

Can Aerobic Training Improve Muscle Strength and Power in Older Men?

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This study examined the effect of aerobic training on leg strength, power, and muscle mass in previously sedentary, healthy older men (70–80 yr). Training consisted of 30–45 min of cycle ergometry at 50–70% maximal oxygen consumption ($\text{VO}_{2\text{max}}$), 3 times weekly for 16 wk, then 4 wk detraining, or assignment to a nontraining control group ($n = 12$ both groups). Training increased leg strength, leg power, upper leg muscle mass, and $\text{VO}_{2\text{max}}$ above pretraining values (21%, 12%, 4%, and 15%, respectively; $p < .05$). However, all gains were lost after detraining, except for some gain in $\text{VO}_{2\text{max}}$. This suggests that cycle ergometry is sufficient stimulus to improve neuromuscular function in older men, but gains are quickly lost with detraining. For the older population cycle ergometry provides the means to not only increase aerobic fitness but also increase leg strength and power and upper leg muscle mass. However, during periods of inactivity neuromuscular gains are quickly lost.

Keywords: lean mass, detraining, neuromuscular function, cardiovascular fitness

Aging is associated with significant reductions in muscle strength and power. In particular, after the seventh decade, the decline in muscle strength is reported to be greater than 3% per year and the decline in power greater than 5% per year (Daley & Spinks, 2000; Harries & Bassey, 1990; Vandervoot & Symons, 2001). In addition, the decline in muscle strength and power appears to be greatest in the lower extremities (Aoyagi & Shephard, 1992), with a decrease in muscle mass as the major factor underlying the decline. The decline in muscle mass with aging, or sarcopenia, has significant implications for the quality of life of older individuals (Macaluso & De Vito, 2004).

The capacity of older individuals to maintain muscle strength and power is an essential factor in maintaining independence (Rantanen, 2003). A threshold level of muscle strength is required to perform basic activities of daily living and to participate in activities designed to maintain cardiorespiratory fitness (American College of Sports Medicine, 1998). Indeed, it has been suggested that a 10–20% increase in the muscle strength of the quadriceps in older individuals could delay the onset of the threshold for dependency by 1 or 2 decades (Young, Stokes, & Crowe, 1984).

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Although resistance training is an effective form of exercise to increase the muscle strength and power of older individuals (Caserotti, Aagaard, & Puggaard, 2008; Hortobagyi, Tunnel, Moody, Beam, & DeVita, 2001; Latham, Bennett, Stretton, & Anderson, 2004; Macaluso & De Vito, 2004; Sayers, 2007), the influence of aerobic training on the age-associated changes in muscle strength and power is largely unknown. Specificity of training suggests that in healthy individuals, endurance training has little effect on development of muscle strength or power (Nader, 2006). However, the reduced physical function of older individuals allows for greater initial gains in muscle function as a result of training because of a large adaptation potential (Fleck & Kraemer, 2004). Whether cycle ergometry is a sufficient stimulus to increase leg strength and power in older individuals is yet to be determined.

Dreyer et al. (2006) reported that there was no significant difference in the leg strength and power of chronically aerobically trained older men compared with sedentary older men. There was also no significant difference in the leg lean mass of the older men. Similar results have been found for chronically trained older women runners and their sedentary counterparts (Tarpennig, Hawkins, Marcell, & Wiswell, 2006). However, both of these studies were cross-sectional and may not have accurately reflected changes in leg strength over time. In addition, there are few data on the effect of aerobic training on the muscle strength and power of individuals over 70 years of age.

For individuals who exercise, regardless of age, periods of training cessation (detraining) or inactivity can be anticipated, but periods of inactivity are more prevalent in older adults because of illness, hospitalization, and limited periods of disability. Although some studies have examined the effect of detraining (>12 weeks) after a period of resistance or aerobic training (Fatouros et al., 2004; Pickering et al., 1997; Taaffe & Marcus, 1997), no studies have examined the effect of short-term detraining (4 weeks) after a period of aerobic training on the muscle strength and power of older individuals.

