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**Article Title:** Age-related Changes in Performance and Recovery Kinetics in Masters Athletes: A Narrative Review

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## **Age-related Changes in Performance and Recovery Kinetics in Masters Athletes**

**Submission Type:** Literature Review

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## **Abstract**

Despite increasing participation rates in masters sport and extensive research examining age-related changes in performance, little is known about the effect of age on recovery kinetics in masters athletes. This narrative review focuses on the relationship between ageing and sports participation, and their effect on both performance and recovery following an exercise bout. Current research suggests the effect of age on performance and recovery may be smaller than originally suggested and that increasing sedentary lifestyles appear play a larger role in any observed decrements in performance and recovery in masters athletes. Currently, it appears that performance decrements are inevitable with age. However, performance capacities can be maintained through systematic physical training. Moreover, the limited current research suggests there may be an age effect on recovery kinetics following an exercise bout although further research is required to understand the acute and chronic recovery processes in the masters athlete.

## **1 Introduction**

Masters athletes are defined as individuals who systematically train and compete in organised forms of competitive sport specifically designed for older adults (Reaburn & Dascombe, 2009). Over recent years there has been a dramatic increase in the number of older athletes continuing to train and compete at high levels (Bernard, Sultana, Lepers, Hausswirth, & Brisswalter, 2009; Lepers, Rust, Stapley, & Knechtle, 2013). To excel in most competitive sports it is essential that athletes exhibit high aerobic and anaerobic capacities and produce strong and powerful muscular contractions (Stone et al., 2004). However, in normal ageing there are marked decreases in aerobic (Vigorito & Giallauria, 2014), anaerobic (Neder, Jones, Nery, & Whipp, 2000), exercise efficiency (Woo, Derleth, Stratton, & Levy, 2006), strength (Peiffer et al., 2010b) and power (Kostka, 2005) capacities due to declines within the metabolic (Hagberg et al., 1988), cardiovascular (Ogawa et al., 1992; Simoes et al., 2013) and hormonal systems (Ari, Kutlu, Uyanik, Taneli, & Buyukyazi, 2004; Lanfranco et al., 2003).

Historically, these age-related declines were thought to be due to the normal ageing process. However, research has consistently shown improvements in the physical capacities of older sedentary individuals following physical training (Burd, Gorissen, & van Loon, 2013; Steib, Schoene, & Pfeifer, 2010; Woo et al., 2006). These findings suggest that a major contributor to the declines in physiological systems may be both the reduced physical activity levels into older age (Reaburn, Macgregor, & Climstein, 2013) and an observed age-related reduction in sports participation (Foster, Wright, Battista, & Porcari, 2007; Hawkins, Wiswell, & Marcell, 2003; Tanaka & Seals, 2008).

It is widely acknowledged that continuing to train and compete at competitive levels into older age enables masters athletes to maintain higher levels of aerobic and anaerobic capacities (Darr, Bassett, Morgan, & Thomas, 1988; Gent & Norton, 2013) as well as muscular strength and power (Cristea et al., 2008; Louis, Hausswirth, Bieuzen, & Brisswalter, 2009; Louis, Hausswirth, Easthope, & Brisswalter, 2012) observed in an age-matched sedentary population. However, the age-related declines in the aerobic, anaerobic and muscular strength and power capacities of masters athletes may lead to a decreased rate of recovery following exercise.

To date, there is limited research (Easthope et al., 2010; Sultana et al., 2012) and anecdotal evidence to suggest that as athletes age they may exhibit impaired recovery kinetics (time taken to recover from a given exercise bout) compared to younger athletes. Consequently, age-related reductions in recovery kinetics may have an effect on subsequent bouts of exercise training, leading to a reduction in overall training load and a potentially increased risk of injury. A previous review (Fell & Williams, 2008) has examined the effect of age on skeletal muscle recovery after exercise although due to the paucity of research into masters athletes at the time, the review relies on a tentative link between animal studies and investigations comparing young and non-athletic older populations to draw conclusions about a possible age effect on recovery. Recent research comparing younger and masters athletes has increased knowledge in this specific population and shown the significance of neuromuscular recovery in masters athletes. Despite this, limited research has empirically examined recovery kinetics of older versus younger athletes (Bieuzen, Hausswirth, Louis, & Brisswalter, 2010; Darr et al., 1988; Easthope et al., 2010; Fell, Haseler, Gaffney, Reaburn, & Harrison, 2006; Fell, Reaburn, & Harrison, 2008). Moreover, the possible mechanisms explaining the slower recovery kinetics in older athletes remain to be investigated. This narrative review will examine the effects that physical activity and systematic training may have on performance and recovery in both sedentary and athletic ageing populations and highlight the need for further research into recovery within masters athletes.

