

Bond University
Research Repository



Age-related changes in performance and recovery kinetics in masters athletes: A narrative review

Borges, Nattai; Reaburn, Peter; Driller, Matthew; Argus, Christos

Published in:
Journal of Aging and Physical Activity

DOI:
[10.1123/japa.2015-0021](https://doi.org/10.1123/japa.2015-0021)

Licence:
CC BY-NC-ND

[Link to output in Bond University research repository.](#)

Recommended citation(APA):
Borges, N., Reaburn, P., Driller, M., & Argus, C. (2016). Age-related changes in performance and recovery kinetics in masters athletes: A narrative review. *Journal of Aging and Physical Activity*, 24(1), 149-157.
<https://doi.org/10.1123/japa.2015-0021>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

For more information, or if you believe that this document breaches copyright, please contact the Bond University research repository coordinator.

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

Submission Type: Literature Review

Nattai Borges¹

Peter Reaburn¹

Matthew Driller²

Christos Argus^{3,4}

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

² *Department of Sport and Leisure Studies, The University of Waikato, Hamilton, New Zealand*

³ *Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia*

⁴ *ACT Brumbies Rugby, Canberra, Australia*

Corresponding Author

✉ Mr Nattai Borges
School of Medical and Applied Sciences
Central Queensland University
Bruce Highway
Rockhampton, Queensland, 4702
Australia
Phone : +61 7 4930 9720
Email: n.borges@cqu.edu.au

Abstract Word Count: 227

Number of References: 95

Text-Only Word Count: 4881

Number of Figures and Tables: 3

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

2 **A Narrative Review**

3 **Submission Type:** Literature Review

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

1 **Abstract**

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

12
13

14

15

16

17

18

19

20

21

22

23

24

1 1 Introduction

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

12 Historically, these age-related declines were thought to be due to the normal ageing process. However, research
13 has consistently shown improvements in the physical capacities of older sedentary individuals following physical
14 training (Burd, Gorissen, & van Loon, 2013; Steib, Schoene, & Pfeifer, 2010; Woo et al., 2006). These findings
15 suggest that a major contributor to the declines in physiological systems may be both the reduced physical activity
16 levels into older age (Reaburn, Macgregor, & Climstein, 2013) and an observed age-related reduction in sports
17 participation (Foster, Wright, Battista, & Porcari, 2007; Hawkins, Wiswell, & Marcell, 2003; Tanaka & Seals,
18 2008).

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

25 To date, there is limited research (Easthope et al., 2010; Sultana et al., 2012) and anecdotal evidence to suggest
26 that as athletes age they may exhibit impaired recovery kinetics (time taken to recover from a given exercise bout)
27 compared to younger athletes. Consequently, age-related reductions in recovery kinetics may have an effect on
28 subsequent bouts of exercise training, leading to a reduction in overall training load and a potentially increased

1 risk of injury. A previous review (Fell & Williams, 2008) has examined the effect of age on skeletal muscle
2 recovery after exercise although due to the paucity of research into masters athletes at the time, the review relies
3 on a tentative link between animal studies and investigations comparing young and non-athletic older populations
4 to draw conclusions about a possible age effect on recovery. Recent research comparing younger and masters
5 athletes has increased knowledge in this specific population and shown the significance of neuromuscular
6 recovery in masters athletes. Despite this, limited research has empirically examined recovery kinetics of older
7 versus younger athletes (Bieuzen, Hausswirth, Louis, & Brisswalter, 2010; Darr et al., 1988; Easthope et al., 2010;
8 Fell, Haseler, Gaffney, Reaburn, & Harrison, 2006; Fell, Reaburn, & Harrison, 2008). Moreover, the possible
9 mechanisms explaining the slower recovery kinetics in older athletes remain to be investigated. This narrative
10 review will examine the effects that physical activity and systematic training may have on performance and
11 recovery in both sedentary and athletic ageing populations and highlight the need for further research into recovery
12 within masters athletes.

13 **2 Methods**

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

20 **3 The Effects of Physical Activity and the Ageing Process on Physical Performance**

21 The ageing process leads to a number of physical changes in both a normal ageing and masters athlete populations
22 that can affect aerobic and anaerobic performance (Brisswalter, Wu, Sultana, Bernard, & Abbiss, 2014; Reaburn
23 & Dascombe, 2009; Tanaka & Seals, 2008) as well as muscular strength and power performance (Burd et al.,
24 2013; Korhonen et al., 2012; Louis et al., 2012; Peiffer et al., 2010b).