Therefore, the aim of this study was to examine the change in muscle strength and power of men 70–80 years of age in response to 16 weeks of aerobic training with cycle ergometry. The study also measured the response of upper leg muscle mass (ULMM) to the aerobic training. In addition, the effect of 4 weeks detraining was also assessed after the 16 weeks of aerobic training. We hypothesized that aerobic training would result in significant increases in strength and aerobic capacity, but strength and aerobic capacity would return to pretraining levels after detraining.

Methods

Participants

Participants in the study were recruited through advertisements placed in local newspapers and consisted of healthy men between 70 and 80 years of age. Respondents to the newspaper advertisement completed a physical activity readiness questionnaire (PAR-Q) by telephone interview. Each respondent identified as potentially suitable for the study then attended the laboratory on three separate occasions for further screening and familiarization. On these occasions, each participant was provided with an information sheet setting out details of the experiment, completed

a medical history questionnaire, and underwent spirometry and a resting 12-lead electrocardiogram (ECG).

Participants then underwent a detailed medical examination and an incremental exercise test to volitional fatigue on the cycle ergometer with direct medical supervision. As a result of the familiarization and screening process, each participant selected for the study was clinically free from known cardiovascular and respiratory disease, was not taking any medication known to interfere with the exercise response, had normal spirometry and resting 12-lead ECG, had resting blood pressure of less than 150/90 mm Hg, and had no evidence of clinically significant exercise-induced myocardial ischemia.

Subsequently, 24 older men who were moderately active, with walking and gardening as their main activities, but not participating in regular physical activity were selected to participate in the study. Participants were randomly assigned to either an aerobic-training group (age 75.2 ± 0.8 years, height 174 ± 2 cm, weight 79.4 ± 4.5 kg) or a nontraining control group (age 73.7 ± 1 years, height 175 ± 1 cm, weight 78.9 ± 4.3 kg). The study was approved by the Griffith University Ethics Committee, and written consent was obtained from all participants.

Experimental Design

The 20-week study consisted of 16 weeks of training and a 4-week detraining period. All participants were tested for lower extremity muscle strength and power, body composition, and maximum oxygen consumption (VO_{2max}) before and after 16 weeks of training and after the 4-week detraining period. Lower extremity strength and VO_{2max} were also tested every 4 weeks during the 16 weeks of training in both the aerobic-training and control groups. Participants were advised to maintain their normal daily routines and eating habits and to refrain from beginning any new exercise program during the study.

Training Protocol

For each session in the 16-week training protocol, participants warmed up and cooled down for 5 min on an unloaded cycle ergometer. Training was 3 days/week (Monday, Wednesday, and Friday), with all sessions supervised by the first author, and heart rate was monitored by three-lead ECG. During the first 2 weeks of training, participants cycled at 50% of VO_{2max} for 30 min. Training intensity then increased to 70% of VO_{2max} for 45 min in the third week of training, and training continued at this intensity until the 16th week of the program. Increments in power were made during the 16 weeks to maintain the participants' training intensity at a heart rate corresponding to 70% of VO_{2max} . Blood pressure was measured before and immediately after each training session.

Strength Measurement

One-repetition maximum strength was tested on an incline squat machine (Body/Solid Inc., Broadview, IL, USA) using standardized procedures as described previously (Levinger et al., 2007). All participants attended two familiarization sessions before the start of the study to reduce their risk of injury and muscle soreness after the testing.

Power and Rate of Force Development

To determine power and rate of force development (RFD), participants performed an isometric contraction in the squat position. Knees were kept at 110° throughout the test. At a given signal, participants exerted maximum force with their legs against a force platform by pressing their shoulders against fixed pads on a squat bar. Participants were instructed to exert their maximum force as fast as possible during a period of 4 s. Body position was carefully monitored throughout the power and RFD test to ensure maximum effort and safety. Three trials were completed, and the best performance was used for subsequent statistical analysis.

A Kistler 900×600 -mm (Type 9287A) multicomponent force platform and a Kistler (Type 9865C) eight-channel charge amplifier were used to measure the power and RFD. The force signal was sampled at 50 Hz and recorded on an IBM-compatible computer (Pentium II). Maximum power was defined as the highest value recorded during each isometric contraction. Force–time analysis on the absolute scale was used to calculate the maximum bilateral isometric force (MBIF) and the force produced from the start of the contraction up to 500 ms ($F_{500\text{ms}}$; Thorstensson, Grimby, & Karlsson, 1976). The RFD was calculated from the maximum force that occurred over the first derivative of the force–time curve.