## **2 Methods**

A literature search was conducted between April 2013 – January 2015 on the PubMed, Scopus and SPORTDiscus databases. Search terms included “Age” OR “Masters” OR “Older” OR “Veteran” AND “Exercise” OR “Performance” OR “Fatigue” OR “Recovery”. All languages and articles types were included in the search to increase the number of articles. The reference lists of the resultant articles were examined for further articles not found during the literature search. Articles comparing younger and masters athletes that failed to match their subjects for training load were excluded. No other exclusion criteria were applied.

### **3 The Effects of Physical Activity and the Ageing Process on Physical Performance**

The ageing process leads to a number of physical changes in both a normal ageing and masters athlete populations that can affect aerobic and anaerobic performance (Brisswalter, Wu, Sultana, Bernard, & Abbiss, 2014; Reaburn & Dascombe, 2009; Tanaka & Seals, 2008) as well as muscular strength and power performance (Burd et al., 2013; Korhonen et al., 2012; Louis et al., 2012; Peiffer et al., 2010b).

#### Sedentary Ageing Population and Physical Performance

Both maximal oxygen uptake and maximal heart rate have been shown to be reduced in a normal ageing population (Carrick-Ranson et al., 2013; Sabapathy, Schneider, Comadira, Johnston, & Morris, 2004). Similarly, muscular strength and power have also been shown to decline in ageing sedentary populations (Cruz-Jentoft et al., 2014; Kostka, 2005; Peiffer et al., 2010b). An investigation of 301 sedentary healthy Australian males and females demonstrated that younger participants were significantly stronger as measured by one-repetition maximum strength tests (chest press, seated row, leg extension and leg press) and performed significantly better in functional performance tests such as a 400m walk, 6m walk, 6m backwards walk and sit to stands than individuals over 65 years of age (Peiffer et al., 2010b). These decreases in strength and functional abilities have been suggested to be linked with a decreasing muscle cross-sectional area specifically in type II muscle fibres in older sedentary individuals (Gouzi et al., 2013).

High intensity training such as resistance training into older age has also been shown to enhance muscular strength and power performance (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010; Latham, Bennett, Stretton, & Anderson, 2004; Steib et al., 2010). An investigation by Deley et al. (2007) demonstrated similar significant improvements in physical parameters in elderly (>70 years) sedentary subjects following one year of moderate intensity training. The researchers reported that training for one hour three times a week with a combination of aerobic, strength, and flexibility exercises, plus adapted Tai-chi, lead to significant improvements in maximal oxygen uptake (14.8%), distance walked in six minutes (10%), and maximal muscle strength of the knee extensors (15.2%) and plantar flexors (17.4%) in the intervention group compared to a an age-matched control group

who maintained normal activity levels. Therefore, in a normal ageing population the research suggests that physical performance decreases with age although improvements can be made through systematic physical training.

#### The Masters Athlete and Physical Performance

Similar trends are reported in masters athletes as declines in both maximal oxygen consumption and maximal heart rate have been observed in masters athletes from a range of sports (Gent & Norton, 2013; Kusy & Zielinski, 2014). Peak endurance performance has been shown to be maintained until approximately the age of 35 years after which it declines slowly until the age of 50-60 years after which there is an increased rate of decline due primarily to a decrease in maximal oxygen consumption (Pimentel, Gentile, Tanaka, Seals, & Gates, 2003; Ransdell, Vener, & Huberty, 2009; Tanaka & Seals, 2008). Decreases in the strength and power have also been observed in an ageing athletic population by Korhonen et al. (2006) who reported that both type II muscle fibre size and maximal voluntary contraction (MVC) were significantly lower in 75 male masters sprint runners aged 40-87 years old compared to 16 younger adult male sprinters aged 18-33 years. However, when compared with age-matched or younger sedentary groups, muscle integrity was well preserved in the masters sprinters group. This finding strongly suggests that systematic sprint training into older age may attenuate the loss of type II muscle fibre size.

The suggestion that systematic physical training can attenuate declines in physical performance is also supported by Cristea et al. (2008) who investigated the effect of strength training in seven masters sprint runners aged  $66 \pm 3$  years compared to a control group of four masters sprinters aged  $71 \pm 5$  years. They observed that the combination of both strength and sprint running training elicited a significant increase in sports-specific maximal and explosive force production due to an increase in the size of the type II muscle fibres in the masters sprint runners.

