance in masters cyclists. However, studies investigating the effects of concurrent strength and sprint running training have reported favourable effects on sprint running performance (10,33). For example, Cristea et al. (10) reported a significant improvement in 60 meter sprint running time (2%) following 20 weeks of progressive strength training program performed 4 times per week in a group of male masters sprint runners. In addition, Reaburn et al. (33) reported a significant improvement in 100 meter (4%) and 300 meter (2%) sprint running time following eight weeks of concurrent strength and sprint running training performed four times per week. Surprisingly, 12 weeks of ST did not significantly improve TT performance in the ST group.

The lack of improvement in TT performance in the ST group, could be attributed to a small sample size or inadequate recovery. Training logs show, several participants in the ST group did not reduce their endurance training volume, on the days leading into the final TT. Finally, in the present study there was no between group differences in TT performance amid the CT group and ST groups, suggesting that the addition of strength training to a ST program may not provide additional benefits to sprint cycling performance. Taken together, these results suggest 12 weeks of CT significantly improves TT performance, which can benefit the masters road cyclists by improving sprint speed to the finish line.

We acknowledge several limitations to the current study. Firstly, improvements observed in sprint cycling performance in the CT may have resulted from a placebo effect. For example, the ST group undertook two modified ST sessions per week, in comparison, the CT undertook four modified CT sessions per week, which may have doubled the placebo effect. Secondly, the CT had greater adherence to the sprint training sessions when compared to the ST group, which may further explain the larger improvements in sprint performance observed in the CT group and ST groups. Future studies should match total sprint and strength training volumes. Thirdly, the specialised population of this group, limited the statistical power of this study. Finally, it should also be acknowledged that sprints performed during a competitive road-cycling event often occur in a fatigued state, whereas in the present study, sprinting time trials were performed in non-fatigued state, further limiting the applications of these findings.

Practical Applications

Previous research suggests masters cyclists face an age-related decline in lean mass, muscular strength and power, and sprinting performance. These declines may contribute to the age-related decline in competitive cycling performance, particularly the ability to accelerate rapidly or sprint to the finish line during a race. The results of the present study suggest that

12 weeks of CT significantly improves lower body lean mass and sprint cycling time trial performance. In the ST group, 12 weeks of ST significantly improved lower body lean mass only. Based on these findings, improvements in sprint-cycling performance in masters endurance cyclists can be made by undertaking 12-weeks of CT during the general preparation phase of training. Thereafter, the effects of CT could be maintained by performing one strength session and one sprint training session per week throughout the late preparation and competitive periods. Moreover, performing sprint training at a cycling velodrome, including the use of banking, can be used to develop speed, acceleration and maximum velocity. Finally, the use of progressively heavier gearing ratios can enhance cycling specific strength development. However, a more definitive study over several months should be undertaken to clarify the optimal trimming and amount of CT, particularly how the replacement of a portion of endurance training impacts road cycling performance. Finally, it should also be emphasized that this study provides only initial findings about the good adaptive capacity and training specificity in masters cyclists. In future it is essential to obtain knowledge of potential negative effects of combined training with decreased aerobic training on overall competitive cycling performance as a base for planning optimal training for masters cyclists.

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Table 1: Physical and training characteristics of participants.

	CT (n=9)	ST (n=7)	CG (n=9)
Age (years)	53.5 ± 9.3	49.4 ± 4.8	56.9 ± 8.6
Stature (m)	1.80 ± 0.08	1.80 ± 0.10	1.75 ± 0.10
Body mass (kg)	81.9 ± 6.1	78.5 ± 6.1	83.5 ± 10.0
Training hours (hr/week)	8.2 ± 1.0	8.1 ± 1.3	8.0 ± 1.2

CT = combined strength and sprint group; ST = sprint training group; CG = control group; data are Mean ± SD.