$\text{VO}_{2\text{max}}$ Measurement

Each participant performed an incremental exercise test, using a continuous ramp protocol, to volitional fatigue on an electronically braked cycle ergometer (Excalibur Sport V2.0, Groningen, The Netherlands). The exercise test began with a 3-min warm-up at 15 W, after which the power was increased by 5 W every 20 s until volitional fatigue or the onset of clinical signs or symptoms that precluded further exercise. $\text{VO}_{2\text{max}}$ values were calculated from the average of the last minute of exercise before volitional fatigue. The highest heart rate, power, and ventilation rate achieved before volitional fatigue were considered maximal values. A true $\text{VO}_{2\text{max}}$ was considered to be attained if two of the following three criteria were met: respiratory-exchange ratio at maximal exercise >1.15 , maximal heart rate ± 10 beats/min of age-predicted maximum (220 minus age), and a plateau in VO_2 with an increasing workload.

Body-Composition Analysis

The body composition of all participants was measured by dual-energy X-ray absorptiometry (DEXA; Norland XR36, Fort Atkinson, WI, USA). The DEXA scans were performed in the pencil beam mode (scan time approximately 4 min, radiation exposure approximately 0.4 mrem). From the DEXA scans, upper limb muscle mass, total-body fat mass, and percentage body fat were determined. ULMM was assessed using the ischial tuberosity and the knee joint as upper and lower margins, respectively, and was calculated using the equation $\text{ULMM} = \text{total upper leg muscle mass} - \text{upper leg fat mass} - (1.82 \times \text{upper limb BMC})$; Heymsfield et al., 1990). The coefficient of variation for repeated measures was $<1\%$ for ULMM and fat mass.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Version 10.0). All data are reported as $M \pm SEM$. A repeated-measures ANOVA using a general linear model was used to determine differences within and between groups before training, after 16 weeks of training, and after 4 weeks of detraining. When significant results were noted, a Bonferroni post hoc test was used to determine the difference between groups. The level of significance was set at $p < .05$.

Results

All participants completed the 20-week study, with the attendance rate for the aerobic-training group greater than 98%, with only 5 participants absent for seven training sessions during the 16 weeks of training. Initially, the training and control groups did not differ significantly in age, body composition, VO_{2max} , or muscle strength and power.

Leg Strength

In the training group, leg strength did not significantly change during the first 8 weeks of training. After 12 weeks of training, leg strength had significantly increased, and after 16 weeks of training it had increased by approximately 21% compared with pretraining values (Table 1). However, after 4 weeks of detraining, leg strength had declined and was not significantly different from pretraining values. In contrast, leg strength in the control group did not vary significantly during the study period (Table 1).

Power and RFD

After 16 weeks of aerobic training, MBIF and F_{500ms} in the training group had increased significantly above pretraining values, but the values decreased to pretraining levels after 4 weeks of detraining (Table 2). The RFD did not significantly change above pretraining values in the training group but was significantly higher than the control group after 16 weeks of training. The values for RFD, MBIF, and F_{500ms} in the control group did not change significantly throughout the 20 weeks of the study (Table 2).

Table 1 Changes in Muscle Strength (One-Repetition Maximum) Over 16 Weeks of Cycle-Ergometry Training and 4 Weeks of Detraining for the Aerobic-Training (AT) and Control (C) Groups, $M \pm SEM$

	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks
AT ($n = 12$)	45.8 \pm 7.9	45.5 \pm 8.0	48.5 \pm 7.7	52.8 \pm 8.1*‡	54.0 \pm 8.0*‡	48.5 \pm 7.2†
C ($n = 12$)	48.6 \pm 5.5	48.2 \pm 5.2	46.8 \pm 5.5	47.8 \pm 5.6	48.2 \pm 5.5	48.0 \pm 5.4

* $p < .05$, greater than Weeks 4 and 8 of training and pretraining (0 weeks). † $p < .05$, lower than after 12 and 16 weeks of training. ‡ $p < .05$, greater than control group; 16–20 weeks represents 4 weeks detraining.