Taken together, the above research strongly suggests that although physical performance decrements occur with age in both sedentary and athletic populations, specific systematic training in older individuals leads to significant physical adaptations that can attenuate the age-related declines in capacities that effect physical performance. Furthermore, given an age-related increase in sedentary

lifestyle (Breuer, Hallmann, Wicker, & Feiler, 2010), it might be suggested that the commonly observed age-related decreases in physical performance parameters may be due to age-related decreases in physical activity rather than the ageing process *per se*. Therefore, masters athletes may be seen as a population of research interest given that their physical capacities and levels of systematic training may produce an independent effect of age on physical performance and highlight the importance of continuing participation in sport into older age.

#### **4 Masters Athletes**

Despite the typically observed age-related decrements in physical performance in masters athletes (Bernard et al., 2009; Gent & Norton, 2013; Peiffer, Abbiss, Chapman, Laursen, & Parker, 2008), the numbers of masters athletes participating in sport is increasing and their performances relative to their age groups have been increasing over time (Hajkowicz, Cook, Wilhelmseder, & Boughen, 2013; Ransdell et al., 2009). Since the commencement of the World Masters Games held in Toronto in 1985 there has been a 245% increase in competitors from 107 countries competing in 30 sports (International Masters Games Association, 2013). Increasing participation rates are not limited solely to the World Masters Games, as similar increases in participation have been reported in individual sports. For example, Figure 1 illustrates the number of participants that were able to finish during the Olympic distance triathlon world championships in both 2004 and 2007.

The increase in the number of participants over 45 years of age that completed the triathlon increased by 65% over a four year period. A similar increase in participation rates at the Hawaii Ironman world championships has been reported by Lepers et al. (2013) with an 80% increase in male and 104% increase in female participants over 40 years of age completing the race. Interestingly, the same researchers also reported an increased performance relative to age groups in all three disciplines of triathlon from 1986 to 2010 in male competitors over 45 years and female competitors over 40 years (Lepers et al., 2013). These results suggest that masters athletes are participating in systematic training programs and organised competitions at an increasing rate into older age.

Despite the increasing participation rates of masters athletes, only a small number of studies have investigated the training practices of masters athletes (Berger et al., 2006; Macgregor, Reaburn,

& Climstein, 2013). Any age-related changes to training intensity or volume when comparing masters athletes to younger athletes seems to be equivocal. Some research suggests there is a significant reduction in training volume and running performance in well-trained runners over 50 years of age compared to runners under the age of 50 years (Pimentel et al., 2003). The reduction in training volume may explain the commonly observed age-related decrease in endurance performance. However, more recent research has reported that older athletes still report high training volumes relative to younger athletes (Berger et al., 2006; Macgregor et al., 2013).

Previous research has suggested that athletes who maintain a high level of training volume and intensity into older age are able to significantly attenuate age-related decrements in endurance performance (Berger et al., 2006; Bieuzen et al., 2010; Darr et al., 1988; Ransdell et al., 2009; Sultana et al., 2012). The ability to maintain performance through systematic training was also highlighted in a recent investigation by Gent and Norton (2013) who measured anaerobic and aerobic capacities using cycle ergometry in 173 healthy masters cyclists and triathletes aged between 35-64 years. They observed no significant difference between age groups in aerobic capacity ( $-1.8 \pm 1.5\%$  per decade) but significant age-related declines in both anaerobic power ( $-8.1 \pm 4.1\%$  per decade) and anaerobic capacity ( $-8.0 \pm 3.3\%$  per decade). These findings highlight the importance of specificity of training into older age for endurance athletes who train the aerobic energy system to a greater level than the anaerobic systems and therefore appear to maintain their aerobic capacity into older age (Cipriani, Swartz, & Hodgson, 1998).

In support of this suggestion, a recent investigation by Brisswalter et al. (2014) observed an effect of age on both aerobic and anaerobic performance in well trained triathletes ( $n = 60$ ) aged 20-29 years; 30-39 years; 40-49 years; 50-59 years; 60-69 years and older than 70 years who reported no difference in weekly training volume. The study participants performed an incremental cycling test, a 10 minute sub-maximal cycling test, and maximal sprint cycle tests to determine both aerobic and anaerobic function. Maximal oxygen consumption ( $-17.1 \pm 6.6\%$ ) and maximal aerobic power ( $-15.6 \pm 0.4\%$ ) showed significant differences between the 50-59 year age group and 20-29 year age group. The age-related decrease in aerobic performance continued with age with the over 70 year age group

reporting even greater decreases in maximal oxygen consumption ( $-37.3 \pm 0.5 \%$ ) and maximal aerobic power ( $-38.4 \pm 6.8\%$ ) compared to the younger 20-29 year group. Additionally, the researchers reported an age effect on both cycling efficiency and sprint performance. A significant difference in cycling efficiency was also observed in the 50-59 year group ( $-7.3 \pm 1.8\%$ ) compared to the 20-29 year group. Finally, the researchers also observed that significant differences in peak sprint power between all age groups older than 40 years. This comprehensive investigation strongly suggests that although masters triathletes can maintain similar training volumes into older age they still demonstrate decrements in both aerobic and anaerobic cycle performance into older age.