25 Sedentary Ageing Population and Physical Performance

26 Both maximal oxygen uptake and maximal heart rate have been shown to be reduced in a normal ageing
27 population (Carrick-Ranson et al., 2013; Sabapathy, Schneider, Comadira, Johnston, & Morris, 2004). Similarly,
28 muscular strength and power have also been shown to decline in ageing sedentary populations (Cruz-Jentoft et al.,

1 2014; Kostka, 2005; Peiffer et al., 2010b). An investigation of 301 sedentary healthy Australian males and females
2 demonstrated that younger participants were significantly stronger as measured by one-repetition maximum
3 strength tests (chest press, seated row, leg extension and leg press) and performed significantly better in functional
4 performance tests such as a 400m walk, 6m walk, 6m backwards walk and sit to stands than individuals over 65
5 years of age (Peiffer et al., 2010b). These decreases in strength and functional abilities have been suggested to be
6 linked with a decreasing muscle cross-sectional area specifically in type II muscle fibres in older sedentary
7 individuals (Gouzi et al., 2013).

8 High intensity training such as resistance training into older age has also been shown to enhance muscular strength
9 and power performance (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010; Latham, Bennett, Stretton, &
10 Anderson, 2004; Steib et al., 2010). An investigation by Deley et al. (2007) demonstrated similar significant
11 improvements in physical parameters in elderly (>70 years) sedentary subjects following one year of moderate
12 intensity training. The researchers reported that training for one hour three times a week with a combination of
13 aerobic, strength, and flexibility exercises, plus adapted Tai-chi, lead to significant improvements in maximal
14 oxygen uptake (14.8%), distance walked in six minutes (10%), and maximal muscle strength of the knee extensors
15 (15.2%) and plantar flexors (17.4%) in the intervention group compared to a an age-matched control group who
16 maintained normal activity levels. Therefore, in a normal ageing population the research suggests that physical
17 performance decreases with age although improvements can be made through systematic physical training.

18 The Masters Athlete and Physical Performance

19 Similar trends are reported in masters athletes as declines in both maximal oxygen consumption and maximal
20 heart rate have been observed in masters athletes from a range of sports (Gent & Norton, 2013; Kusy & Zielinski,
21 2014). Peak endurance performance has been shown to be maintained until approximately the age of 35 years
22 after which it declines slowly until the age of 50-60 years after which there is an increased rate of decline due
23 primarily to a decrease in maximal oxygen consumption (Pimentel, Gentile, Tanaka, Seals, & Gates, 2003;
24 Ransdell, Vener, & Huberty, 2009; Tanaka & Seals, 2008).Decreases in the strength and power have also been
25 observed in an ageing athletic population by Korhonen et al. (2006) who reported that both type II muscle fibre
26 size and maximal voluntary contraction (MVC) were significantly lower in 75 male masters sprint runners aged
27 40-87 years old compared to 16 younger adult male sprinters aged 18-33 years. However, when compared with
28 age-matched or younger sedentary groups, muscle integrity was well preserved in the masters sprinters group.

1 This finding strongly suggests that systematic sprint training into older age may attenuate the loss of type II muscle
2 fibre size.

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

9 Taken together, the above research strongly suggests that although physical performance decrements occur with
10 age in both sedentary and athletic populations, specific systematic training in older individuals leads to significant
11 physical adaptations that can attenuate the age-related declines in capacities that effect physical performance.
12 Furthermore, given an age-related increase in sedentary lifestyle (Breuer, Hallmann, Wicker, & Feiler, 2010), it
13 might be suggested that the commonly observed age-related decreases in physical performance parameters may
14 be due to age-related decreases in physical activity rather than the ageing process *per se*. Therefore, masters
15 athletes may be seen as a population of research interest given that their physical capacities and levels of
16 systematic training may produce an independent effect of age on physical performance and highlight the
17 importance of continuing participation in sport into older age.

18 **4 Masters Athletes**

19 Despite the typically observed age-related decrements in physical performance in masters athletes (Bernard et al.,
20 2009; Gent & Norton, 2013; Peiffer, Abbiss, Chapman, Laursen, & Parker, 2008), the numbers of masters athletes
21 participating in sport is increasing and their performances relative to their age groups have been increasing over
22 time (Hajkowicz, Cook, Wilhelmseder, & Boughen, 2013; Ransdell et al., 2009). Since the commencement of the
23 World Masters Games held in Toronto in 1985 there has been a 245% increase in competitors from 107 countries
24 competing in 30 sports (International Masters Games Association, 2013). Increasing participation rates are not
25 limited solely to the World Masters Games, as similar increases in participation have been reported in individual
26 sports. For example, Figure 1 illustrates the number of participants that were able to finish during the Olympic
27 distance triathlon world championships in both 2004 and 2007.