Table 2 Changes in Force Characteristics After 16 Weeks of Cycle-Ergometry Training and 4 Weeks of Detraining for the Aerobic-Training (AT) and Control (C) Groups, $M \pm SEM$

Variable	AT ($n = 12$)			C ($n = 12$)		
	0 weeks	4 weeks	20 weeks	0 weeks	4 weeks	20 weeks
MBIF (N)	687 \pm 45	762 \pm 51*†	679 \pm 48	724 \pm 65	711 \pm 58	706 \pm 63
RFD (N/s)	966 \pm 82	1,035 \pm 101†	953 \pm 86	895 \pm 87	882 \pm 83	892 \pm 88
F _{500ms} (N)	384 \pm 35	425 \pm 43*†	354 \pm 36	363 \pm 36	351 \pm 37	348 \pm 35

Note. MBIF = maximum bilateral isometric force; RFD = rate of force development; F_{500ms} = force in 500 ms. 16–20 weeks represents 4 weeks of detraining.

* $p < .05$, greater than pretraining values (0 weeks). † $p < .05$, greater than C.

VO_{2max}

In the training group, VO_{2max} increased significantly every 4 weeks over the training program to approximately 15% above pretraining levels by Week 16 (Table 3). After 4 weeks of detraining, although VO_{2max} had declined significantly compared with values at Weeks 12 and 16, the value was still significantly higher than pretraining levels (Table 3). Time to exhaustion and peak power significantly increased after 8 weeks of training and again after Weeks 12 and 16 of training. After 4 weeks detraining, time to exhaustion and peak power had declined significantly compared with values at Weeks 12 and 16 but remained significantly above pretraining levels (Table 3). Again, control values did not vary significantly throughout the study.

Body Composition

After 16 weeks of training, body mass and percent body fat decreased significantly and ULMM increased significantly compared with pretraining values (Table 4). After 4 weeks of detraining, however, body mass, percent body fat, and ULMM had returned to pretraining values.

Discussion

The aim of this study was to examine the change in muscle strength, power, and ULMM of men age 70–80 years in response to 16 weeks of aerobic training followed by 4 weeks of detraining. The results showed significant increases in leg strength, power, ULMM, and VO_{2max} after 16 weeks of aerobic training. However, after 4 weeks of detraining, only some of the gain in VO_{2max} remained.

The significant increase in VO_{2max} in our study was not unexpected, because similar increases have been reported by most aerobic-training studies of 16–20 weeks duration in men of similar ages (Hepple, Mackinnon, Goodman, Thomas, & Plyley, 1997; Pickering et al., 1997; Posner et al., 1992). However, the significant increase in leg strength of the aerobically trained men in our study is in contrast to other cross-sectional and longitudinal studies of aerobically trained older men (Dreyer et al., 2006; Hagberg et al., 1989; Sipila, Viitasalo, Era, & Suominen, 1991;

Table 3 Peak Exercise Results Over 16 Weeks of Cycle-Ergometry Training and 4 Weeks of Detraining for the Aerobic-Training and Control Groups, $M \pm SEM$

Variable	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks
	Aerobic Training, $n = 12$					
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	22.6 \pm 0.7	23.3 \pm 0.9*	24.3 \pm 0.9*§	25.0 \pm 1.0*§	25.9 \pm 0.9*§	23.6 \pm 0.8†
Time to exhaustion (min)	11:27	11:29	12:00*	12:40*§	13:01*§	12:12#
Peak power (W)	144 \pm 5	145 \pm 5	152 \pm 5*	162 \pm 7*§	168 \pm 6‡§	155 \pm 6#
HR_{peak} (beats/min)	150 \pm 4	148 \pm 3	150 \pm 4	151 \pm 4	152 \pm 4	150 \pm 4
Control, $n = 12$						
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	23.8 \pm 1.3	23.4 \pm 1.1	23.0 \pm 1.1	23.4 \pm 1.2	23.3 \pm 1.2	23.0 \pm 1.2
Time to exhaustion (min)	12:10	12:03	12:03	12:12	12:16	12:14
Peak power (W)	155 \pm 7	153 \pm 7	153 \pm 7	155 \pm 7	156 \pm 7	155 \pm 7
HR_{peak} (beats/min)	152 \pm 3	150 \pm 3	150 \pm 3	150 \pm 3	151 \pm 3	152 \pm 3

Note. VO_{2max} = maximum oxygen uptake; HR_{peak} = peak heart rate. 16–20 weeks represents 4 weeks of detraining.