In addition to age-related decreases in both aerobic and anaerobic performance, endurance masters athletes also exhibit age-related decreases in muscular strength (Korhonen et al., 2006). Although muscular strength decreases with age despite continued participation in endurance training, masters athletes appear to maintain the ability to increase muscular strength if the correct stimulus is placed on the older athlete (Louis et al., 2012). For example a recent investigation by Louis et al. (2012) demonstrated that in both well-trained younger ( $25.6 \pm 5.0$  years) and masters cyclists ( $51.5 \pm 5.5$  years), the implementation of a three-week strength training program showed a significant increase in the MVC of both masters athletes ( $17.8 \pm 12.9\%$ ) and younger cyclists ( $5.9 \pm 11.8\%$ ) compared to pre-intervention values, although there were no significant between-group differences. Moreover, the masters cyclists also exhibited a significant 10.7% increase in cycling delta efficiency following the strength training program where the younger group only demonstrated a trend. The greater increase in muscle strength of the masters cyclists compared to the younger cyclists suggests that training adaptations to resistance training may not be compromised into older age. Furthermore, with a specific resistance training program, strength performance decrements that are reported in endurance trained masters athletes can be reversed (Louis et al., 2012).

In summary, the ability of masters athletes (Bieuzen et al., 2010; Darr et al., 1988; Fell et al., 2008; Louis et al., 2012) to improve and maintain physical performance and capacities through specific systematic training into older age has been demonstrated in recent studies. Moreover, it appears that both resistance and concurrent training (combined endurance and resistance training)

may play a greater role in masters athletes to help maintain muscle strength and anaerobic capacity into older age. Although specific systematic training is important to an athlete's development, the athlete's ability to overcome fatigue and recover from a previous training or competition bout is just as important (Buchheit et al., 2013; Carfagno & Hendrix, 2014).

## **5 Importance of Recovery for Sports Performance**

Recovery from physical training is a multifaceted process involving various physiological, biochemical, hormonal, biomechanical and psychological systems (Nédélec et al., 2012). The number of components and the complexity of the interactions of these systems with their environment make recovery kinetics difficult to quantify. This complexity is magnified by the two-phase nature of exercise recovery consisting of both acute (immediate post-exercise) and chronic (24-72 hours post-exercise) phases (Daanen, Lamberts, Kallen, Jin, & Van Meeteren, 2012).

The acute recovery phase immediately post-exercise consists mainly of rapidly returning the cardiovascular system to near homeostatic resting values and the immediate removal of biochemical by-products accumulated during exercise such as the buffering of hydrogen and inorganic phosphate ions shortly following cessation of exercise to restore homeostatic pH (Burke, 2010; Siegler & Robergs, 2005). Consequently, marked decreases in autonomic sympathetic drive, heart rate, oxygen consumption and various changes to haematological plasma levels and hormone profiles occur to return physiological systems back to resting states (Aubert, Seps, & Beckers, 2003; Daanen et al., 2012; Leti & Bricout, 2013; Nybo et al., 2013; Sachdev & Davies, 2008). Furthermore, there is an up-regulation of absorption of glucose and protein to increase protein synthesis and glycogen refuelling to return muscles to a pre-exercise state (Hauswirth & Meur, 2011). Although these processes may continue into the chronic phase of recovery, their kinetics are exponentially reduced in the chronic phase of recovery.

The chronic recovery phase is generally observed to last up to 72 hours post-exercise but, depending on the intensity and duration of the exercise stimulus, may last longer (Ascensao et al., 2008; Brancaccio, Lippi, & Maffulli, 2010; Jurimae, Maestu, Purge, & Jurimae, 2004; Sachdev & Davies, 2008). Chronic recovery post-exercise can be quantified as the time it takes to restore physical

performance back to pre-exercise values (Nédélec et al., 2012). This phase of recovery consists of restoring the morphological, physiological and biomechanical changes that may have occurred due to the oxidative and mechanical stresses of exercise (Allman & Rice, 2001; Brancaccio et al., 2010; Easthope et al., 2010; Hartmann & Mester, 2000; Klein, Cunningham, Paterson, & Taylor, 1988; Louis et al., 2009; Ploutz-Snyder, Giamis, Formikell, & Rosenbaum, 2001; Sultana et al., 2012). Once an athlete has returned to pre-exercise performance values, they are deemed to have physically recovered from the prior exercise bout. Psychological, emotional and mental strain can also reduce overall recovery from a previous exercise bout and should also be considered when attempting to quantify and improve recovery kinetics (Wagstaff, 2014). Due to the multifaceted nature of recovery, pinpointing a single causative effect that age may have on recovery kinetics is unlikely. Any age-effect on recovery kinetics is most likely to be individual and due to an alteration of one or more of the processes detailed above. However, recovery kinetics in masters athletes is a significant issue as it can not only have an effect on subsequent sports performance but potentially also the incidence of injury (Kreher & Schwartz, 2012).