28
INSERT FIGURE 1 HERE

1 The increase in the number of participants over 45 years of age that completed the triathlon increased by 65%
2 over a four year period. A similar increase in participation rates at the Hawaii Ironman world championships has
3 been reported by Lepers et al. (2013) with an 80% increase in male and 104% increase in female participants
4 over 40 years of age completing the race. Interestingly, the same researchers also reported an increased
5 performance relative to age groups in all three disciplines of triathlon from 1986 to 2010 in male competitors over
6 45 years and female competitors over 40 years (Lepers et al., 2013). These results suggest that masters athletes
7 are participating in systematic training programs and organised competitions at an increasing rate into older age.

8 Despite the increasing participation rates of masters athletes, only a small number of studies have investigated the
9 training practices of masters athletes (Berger et al., 2006; Macgregor, Reaburn, & Climstein, 2013). Any age-
10 related changes to training intensity or volume when comparing masters athletes to younger athletes seems to be
11 equivocal. Some research suggests there is a significant reduction in training volume and running performance
12 in well-trained runners over 50 years of age compared to runners under the age of 50 years (Pimentel et al., 2003).
13 The reduction in training volume may explain the commonly observed age-related decrease in endurance
14 performance. However, more recent research has reported that older athletes still report high training volumes
15 relative to younger athletes (Berger et al., 2006; Macgregor et al., 2013).

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

27 In support of this suggestion, a recent investigation by Brisswalter et al. (2014) observed an effect of age on both
28 aerobic and anaerobic performance in well trained triathletes ($n = 60$) aged 20-29 years; 30-39 years; 40-49 years;
29 50-59 years; 60-69 years and older than 70 years who reported no difference in weekly training volume. The study

1 participants performed an incremental cycling test, a 10 minute sub-maximal cycling test, and maximal sprint
2 cycle tests to determine both aerobic and anaerobic function. Maximal oxygen consumption ($-17.1 \pm 6.6 \%$) and
3 maximal aerobic power ($-15.6 \pm 0.4 \%$) showed significant differences between the 50-59 year age group and 20-
4 29 year age group. The age-related decrease in aerobic performance continued with age with the over 70 year age
5 group reporting even greater decreases in maximal oxygen consumption ($-37.3 \pm 0.5 \%$) and maximal aerobic
6 power ($-38.4 \pm 6.8\%$) compared to the younger 20-29 year group. Additionally, the researchers reported an age
7 effect on both cycling efficiency and sprint performance. A significant difference in cycling efficiency was also
8 observed in the 50-59 year group ($-7.3 \pm 1.8\%$) compared to the 20-29 year group. Finally, the researchers also
9 observed that significant differences in peak sprint power between all age groups older than 40 years. This
10 comprehensive investigation strongly suggests that although masters triathletes can maintain similar training
11 volumes into older age they still demonstrate decrements in both aerobic and anaerobic cycle performance into
12 older age.

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

26 In summary, the ability of masters athletes (Bieuzen et al., 2010; Darr et al., 1988; Fell et al., 2008; Louis et al.,
27 2012) to improve and maintain physical performance and capacities through specific systematic training into older
28 age has been demonstrated in recent studies. Moreover, it appears that both resistance and concurrent training
29 (combined endurance and resistance training) may play a greater role in masters athletes to help maintain muscle

1 strength and anaerobic capacity into older age. Although specific systematic training is important to an athlete's
2 development, the athlete's ability to overcome fatigue and recover from a previous training or competition bout
3 is just as important (Buchheit et al., 2013; Carfagno & Hendrix, 2014).