Table 2 Flying 200-m Track Cycling Program

	Session 1	Session 2
Weeks 1-4	Warm up: • 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@80% of max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 3 x 65m @ G92 standing start. 1 x 100m seated from 20kph Set 2: • 3 x 65m @ G94 standing start. 3 minutes active recovery between repetitions	Warm up: • 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@80% of max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 1 x Flying 100m @ G94 • 1 x Flying 100m @ G96 • 1 x Flying 100m @G 98 Set 2:

	• 1 x 200m seated from 20kph Set 3: 3 x 65m @ G96 standing start. • 1 x 333m seated from 30kph Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers	• 1x flying 33m @G98 • 1x flying 33m @G100 Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers
Weeks 5-8	Warm up: • 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@ 90% max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 3 x 65m @ G96 standing start. • 1 x 100m seated from 20kph Set 2: • 3 x 65m @ G98 standing start.	Warm up: • 15 minute easy rolling laps (low gear) with gradual windup from 30km/h up to 40km/h Conditioning phase (@ 90% max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 1 x Flying 100m @ G98 • 1 x Flying 100m @ G100 • 1 x Flying 100m @ G102 Set 2:

	• 1 x 200m seated from 20kph Set 3: 3 x 65m @ G100 standing start. • 1 x 333m seated from 30kph Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers	• 1x flying 33m @ G102 • 1x flying 33m @ G104 Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers
Weeks 9-12	Warm up: • Rollers 10 minutes, including several short sprints Conditioning phase (@90-98% max speed): • 3-5 minutes active recovery between reps • 15 minutes passive recovery between sets Set 1: • 3 x 65m @ G98 standing start. • 1 x 100m seated from 20kph Set 2: • 3 x 65m @ G96 standing start. • 1 x 200m seated from 20kph Set 3: 3 x 65m @ G194 standing start.	Warm up: • Rollers 10 minutes, including several short sprints Conditioning phase (@90-98% max speed): Set 1: • 1 x Flying 100m @ G100 • 1 x Flying 100m @ G98 • 1 x Flying 100m @ G96 Cool-down: • 10-15 laps at a very low intensity or 5-10 minutes on rollers

- 1 x 333m seated from 30kph

Cool-down:

- 10-15 laps at a very low intensity or 5-10 minutes on rollers

G= gear ratio; K1= started gate sprints; fly-session = all sprints completed from a flying-start

Table 3: Endurance Training Program

Day	Training Session Description
Monday	Recovery ride– 60 minutes @ 60% of HRmax
Tuesday	Endurance ride 90-180 minutes @ 60-70% of HRmax
Wednesday	Tempo ride – 60-90 minutes (3 x 15 minute efforts @ 85% of HRmax incorporated into the ride)
Thursday	Recovery ride 60 minutes @ 60% of HRmax
Friday	Cross training (swim, spin bike, cross-trainer) 45-60 minutes @ 60-70% of HRmax
Saturday	Group ride 60-90 minutes @ 75-85% HRmax; practise skills such as drafting
Sunday	Rest day

HRmax = age predicted maximal heart rate.

Table 4 strength training program

Day 1	Hypertrophy Phase				Day 2	Hypertrophy Phase			
Weeks	1	2	3	4	**Weeks**	1	2	3	4
Warm up	5 minutes stationary bike				**Warm up**	5 minutes stationary bike			
Plyometric Exercises					**Plyometric Exercises**				
ankle hops	2 x 8	2 x 10	2 x 12	2 x 10	ankle hops	2 x 8	2 x 10	2 x 12	2 x 10
side to side ankle hops	2 x 8	2 x 10	2 x 12	2 x 10	side to side ankle hops	2 x 8	2 x 10	2 x 12	2 x 10
standing jump & reach	2 x 8	2 x 10	2 x 12	2 x 10	standing jump & reach	2 x 8	2 x 10	2 x 12	2 x 10
Strength Exercises					**Strength Exercises**				
Leg Press	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12	Leg Press	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12
Seated Hip Flexion	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12	Seated Hip Flexion	50% 2 x 12	60% 2 x 10	65% 2 x 10	60% 2 x 12
Hypertrophy Exercises					**Hypertrophy Exercises**				
Leg Curls	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4	Leg Curls	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Leg Ext	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4	Leg Ext	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
seated Calve Raise	40% 12 x 4	50% 12 x 6	55% 12 x 4	45% 12 x 4	Calve Raise standing	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4
Chest Press *	40% 12 x 4	50% 12 x 7	55% 12 x 4	45% 12 x 4	Shoulder Press	40% 12 x 4	50% 12 x 4	55% 12 x 4	45% 12 x 4

Trunk Stability					**Trunk Stability**				
plank	2 x 20secs	2 x3 0secs	1 x 60	3 x 30secs	plank	2 x 20secs	2 x3 0secs	1 x 60	3 x 30secs
prone back extensions	2 x 10	2 x 12	2 x 15	3 x 12	prone back extensions	2 x 10	2 x 12	2 x 15	3 x 12
Recovery and Cool Down					**Recovery and Cool Down**				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	3 - 5 mins foam-rolling over all major muscle groups				Foam Roller	3 - 5 mins foam-rolling over all major muscle groups			