#### Recovery and Incidence of Injury

Poor recovery from a physical exercise bout can lead to overreaching, overtraining and possibly subsequent injury (Kreher & Schwartz, 2012). Currently, little is known about what effect age may have on recovery kinetics after exercise in a masters athlete or ageing sedentary population. Research in sedentary ageing populations seems to suggest that recovery of exercise capacities is reduced due to the ageing process (Bouزيد, Hammouda, Matran, Robin, & Fabre, 2014; Conchola, Thompson, & Smith, 2013; Conley, Jubrias, & Esselman, 2000). Despite this, the levels of physical activity examined in these studies again seems to be a major confounding factor effecting the recovery kinetics of an sedentary ageing population suggesting that research into masters athletes would be of significance. Due to the fact that masters athletes adhere to higher levels of systematic training than a sedentary ageing population, a reduced recovery capacity would not only have a negative effect on training quality and sports performance but could also increase the risk of musculoskeletal injury.

At present, the research reports contradictory findings when investigating injury rates in masters athletes with studies reporting less incidence of injury (Heazlewood et al., 2014) and no difference in the incidence of injury (Walsh et al., 2013) in masters athletes when compared to younger cohorts in both team sports and swimming. However, an increase incidence of injury has been reported in masters runners compared to younger runners (McKean, Manson, & Stanish, 2006), specifically overuse injuries (Knobloch, Yoon, & Vogt, 2008). The results of a survey of 2886 runners of which 34% consisted of masters runners ( $\geq 40$  years) reported that masters runners were significantly more prone to injury than a younger cohort of runners. Specifically, this investigation reported that soft-tissue injuries to the calf, achillies tendon and hamstrings were significantly greater in the masters runners. Although there was an increased reporting of the incidence of injury in masters runners, there was also a significantly greater number of masters runners completing more than 30 miles per week and training more than six times a week compared to younger runners. Therefore, it is difficult to conclude that with age masters runners suffer a greater incidence of injury as the increased training volume in the masters runners would lead to greater accumulative compressive and eccentric forces through the lower limbs. The increased training volume could predispose the masters runners to a greater risk of injury and this could explain the heterogeneous results in the research between sports. Despite the heterogeneity of current research, recovery after exercise remains an important issue and to reduce the incidence of injury and decrease the time taken in recovery following exercise a number of recovery interventions or strategies have been utilised in younger athletic populations. Currently the efficacy of these recovery strategies in masters athletes is poorly documented and understood.

### Recovery Strategies

The importance of effectively recovering from a training bout in athletes of any age is well documented (Barnett, 2006; Vaile, Halson, & Graham, 2010). Frequently utilised recovery interventions include active recovery (Greenwood, Moses, Bernardino, Gaesser, & Weltman, 2008; Menzies et al., 2010), stretching (Torres, Pinho, Duarte, & Cabri, 2013), compression garments (Bottaro, Martorelli, & Vilaça, 2011; Driller & Halson, 2013; Duffield et al., 2008; MacRae, Cotter, & Laing, 2011), hydrotherapy including cold water immersion and contrast water immersion (Peiffer,

Abbiss, Watson, Nosaka, & Laursen, 2010a; Versey, Halson, & Dawson, 2013), sleep (Venter, 2012), massage (Wiltshire et al., 2010), and nutrition (Beelen, Burke, Gibaia, & Van Loon, 2010).

While a detailed discussion on the utilisation of recovery strategies is beyond the scope of this review (for review see: (Vaile et al., 2010), due to the heterogeneity of methodology used in these recovery studies, it is difficult to formulate conclusions regarding the benefits of the above recovery strategies in athletes of any age. While there is strong anecdotal evidence regarding the efficacy of these recovery interventions being commonly practiced in a wide variety of sports in younger athletic population (Stockwell, McKean, & Burkett, 2012; Venter, Potgieter, & Barnard, 2010), a recent survey by Reaburn et al. (Reaburn et al., 2013) reported that recovery strategies are poorly practiced in both male and female masters cyclists. A recommendation on the efficacy of recovery strategies in masters athletes is again difficult. To the authors' knowledge, there have been no investigations into the efficacy of recovery strategies in masters athletes looking to enhance the rate of post-exercise recovery. This is further complicated by the limited amount of research investigating the recovery kinetics of masters athletes and whether ageing has an effect on any of the processes involved in either acute or chronic recovery from a bout of prior exercise.