4 **5 Importance of Recovery for Sports Performance**

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

10 The acute recovery phase immediately post-exercise consists mainly of rapidly returning the cardiovascular
11 system to near homeostatic resting values and the immediate removal of biochemical by-products accumulated
12 during exercise such as the buffering of hydrogen and inorganic phosphate ions shortly following cessation of
13 exercise to restore homeostatic pH (Burke, 2010; Siegler & Robergs, 2005). Consequently, marked decreases in
14 autonomic sympathetic drive, heart rate, oxygen consumption and various changes to haematological plasma
15 levels and hormone profiles occur to return physiological systems back to resting states (Aubert, Seps, & Beckers,
16 2003; Daanen et al., 2012; Leti & Bricout, 2013; Nybo et al., 2013; Sachdev & Davies, 2008). Furthermore, there
17 is an up-regulation of absorption of glucose and protein to increase protein synthesis and glycogen refuelling to
18 return muscles to a pre-exercise state (Hauswirth & Meur, 2011). Although these processes may continue into
19 the chronic phase of recovery, their kinetics are exponentially reduced in the chronic phase of recovery.

20 The chronic recovery phase is generally observed to last up to 72 hours post-exercise but, depending on the
21 intensity and duration of the exercise stimulus, may last longer (Ascensao et al., 2008; Brancaccio, Lippi, &
22 Maffulli, 2010; Jurimae, Maestu, Purge, & Jurimae, 2004; Sachdev & Davies, 2008). Chronic recovery post-
23 exercise can be quantified as the time it takes to restore physical performance back to pre-exercise values (Nédélec
24 et al., 2012). This phase of recovery consists of restoring the morphological, physiological and biomechanical
25 changes that may have occurred due to the oxidative and mechanical stresses of exercise (Allman & Rice, 2001;
26 Brancaccio et al., 2010; Easthope et al., 2010; Hartmann & Mester, 2000; Klein, Cunningham, Paterson, & Taylor,
27 1988; Louis et al., 2009; Ploutz-Snyder, Giamis, Formikell, & Rosenbaum, 2001; Sultana et al., 2012). Once an
28 athlete has returned to pre-exercise performance values, they are deemed to have physically recovered from the

1 prior exercise bout. Psychological, emotional and mental strain can also reduce overall recovery from a previous
2 exercise bout and should also be considered when attempting to quantify and improve recovery kinetics (Wagstaff,
3 2014). Due to the multifaceted nature of recovery, pinpointing a single causative effect that age may have on
4 recovery kinetics is unlikely. Any age-effect on recovery kinetics is most likely to be individual and due to an
5 alteration of one or more of the processes detailed above. However, recovery kinetics in masters athletes is a
6 significant issue as it can not only have an effect on subsequent sports performance but potentially also the
7 incidence of injury (Kreher & Schwartz, 2012).

8

9 Recovery and Incidence of Injury

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

20

21 At present, the research reports contradictory findings when investigating injury rates in masters athletes with
22 studies reporting less incidence of injury (Heazlewood et al., 2014) and no difference in the incidence of injury
23 (Walsh et al., 2013) in masters athletes when compared to younger cohorts in both team sports and swimming.
24 However, an increase incidence of injury has been reported in masters runners compared to younger runners
25 (McKean, Manson, & Stanish, 2006), specifically overuse injuries (Knobloch, Yoon, & Vogt, 2008). The results
26 of a survey of 2886 runners of which 34% consisted of masters runners (≥ 40 years) reported that masters runners
27 were significantly more prone to injury than a younger cohort of runners. Specifically, this investigation reported
28 that soft-tissue injuries to the calf, achillies tendon and hamstrings were significantly greater in the masters runners.
29 Although there was an increased reporting of the incidence of injury in masters runners, there was also a
30 significantly greater number of masters runners completing more than 30 miles per week and training more than

1 six times a week compared to younger runners. Therefore, it is difficult to conclude that with age masters runners
2 suffer a greater incidence of injury as the increased training volume in the masters runners would lead to greater
3 accumulative compressive and eccentric forces through the lower limbs. The increased training volume could
4 predispose the masters runners to a greater risk of injury and this could explain the heterogeneous results in the
5 research between sports. Despite the heterogeneity of current research, recovery after exercise remains an
6 important issue and to reduce the incidence of injury and decrease the time taken in recovery following exercise
7 a number of recovery interventions or strategies have been utilised in younger athletic populations. Currently the
8 efficacy of these recovery strategies in masters athletes is poorly documented and understood.