* $p < .05$, greater than preceding 4 weeks training. † $p < .05$, lower than Weeks 8, 12, and 16 of training and higher than pretraining (0 weeks). ‡ $p < .05$, greater than Weeks 4 and 8 of training and pretraining. # $p < .05$, lower than Weeks 12 and 16 of training and higher than Week 4 of training and pretraining. § $p < .05$, greater than control group.

Table 4 Body Composition of the Aerobic-Training and Control Groups After 16 Weeks of Cycle-Ergometry Training and 4 Weeks of Detraining, $M \pm SEM$

Variable	Aerobic Training, $n = 12$				Control, $n = 12$		
	0 weeks	16 weeks	20 weeks	0 weeks	16 weeks	20 weeks	
Body mass (kg)	78 \pm 4.1	76 \pm 4.2 [†]	77 \pm 4.2	75 \pm 4.1	75 \pm 4.1	75 \pm 4.2	
Body fat (%)	29.2 \pm 1	27.7 \pm 1 [†]	28.8 \pm 1	27.9 \pm 2	27.5 \pm 2	27.9 \pm 2	
Whole-body lean mass (kg)	54.4 \pm 2.4	55.0 \pm 2.6	55.5 \pm 2.8	52.4 \pm 1.5	53.5 \pm 1.5	52.6 \pm 1.5	
Total-leg muscle mass (kg) ^a	12.04 \pm 4.8	12.87 \pm 5.1*	12.55 \pm 5.3	11.92 \pm 4.3	11.86 \pm 4.3	11.96 \pm 4.1	
Upper leg muscle mass (kg) ^a	10.22 \pm 5.3	10.98 \pm 5.4*	10.61 \pm 4.9	10.41 \pm 3.3	10.52 \pm 3.1	10.54 \pm 3.3	

Note. 16–20 weeks represents 4 weeks of detraining.

^aMuscle mass of both legs combined.

* $p < .05$, greater than pretraining (0 weeks). [†] $p < .05$, less than pretraining.

Tarpenning et al., 2006). The contrasting results might be caused by methodological differences, in particular the mode of exercise used for the aerobic training. Hagberg et al., for example, used walking as the aerobic-exercise stimulus, whereas we used cycling. Other factors that may account for differing results include the use of male and female subjects (Dreyer et al.; Hagberg et al.) and different methods of assessing muscle strength (Abernethy, Wilson, & Logan, 1995). We used the incline squat, which simulates functional tasks such as walking and cycling (Fleck, 1988), to assess changes in leg strength, whereas Hagberg et al. used leg extension. Leg extension is an adequate measure of strength per se, but not necessarily an adequate measure of functional strength (Sale, 1988). The 21% increase in leg strength found in the current study is substantially less than the increase in strength found after similar periods of high- and low-intensity resistance training in older individuals (Hortobagyi et al., 2001; Posner et al.). The greater increase in strength found with resistance-training protocols most likely reflects the higher intensities used with resistance training and the specific nature of the resistance-training exercise (Macaluso & De Vito, 2004).

In the current study, the significant increase in leg strength only occurred after 12 weeks of aerobic training. The influence of neural drive seen during the early stages of resistance training (Sale, 1988) may have been reduced in the aerobically trained group, possibly because of the nature of the training stimulus and the infrequent use (once every 4 weeks) of the incline squat. However, no electromyography (EMG) was used in this study to determine whether there was a change in neural activity during the incline squat.