## **6 Current Research on Recovery Kinetics of Masters Athletes**

To date, a limited number of studies have investigated the recovery kinetics of masters athletes. Table 1 below summarises the research that has investigated recovery from prior exercise in masters athletes.

A recent investigation by Sultana et al. (2012) examined levels of recovery in nine young ( $28 \pm 6.1$  years) and 10 masters ( $52.4 \pm 10$  years) triathletes following an Olympic distance triathlon. The researchers measured baseline muscle strength and cardiovascular parameters prior to the triathlon and compared them to 24 hours post-triathlon measures. Neither age group showed decreased muscular strength (MVC) 24 hours post-triathlon. Furthermore, both young and masters triathletes showed similar decrements in cardiovascular parameters including maximal oxygen consumption and running velocity at maximal oxygen consumption 24 hours post-triathlon. Only speed at ventilatory

threshold 2 was significantly different between the masters (-8.3 %) and younger (-2.5 %) triathletes 24 hours following the Olympic distance triathlon. Given that the velocity at ventilatory thresholds have been shown to be a valid predictor of endurance performance (Amann, Subudhi, & Foster, 2006), this finding suggests an age-related decrease in subsequent endurance performance in masters versus younger endurance athletes.

An earlier investigation on ultra-endurance athletes by Easthope et al. (2010) examined the recovery rate of 10 younger ( $30.5 \pm 7.0$  years) and 13 master ( $45.9 \pm 5.9$  years) similarly-performing runners following a 55 km trail running event. Muscular strength and haematological biomarkers of muscle damage (creatine kinase and lactate dehydrogenase) were assessed over 72 hours following the event to examine both fatigue levels and relative recovery from the trail run. The results demonstrated that masters athletes had similar fatigue levels to younger athletes. Moreover, recovery rates of both biochemical markers of muscle damage and cycling efficiency showed no significant differences between the two age groups. However, the masters ultra-endurance athletes took significantly longer for muscular function to return to baseline. Both MVC, and muscular twitch and M-wave properties returned to baseline levels 24 hours after the 55km trail run in the younger ultra-endurance group. In contrast, the masters ultra-endurance group muscular function returned to baseline levels 48 hours after the 55km trail run and muscular twitch and M-wave properties failed to return to baseline levels after the 72 hour recovery period. These findings suggest that although the magnitude of fatigue seems to be independent of age, masters athletes take longer to recover after a stimulus that causes significant muscular damage. Moreover, it appears that neuromuscular function remains significantly reduced in the masters athlete group compared to younger athletes.

Similar findings of reduced recovery of neuromuscular function with muscle damaging exercise have been reported following bouts of resistance training in masters athletes. For example, Bieuzen et al. (2010) compared neuromuscular performance in 16 endurance-trained masters athletes ( $66.1 \pm 5.8$  years) and 10 younger endurance-trained athletes ( $25.4 \pm 4.6$  years) following a resistance training protocol consisting of 10 sets of 10 repetitions of horizontal leg press at 70% maximum. The researchers measured MVC and electrically evoked contractions and reported that both groups

demonstrated a reduced MVC (masters = -9.7%; young = -14.3%) following the resistance training protocol. No between-group differences were observed in MVC or electromyography activity following the training protocol. However, the researchers reported a significantly decreased peak twitch in the masters (-25.8%) compared to the younger endurance-trained men who showed no change in peak twitch. This supports the suggestion that neuromuscular fatigue and recovery may differ in masters versus younger athletes following muscle damaging exercise which may cause a delay in overall recovery from prior exercise.

Although the effect of decreased neuromuscular activity on athletic performance is poorly understood, it has been suggested that during dynamic movements involved in sport, muscle activation and coordination may be effected by a loss of neuromuscular control and central fatigue (Byrne, Twist, & Eston, 2004). The reduced muscle activation and co-ordination could lead to a decrease in fine motor skills that may have a significant impact on the physical performance of athletes of any age.

Despite these previous investigations reporting similar or greater levels of physical fatigue and recovery time in masters athletes compared to younger athletes, other investigations have failed to observe differences in recovery kinetics between younger and older groups of athletes. For example, an investigation by Fell et al. (2008) showed no delay in time trial performance recovery in 9 masters ( $45 \pm 6$  years) compared to 9 younger ( $24 \pm 5$  years) cyclists. Both groups of cyclists completed three 30-minute cycling time trials over three consecutive days that were designed to induce muscle fatigue. Although neither group showed a decrease in performance over the three 30-minute time trials, the investigators demonstrated that older cyclists exhibited a significant difference in perceptual measures of fatigue, recovery, and muscle soreness between the first and third time trail. In contrast, the younger group showed no significant change in the same perceptual measures from the first to the third time trail. Moreover, there was also a significant difference between groups in the change of perception of muscular soreness from the first to the third time trial demonstrating altered rates of muscular soreness. An earlier investigation by Fell et al. (2006) utilising the same fatiguing protocol also reported no between group differences in 9 younger ( $24 \pm 5$  years) and 9 masters ( $45 \pm 6$  years)

cyclists in MVC, countermovement jump and 10-second sprint performance or creatine kinase levels after each time trial.