9

10 Recovery Strategies

11 The importance of effectively recovering from a training bout in athletes of any age is well documented (Barnett,
12 2006; Vaile, Halson, & Graham, 2010). Frequently utilised recovery interventions include active recovery
13 (Greenwood, Moses, Bernardino, Gaesser, & Weltman, 2008; Menzies et al., 2010), stretching (Torres, Pinho,
14 Duarte, & Cabri, 2013), compression garments (Bottaro, Martorelli, & Vilaça, 2011; Driller & Halson, 2013;
15 Duffield et al., 2008; MacRae, Cotter, & Laing, 2011), hydrotherapy including cold water immersion and contrast
16 water immersion (Peiffer, Abbiss, Watson, Nosaka, & Laursen, 2010a; Versey, Halson, & Dawson, 2013), sleep
17 (Venter, 2012), massage (Wiltshire et al., 2010), and nutrition (Beelen, Burke, Gibaia, & Van Loon, 2010).

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

1 **6 Current Research on Recovery Kinetics of Masters Athletes**

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

4 INSERT TABLE 1 HERE

5 A recent investigation by Sultana et al. (2012) examined levels of recovery in nine young (28 ± 6.1 years) and 10
6 masters (52.4 ± 10 years) triathletes following an Olympic distance triathlon. The researchers measured baseline
7 muscle strength and cardiovascular parameters prior to the triathlon and compared them to 24 hours post-triathlon
8 measures. Neither age group showed decreased muscular strength (MVC) 24 hours post-triathlon. Furthermore,
9 both young and masters triathletes showed similar decrements in cardiovascular parameters including maximal
10 oxygen consumption and running velocity at maximal oxygen consumption 24 hours post-triathlon. Only speed
11 at ventilatory threshold 2 was significantly different between the masters (-8.3 %) and younger (-2.5 %) triathletes
12 24 hours following the Olympic distance triathlon. Given that the velocity at ventilatory thresholds have been
13 shown to be a valid predictor of endurance performance (Amann, Subudhi, & Foster, 2006), this finding suggests
14 an age-related decrease in subsequent endurance performance in masters versus younger endurance athletes.

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

1 Similar findings of reduced recovery of neuromuscular function with muscle damaging exercise have been
2 reported following bouts of resistance training in masters athletes. For example, Bieuzen et al. (2010) compared
3 neuromuscular performance in 16 endurance-trained masters athletes (66.1 ± 5.8 years) and 10 younger
4 endurance-trained athletes (25.4 ± 4.6 years) following a resistance training protocol consisting of 10 sets of 10
5 repetitions of horizontal leg press at 70% maximum. The researchers measured MVC and electrically evoked
6 contractions and reported that both groups demonstrated a reduced MVC (masters = -9.7%; young = -14.3%)
7 following the resistance training protocol. No between-group differences were observed in MVC or
8 electromyography activity following the training protocol. However, the researchers reported a significantly
9 decreased peak twitch in the masters (-25.8%) compared to the younger endurance-trained men who showed no
10 change in peak twitch. This supports the suggestion that neuromuscular fatigue and recovery may differ in masters
11 versus younger athletes following muscle damaging exercise which may cause a delay in overall recovery from
12 prior exercise.

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

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

1 in 9 younger (24 ± 5 years) and 9 masters (45 ± 6 years) cyclists in MVC, countermovement jump and 10-second
2 sprint performance or creatine kinase levels after each time trial.

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

11 Similar recovery trends in masters athletes were also reported by Darr et al. (1988) who investigated the acute
12 recovery of heart rate following maximal exercise. Male subjects ($n = 20$) were divided by age and training status
13 (peak oxygen consumption) into four age groups: young trained (24 ± 2 years), old trained (51 ± 2 years), young
14 untrained (25 ± 3 years) and old untrained (57 ± 4 years). The participants fast (5 – 120 seconds) and slow (120 –
15 240 seconds) phases of heart rate recovery kinetics were measured following maximal graded exercise test on a
16 cycle ergometer. The researchers reported no significant difference in heart rate recovery curve slopes when
17 comparing younger and older participants of trained or untrained status. However, they did observe a significant
18 difference between training groups with the trained groups exhibiting significantly steeper heart rate recovery
19 curve slopes in their recovery kinetics, with heart rate in both young and older trained groups, returning to baseline
20 values at significantly accelerated rate than their age-matched untrained groups. These results suggest that
21 reduced training status has an effect on acute recovery kinetics, specifically on heart rate. In contrast, the results
22 suggest that age has no effect on the kinetics of heart rate recovery following maximal exercise in similarly-trained
23 individuals.