Day 1	**Strength Phase**			
Weeks	5	6	7	8
Warm up	5 minutes stationary bike			
Plyometric Exercises				
Front Box Jump	2 x 10	2 x 12	2 x 15	2 x 12
jump from box	2 x 10	2 x 12	2 x 15	2 x 12
lateral box jump	1 x 5	2 x 6	2 x 8	2 x 6
Explosive Strength Exercises				
single leg press throw	20% 2x5	30% 2x5	40% 2x5	30% 3x5
Strength Exercises				
Single Leg, Leg Press	70% 3 x 8	75% 3 x 8	80% 3 x 6	75% 3 x 8
Seated Hip Flexion	70% 3 x 8	75% 3 x 8	80% 3 x 6	75% 3 x 8
Hypertrophy Exercises				
Leg Extensions	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3
Leg Ext	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3
Calve Raise	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3

Day 2	**Strength Phase**			
Weeks	5	6	7	8
Warm up	5 minutes stationary bike			
Plyometric Exercises				
Front Box Jump	2 x 10	2 x 12	2 x 15	2 x 12
jump from box	2 x 10	2 x 12	2 x 15	2 x 12
lateral box jump	1 x 5	2 x 6	2 x 8	2 x 6
Strength Exercises				
single leg press throw	20% 2x5	30% 2x5	40% 2x5	30% 3x5
Strength Exercises				
Single Leg, Leg Press	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8
Seated Hip Flexion	70% 3 x 8	75% 3 x 8	80% 3x6	75% 3 x 8
Hypertrophy Exercises				
Leg Extension	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Leg Curls	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Calve Raise standing	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3

Chest Press	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Chest Press	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Prone row	50% 12 x 3	60% 10 x 3	65% 10 x 3	55% 12 x 3	Prone Row	50% 12 x 3	60% 10 x 3	60% 10 x 3	55% 12 x 3
Trunk Stability					**Trunk Stability**				
Abdominal Curl up	2 x 10	2 x 12	2 x 15	3 x 12	Abdominal Curl up	2 x 10	2 x 12	2 x 15	3 x 12
bird dog	2 x 10	2 x 12	2 x 15	3 x 12	bird dog	2 x 10	2 x 12	2 x 15	3 x 12
Recovery and Cool Down					**Recovery and Cool Down**				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	3 - 5 mins foam-rolling over all major muscle groups				Foam Roller	3 - 5 mins foam-rolling over all major muscle groups			

Day 1	Power Phase				Day 2	Power Phase			
Weeks	9	10	11	12	**Weeks**	9	10	11	12
Warm up	5 minutes stationary bike				**Warm up**	5 minutes stationary bike			
Plyometric Exercises					**Plyometric Exercises**				
alternating step push offs	1 x 10	1 x 15	1 x 20	2 x 15	alternating step push offs	1x10	1x15	1x20	2x15
single leg box push offs	1 x 10	1 x 15	1 x 20	2 x 15	single leg box push offs	1x10	1x15	1x20	2x15
squat depth jumps	2 x 10	2 x 15	2 x 20	2 x 15	squat depth jumps	2x10	2x15	2x20	2x15
Explosive Strength Exercises					**Strength Exercises**				
single leg press throw	45% 3x5	50% 3x5	60% 3x5	55% 3x5	single leg press throw	45% 3x5	50% 3x5	60% 3x5	55% 3x5
Strength Exercises					**Strength Exercises**				
SL Leg Press	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3	SL Leg Press	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3
Seated Hip Flexion	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3	Seated Hip Flexion	85%, 3 x 5	90%, 3x3	95% 3x2	90% 4x3
Hypertrophy Exercises					**Hypertrophy Exercises**				
Leg Curls	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Leg Curl	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Leg Ext	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Leg Ext	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
seated Calve Raise	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Calve Raise standing	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Chest Press	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Chest Press	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2