Taken together, these above investigations suggest that masters athletes are able to physically recover from a fatigued state at a similar rate to younger athletes. However, these same studies suggest that masters athletes may perceive they take longer to recover from a previous exercise bout. This increased perception of muscle soreness and fatigue may have an effect on the training practices of masters athletes. For example, a reduction of training volume or intensity due to perceived muscle soreness or fatigue may have a subsequent negative effect on training and performance levels. Therefore, the measuring of perceptual fatigue in masters athletes might be important for coaching or conditioning staff to monitor in masters athletes in order to maximise both training and competitive performance in their athletes.

Similar recovery trends in masters athletes were also reported by Darr et al. (1988) who investigated the acute recovery of heart rate following maximal exercise. Male subjects ( $n = 20$ ) were divided by age and training status (peak oxygen consumption) into four age groups: young trained ( $24 \pm 2$  years), old trained ( $51 \pm 2$  years), young untrained ( $25 \pm 3$  years) and old untrained ( $57 \pm 4$  years). The participants fast (5 – 120 seconds) and slow (120 – 240 seconds) phases of heart rate recovery kinetics were measured following maximal graded exercise test on a cycle ergometer. The researchers reported no significant difference in heart rate recovery curve slopes when comparing younger and older participants of trained or untrained status. However, they did observe a significant difference between training groups with the trained groups exhibiting significantly steeper heart rate recovery curve slopes in their recovery kinetics, with heart rate in both young and older trained groups, returning to baseline values at significantly accelerated rate than their age-matched untrained groups. These results suggest that reduced training status has an effect on acute recovery kinetics, specifically on heart rate. In contrast, the results suggest that age has no effect on the kinetics of heart rate recovery following maximal exercise in similarly-trained individuals.

In summary, limited research has examined recovery from prior exercise in young versus older athletes. Thus, it is difficult to conclusively state that there is a significant effect of age on

recovery kinetics following an exercise bout. Due to the fact that the recovery process in a masters athlete population is poorly understood, future research investigating the recovery kinetics of masters athletes should initially focus on confirming or refuting any age-effect on recovery kinetics. Furthermore, future research into the recovery kinetics of masters athletes should separate both the acute and chronic phases of recovery to investigate which specific parameters may be causing a difference or delay in recovery kinetics in masters athletes versus younger, similarly-trained athletes. If a delay in the recovery kinetics is identified, further research may then focus on strategies such as modified monitoring of masters athletes' training loads, the inclusion of resistance or concurrent training to combat delays in recovery kinetics, or greater use of recovery strategies in masters athletes, and the efficacy of commonly used recovery strategies in masters athletes.

## **7 Conclusion**

There has been a significant increase in the number of masters athletes participating in both individual sports and competitions organised for older athletes. These increasing participation rates have created an increasing scientific interest in the athletic performance and physiology of masters athletes. Moreover, it seems that continuing participation in systematic training into older age has physical performance benefits for both masters athletes and healthy sedentary populations. With a systematic training program, training specificity and recovery from prior exercise are important to maximise both adaptation and performance in the subsequent training bout or competition.

At present, the limited research examining recovery in masters athletes suggests that recovery from exercise is not effected by age unless muscular damage is induced causing delays in the recovery of neuromuscular function. However, no research to date has examined the possible mechanisms of fatigue or delayed recovery in masters athletes. Furthermore, no research to date has examined acute or chronic recovery kinetics from high intensity exercise in high performance masters athletes compared to those in younger, similarly-trained athletes. Thus, further research is required to understand whether acute and chronic recovery kinetics following exercise are independent of age.