24 In summary, limited research has examined recovery from prior exercise in young versus older athletes. Thus, it
25 is difficult to conclusively state that there is a significant effect of age on recovery kinetics following an exercise
26 bout. Due to the fact that the recovery process in a masters athlete population is poorly understood, future research
27 investigating the recovery kinetics of masters athletes should initially focus on confirming or refuting any age-
28 effect on recovery kinetics. Furthermore, future research into the recovery kinetics of masters athletes should
29 separate both the acute and chronic phases of recovery to investigate which specific parameters may be causing a

1 difference or delay in recovery kinetics in masters athletes versus younger, similarly-trained athletes. If a delay in
2 the recovery kinetics is identified, further research may then focus on strategies such as modified monitoring of
3 masters athletes' training loads, the inclusion of resistance or concurrent training to combat delays in recovery
4 kinetics, or greater use of recovery strategies in masters athletes, and the efficacy of commonly used recovery
5 strategies in masters athletes.

6 **7 Conclusion**

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

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

21 **Acknowledgments**

22 This research manuscript project has been supported by the CQUniversity *HEALTH*
23 *CRN* www.cqu.edu.au/crn and the Australian Government's Collaborative Research Networks Program. The
24 authors have no conflicts of interest that are directly relevant to the content of this review.

25

26

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

References

Aagaard, P., Suetta, C., Caserotti, P., Magnusson, S. P., & Kjær, M. (2010). Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. *Scandinavian Journal of Medicine & Science in Sports*, 20(1), 49-64. doi: 10.1111/j.1600-0838.2009.01084.x

Allman, B. L., & Rice, C. L. (2001). Incomplete recovery of voluntary isometric force after fatigue is not affected by old age. *Muscle & Nerve*, 24(9), 1156-1167.

Amann, M., Subudhi, A. W., & Foster, C. (2006). Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. *Scandinavian Journal of Medicine & Science in Sports*, 16(1), 27-34.

Ari, Z., Kutlu, N., Uyanik, B. S., Taneli, F., & Buyukyazi, G. (2004). Serum testosterone, growth hormone, and insulin-like growth factor-1 levels, mental reaction time, and maximal aerobic exercise in sedentary and long-term physically trained elderly males. *International Journal of Neuroscience*, 114(5), 623-637. doi: 10.1080/00207450490430499

Ascensao, A., Rebelo, A., Oliveira, E., Marques, F., Pereira, L., & Magalhaes, J. (2008). Biochemical impact of a soccer match - analysis of oxidative stress and muscle damage markers throughout recovery. *Clinical Biochemistry*, 41(10-11), 841-851. doi: 10.1016/j.clinbiochem.2008.04.008

Aubert, A. E., Seps, B., & Beckers, F. (2003). Heart rate variability in athletes. *Sports Medicine*, 33(12), 889-919.

Barnett, A. (2006). Using Recovery Modalities between Training Sessions in Elite Athletes: Does it Help? *Sports Medicine*, 36(9), 781-796.