Prone row	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2	Prone row	60% 12 x 2	70% 10 x 2	75% 10 x 2	70% 12 x 2
Trunk Stability					**Trunk Stability**				
Advanced Curl up	2 x 10	2 x 12	2 x 15	3 x 12	Advanced Curl up	2 x 10	2 x 12	2 x 15	3 x 12
back extension bench	2 x 10	2 x 12	2 x 15	3 x 12	back extension bench	2 x 10	2 x 12	2 x 15	3 x 12
Recovery and Cool Down					**Recovery and Cool Down**				
Static Stretching	2-3 x 30 second holds all muscle groups				Static Stretching	2-3 x 30 second holds all muscle groups			
Foam Roller	3 - 5 mins foam-rolling over all major muscle groups				Foam Roller	3 - 5 mins foam-rolling over all major muscle groups			

Table 5. Training volume over the 12 week intervention

Training Modality	CT Group	ST Group	CON Group
Sprint training (hrs/wk)	3.0 ± 0.5	3.0 ± 0.5	0.0
Strength training (hrs/wk)	3.0 ± 0.5	0.0	0.0
Endurance training (hrs/wk)	2.0 ± 0.3	5.0 ± 0.3	8.2 ± 1.0
Total weekly training(hrs/wk)	8.0 ± 1.3	8.0 ± 0.8	8.2 ± 1.0

Table 6: Changes in lean mass, laboratory measures and 200m sprint cycle performance following 12 weeks of CT or ST

	CT		Effect Size	ST		Effect Size	CG		Effect Size	P Values	
	Pre	Post		Pre	Post		Pre	Post		Between-Group	Time
WBLM (kg)	61.8 ± 5.2	63.1 ± 5.4	0.26 Small effect	61.4 ± 4.7	61.6 ± 5.1	0.16 No effect	61.5. ± 5.5	60.6 ± 6.2	-0.15 No effect	0.113	0.441
LLLM (kg)	17.6 ± 1.9	18.4 ± 2.3†	0.35 Small effect	17.0 ± 1.5	17.6 ± 1.4†	0.45 Small effect	16.0 ± 2.0	16.0 ± 1.9	0.00 No effect	0.089	0.004
CMJ (cm)	24.4 ± 3.8	24.9 ± 4.4	0.12 No effect	25.1 ± 12.0	22.7 ± 24.3	-0.12 No effect	23.9 ± 7.0	21.7. ± 6.3	-0.33 Small effect	0.698	0.495

QPT (Nm·kg^{-1})	2.8 ± 0.5	3.0 ± 0.4	0.47 Small effect	3.1 ± 0.4	2.9 ± 0.4	-0.50 Small effect	2.6 ± 0.6	2.4 ± 0.8	-0.28 Small effect	0.096	0.813
HPT (Nm·kg^{-1})	1.0 ± 0.2	1.1 ± 0.2	0.32 Small effect	1.0 ± 0.2	1.1 ± 0.1	0.53 Moderate effect	1.0 ± 0.1	0.9 ± 0.3	-0.44 Small effect	0.149	0.122
PP10 (W·kg)	11.3 ± 1.8	11.5 ± 1.9	0.10 No effect	11.6 ± 1.2	12.0 ± 1.1	0.38 Small effect	10.5 ± 1.2	9.8 ± 1.9	-0.44 Small effect	0.048	0.780
TW (J·kg)	247.4 ± 35.0	255.1 ± 35.8	0.22 Small effect	256.0 ± 28.5	262.4 ± 19.2*	0.26 Small effect	227.5 ± 20.8	211.8 ± 30.9†	-0.59 Moderate effect	0.011	0.896
PPO (watts)	341.6 ± 62.6	338.8 ± 60.0	0.04 No effect	362.5 ± 37.7	378.1 ± 48.9	0.35 Small effect	316.6 ± 54.4	308.3 ± 59.9	-0.14 No effect	0.222	0.881
TT (sec)	16.0 ± 1.9	14.7 ± 1.3†	0.85 Large effect	14.7 ± 1.1	14.2 ± 0.6	0.61 Moderate effect	15.4 ± 1.0	15.9 ± 1.2	-0.45 Small effect	0.000	0.014

CT = combined strength and sprint group; ST = sprint training group; CG = control group; effect size = between group effect size. * = Between-group difference estimated by ANOVA: Tukey post-hoc test ($P < 0.05$); † = Significant effect of time ($p < 0.05$); WBLM = whole body Lean mass; LLLM = total lower limb lean mass; CMJ = counter movement jump height; QPT = quadriceps peak isometric torque; HPT = hamstring peak isometric torque; PP10 = ten second sprint peak power; TW = total 30 second work; TT = flying 200 meter sprint time; PPO = peak power output in incremental cycle ergometer test.