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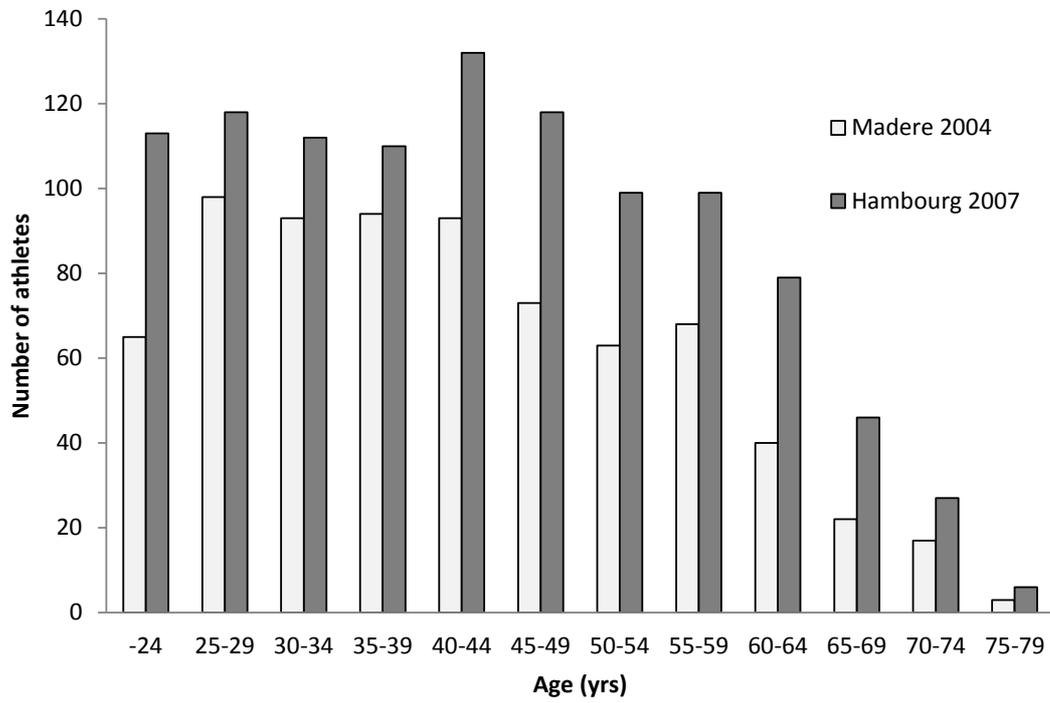
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**Figure 1** Completion rates of Triathlon World Championships in age groups. Figure adapted from Bernard et al., (2009)

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**Table 1** Studies investigating recovery kinetics in young and masters athletes

Study	Participants	Age (yr)	Activity	Measures	Time Frame	Results
Sultana et al. (2012)	9 Y 9 M	28.4 ± 6.1 52.4 ± 10.0	Olympic distance triathlon	MVC, $\dot{V}O_{2max}$ , $v\dot{V}O_{2max}$ , $vVT1$ , $vVT2$ & running economy.	Pre, 24 hr post	Significantly slower 24hr post $vVT2$ in M, no other group differences
Easthope et al. (2010)	10 Y 13 M	30 ± 5.7 45.9 ± 5.9	55-km trail run	CK, LDH, MVC, Pt, Ct, cycling efficiency	Pre, 1, 24, 48, 72 hr post	Significant group differences in MVC, Pt, Ct & DE 48 & 72 hr post
Bieuzen, Hausswirth, Louis, and Brisswalter (2010)	10 Y 10 M	26.2 ± 2.4 62.5 ± 4.1	10 x 10 70% horizontal leg press	MVC, Pt, Ct, HRt, M-wave, RMS/RMS <sub>M</sub>	Pre, post	Significant group difference in post Pt, no other group differences pre to post.
Fell, Reaburn, and Harrison (2008)	9 Y 9 M	24 ± 5 45 ± 6	3 x 30 min cycle time trials	Time trial performance & perceptual measures	Pre & post each trial	Significant group difference in perceived muscle soreness between Trail 1 & 3
Fell, Haseler, Gaffney, Reaburn, and Harrison (2006)	9 Y 9 M	24 ± 5 45 ± 6	3 x 30 min cycle time trials	MVC, CMJ, 10ST, CK	Pre & post each trial	No group differences between Y and M cyclists
Darr, Bassett, Morgan, and Thomas (1988)	5 YT 5 YU 5 MT 5 MU	24 ± 2.4 25 ± 2.6 51 ± 1.8 57 ± 4.0	Maximal cycle exercise test	HR	Continuously for 10 min post exercise	Significantly training effect but no significant age effect on HR recovery after maximal exercise

Y = Young; M = Masters; T = Trained; U = Untrained; MVC = Maximal Voluntary Contraction; VT1 = Ventilatory Threshold 1; VT2 = Ventilatory Threshold 2; 10ST = 10 second sprint; CK = Creatine Kinase; LDH = Lactate Dehydrogenase; Pt = Peak Twitch; Ct = Contraction Time; HRt = Half Relaxation Time; RMS = Root Mean Square; CMJ = Counter Movement Jump; HR = Heart Rate