By Week 12, an increase in muscle contractile proteins and cross-sectional area (CSA) could have contributed to the increase in leg strength (Staron et al., 1994). The suggested increase in muscle CSA would correspond to the increase in ULMM ($3.8\% \pm 2\%$) seen after 16 weeks of aerobic training in our study. Few studies have examined the ULMM of older men after a period of aerobic training. Dreyer et al. (2006) recently found no significant increase in the ULMM of chronically aerobically trained men age 60–74 years compared with sedentary men of similar ages. Tarpenning et al. (2006) did report that the muscle CSA of male runners was maintained from 40 to 70 years of age. However, the association between changes in leg strength and ULMM in the current study must be viewed with caution because no significant ($.34; p = .10$) correlation was found between the change in ULMM and leg strength (data not shown). Although we did expect to see a stronger relationship between the change in leg lean tissue and strength, the relatively low numbers of participants may have influenced the results (Cohen, 1988). Furthermore, DEXA may not be able to measure potential changes in muscle CSA or muscle volume as precisely as magnetic resonance imaging or computed tomography (Genton, Hans, Kyle, & Pichard, 2002).

A novel finding of the current study was the significant increase in MBIF and $F_{500\text{ms}}$ after 16 weeks of aerobic training. The increase in MBIF and $F_{500\text{ms}}$ has important implications for the elderly because aging results in a loss of maximal and explosive force production that is associated with a lower capacity for the neuromuscular response in controlling for postural sway (Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1999).

Generally, cross-sectional data have indicated that aerobically trained and untrained older men have similar MBIF and $F_{500\text{ms}}$ (Alway, Coggan, Sproul, Abdul-

jalil, & Robitaille, 1996; Harridge, Magnusson, & Saltin, 1997). More recently, a cross-sectional study found that chronically aerobically trained older men had absolute and relative (to ULMM) leg power similar to sedentary men of similar ages (Dreyer et al., 2006). However, the results from our study contrast with these findings. Possibly, the increase in MBIF and $F_{500\text{ms}}$ found in our study were the result of the significant increase in leg strength after the 16 weeks of aerobic training. Gains in muscle strength have been shown to be an important factor for increasing MBIF (Cronin, McNair, & Marshall, 2000). Although the RFD of the aerobically trained group did increase after training, the difference was not significant. Why the aerobic-training stimulus of cycle ergometry provided sufficient stimulus to significantly increase MBIF and $F_{500\text{ms}}$, but not RFD, is unclear. The differential response between MBIF and $F_{500\text{ms}}$ and RFD is supported by data that suggest that heavy resistance training or ballistic-type training is required to increase muscle force in the early phase (initial 100–200 ms of contraction) of muscle contraction (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Zatsiorsky, 1995). All measures of muscle strength and power in the current study declined to pretraining levels after 4 weeks of detraining. These declines may have resulted from a corresponding decrease in ULMM and indicate that, once the aerobic training stimulus has been removed, the gains achieved by older men after 16 weeks of training are lost within 4 weeks of detraining. This is a novel finding; we are unaware of any other studies that have examined the effects of detraining on muscle strength and power in similar subjects under these conditions.

In terms of limitations, we only measured ULMM before training and after 16 weeks of training. Accordingly, our results only reflect the amplitude of the increase in ULMM and not the rate of change in ULMM over the 16 weeks of training. Furthermore, the use of DEXA to assess regional muscle mass has been questioned (Blake, McKeeney, Chhaya, Ryan, & Fogelman, 1992). However, the DEXA scanner that we used (Norland XR-36) employed a dynamically changing samarium filtration system that compensates for changes in tissue thickness. This filtration system is unique to the Norland XR-36 and has been shown to be highly accurate for body-composition analysis (Gotfredsen, Baeksgaard, & Hilsted, 1997).

Conclusion

In summary, we found that 16 weeks of aerobic training in men age 70–80 years resulted in a significant increase in leg strength and power, ULMM, and $\text{VO}_{2\text{max}}$. The loss of strength, power, and muscle mass has significant implications for the quality of life and health of older individuals (Daley & Spinks, 2000). Resistance training is the primary mechanism used to reduce these changes, but the current study demonstrates that cycle ergometry can be used to improve neuromuscular function, as well as cardiovascular fitness, in sedentary older men. The current study used the incline squat to determine changes in leg strength, and this exercise may provide a more accurate measure of functional change in leg strength than traditional exercises. However, after 4 weeks of detraining, all gains in leg strength, power, and ULMM were lost, although some gains in $\text{VO}_{2\text{max}}$ were retained. Therefore, aerobic exercise must be performed on a regular basis to maintain training adaptations.

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