- 1 Beelen, M., Burke, L. M., Gibaia, M. J., & Van Loon, L. J. C. (2010). Nutritional Strategies to Promote
2 Postexercise Recovery. *International Journal of Sport Nutrition and Exercise Metabolism*, 20(6), 515-
3 532.
- 4 Berger, N. J., Rittweger, J., Kwiet, A., Michaelis, I., Williams, A. G., Tolfrey, K., & Jones, A. M. (2006).
5 Pulmonary O₂ uptake on-kinetics in endurance- and sprint-trained master athletes. *International*
6 *Journal of Sports Medicine*, 27(12), 1005-1012. doi: 10.1055/s-2006-923860
- 7 Bernard, T., Sultana, F., Lepers, R., Hausswirth, C., & Brisswalter, J. (2009). Age-Related Decline in Olympic
8 Triathlon Performance: Effect of Locomotion Mode. *Experimental Aging Research*, 36(1), 64-78. doi:
9 10.1080/03610730903418620
- 10 Bieuzen, F., Hausswirth, C., Louis, J., & Brisswalter, J. (2010). Age-related changes in neuromuscular function
11 and performance following a high-intensity intermittent task in endurance-trained men. *Gerontology*,
12 56(1), 66-72. doi: 10.1159/000262286
- 13 Bottaro, M., Martorelli, S., & Vilaça, J. (2011). Neuromuscular Compression Garments: Effects on
14 Neuromuscular Strength and Recovery. *Journal of Human Kinetics*, 27-31.
- 15 Bouzid, M. A., Hammouda, O., Matran, R., Robin, S., & Fabre, C. (2014). Changes in Oxidative Stress Markers
16 and Biological Markers of Muscle Injury with Aging at Rest and in Response to an Exhaustive
17 Exercise. *PloS One*, 9(3), 1-7. doi: 10.1371/journal.pone.0090420
- 18 Brancaccio, P., Lippi, G., & Maffulli, N. (2010). Biochemical markers of muscular damage. *Clinical Chemistry*
19 *and Laboratory Medicine*, 48(6), 757-767. doi: 10.1515/CCLM.2010.179
- 20 Breuer, C., Hallmann, K., Wicker, P., & Feiler, S. (2010). Socio-economic patterns of sport demand and ageing.
21 *European Reviews of Aging & Physical Activity*, 7(2), 61-70.
- 22 Brisswalter, J., Wu, S. S., Sultana, F., Bernard, T., & Abbiss, C. R. (2014). Age difference in efficiency of
23 locomotion and maximal power output in well-trained triathletes. *European Journal of Applied*
24 *Physiology*. doi: 10.1007/s00421-014-2977-8
- 25 Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., . . . Coutts, A. J. (2013).
26 Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football
27 players. *Journal of Science and Medicine in Sport*, 16(6), 550-555. doi:
28 <http://dx.doi.org/10.1016/j.jsams.2012.12.003>
- 29 Burd, N. A., Gorissen, S. H., & van Loon, L. J. (2013). Anabolic resistance of muscle protein synthesis with
30 aging. *Exercise and Sport Sciences Reviews*, 41(3), 169-173. doi: 10.1097/JES.0b013e318292f3d5
- 31 Burke, L. (2010). Fasting and recovery from exercise. *British Journal of Sports Medicine*, 44(7), 502-508. doi:
32 10.1136/bjism.2007.071472
- 33 Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular Function After Exercise-Induced Muscle Damage:
34 Theoretical and Applied Implications. *Sports Medicine*, 34(1), 49-69.
- 35 Carfagno, D. G., & Hendrix, J. C. (2014). Overtraining Syndrome in the Athlete: Current Clinical Practice.
36 *Current Sports Medicine Reports*, 13(1), 45-51 10.1249/JSR.0000000000000027.
- 37 Carrick-Ranson, G., Hastings, J. L., Bhella, P. S., Shibata, S., Fujimoto, N., Palmer, D., . . . Levine, B. D.
38 (2013). The effect of age-related differences in body size and composition on cardiovascular
39 determinants of VO₂max. *The journals of gerontology Series A, Biological sciences and medical*
40 *sciences*, 68(5), 608-616. doi: 10.1093/gerona/gls220
- 41 Cipriani, D. J., Swartz, J. D., & Hodgson, C. M. (1998). Triathlon and the multisport athlete. *Journal of*
42 *Orthopaedic and Sports Physical Therapy*, 27(1), 42-50. doi: 10.2519/jospt.1998.27.1.42
- 43 Conchola, E. C., Thompson, B. J., & Smith, D. B. (2013). Effects of neuromuscular fatigue on the
44 electromechanical delay of the leg extensors and flexors in young and old men. *European Journal of*
45 *Applied Physiology*, 113(9), 2391-2399. doi: 10.1007/s00421-013-2675-y
- 46 Conley, K. E., Jubrias, S. A., & Esselman, P. C. (2000). Oxidative capacity and ageing in human muscle. *The*
47 *Journal of Physiology*, 526(Pt 1), 203-210. doi: 10.1111/j.1469-7793.2000.t01-1-00203.x
- 48 Cristea, A., Korhonen, M. T., Hakkinen, K., Mero, A., Alen, M., Sipila, S., . . . Larsson, L. (2008). Effects of
49 combined strength and sprint training on regulation of muscle contraction at the whole-muscle and
50 single-fibre levels in elite master sprinters. *Acta Physiol (Oxf)*, 193(3), 275-289. doi: 10.1111/j.1748-
51 1716.2008.01843.x
- 52 Cruz-Jentoft, A. J., Landi, F., Schneider, S. M., Zúñiga, C., Arai, H., Boirie, Y., . . . Cederholm, T. (2014).
53 Prevalence of and interventions for sarcopenia in ageing adults: a systematic review. Report of the
54 International Sarcopenia Initiative (EWGSOP and IWGS). *Age and Ageing*, 43(6), 748-759. doi:
55 10.1093/ageing/afu115
- 56 Daanen, H. A., Lamberts, R. P., Kallen, V. L., Jin, A., & Van Meeteren, N. L. (2012). A systematic review on
57 heart-rate recovery to monitor changes in training status in athletes. *International Journal of Sports*
58 *Physiology and Performance*, 7(3), 251-260.
- 59 Darr, K. C., Bassett, D. R., Morgan, B. J., & Thomas, D. P. (1988). Effects of age and training status on heart
60 rate recovery after peak exercise. *The American Journal Of Physiology*, 254(2 Pt 2), H340-H343.

- 1 Deley, G., Kervio, G., Van Hoecke, J., Verges, B., Grassi, B., & Casillas, J. M. (2007). Effects of a one-year
2 exercise training program in adults over 70 years old: a study with a control group. *Aging Clinical and*
3 *Experimental Research*, 19(4), 310-315.
- 4 Driller, & Halson. (2013). The effects of wearing lower body compression garments during a cycling
5 performance test. *International Journal of Sports Physiology and Performance*, 8(3), 300-306.
- 6 Duffield, R., Edge, J., Merrells, R., Hawke, E., Barnes, M., Simcock, D., & Gill, N. (2008). The Effects of
7 Compression Garments on Intermittent Exercise Performance and Recovery on Consecutive Days.
8 *International Journal of Sports Physiology and Performance*, 3(4), 454-468.
- 9 Easthope, C. S., Hausswirth, C., Louis, J., Lepers, R., Vercruyssen, F., & Brisswalter, J. (2010). Effects of a trail
10 running competition on muscular performance and efficiency in well-trained young and master
11 athletes. *European Journal of Applied Physiology*, 110(6), 1107-1116. doi: 10.1007/s00421-010-1597-
12 1
- 13 Fell, J., Haseler, L., Gaffney, P., Reaburn, P., & Harrison, G. (2006). Performance during consecutive days of
14 laboratory time-trials in young and veteran cyclists. *Journal of Sports Medicine and Physical Fitness*,
15 46(3), 395-402.
- 16 Fell, J., Reaburn, P., & Harrison, G. (2008). Altered perception and report of fatigue and recovery in veteran
17 athletes. . *Journal of Sports Medicine and Physical Fitness*, , 48, (2) 272-277.
- 18 Fell, J., & Williams, D. (2008). The effect of aging on skeletal-muscle recovery from exercise: possible
19 implications for aging athletes. *J Aging Phys Act*, 16(1), 97-115.
- 20 Foster, C., Wright, G., Battista, R. A., & Porcari, J. P. (2007). Training in the aging athlete. *Current Sports*
21 *Medicine Reports*, 6(3), 200-206.
- 22 Gent, D. N., & Norton, K. (2013). Aging has greater impact on anaerobic versus aerobic power in trained
23 masters athletes. *Journal of Sports Sciences*, 31(1), 97-103. doi: 10.1080/02640414.2012.721561
- 24 Gouzi, F., Maury, J., Molinari, N., Pomiès, P., Mercier, J., Préfaut, C., & Hayot, M. (2013). Reference values
25 for vastus lateralis fiber size and type in healthy subject over 40 years old: a systematic review and
26 metaanalysis. *Journal of Applied Physiology*, 115(2), 346-354.
- 27 Greenwood, J. D., Moses, G. E., Bernardino, F. M., Gaesser, G. A., & Weltman, A. (2008). Intensity of exercise
28 recovery, blood lactate disappearance, and subsequent swimming performance. *Journal of Sports*
29 *Sciences*, 26(1), 29-34.
- 30 Hagberg, J. M., Seals, D. R., Yerg, J. E., Gavin, J., Gingerich, R., Premachandra, B., & Holloszy, J. O. (1988).
31 Metabolic responses to exercise in young and older athletes and sedentary men. *Journal of Applied*
32 *Physiology*, 65(2), 900-908.
- 33 Hajkowicz, S. A., Cook, H., Wilhelmseder, L., & Boughen, N. (2013). *The Future of Australian Sport:*
34 *Megatrends shaping the sports sector over coming decades. A Consultancy Report for the Australian*
35 *Sports Commission.* Australia.
- 36 Hartmann, U., & Mester, J. (2000). Training and overtraining markers in selected sport events. *Medicine &*
37 *Science in Sports & Exercise*, 32(1), 209-215.
- 38 Hausswirth, C., & Meur, Y. L. (2011). Physiological and Nutritional Aspects of Post-Exercise Recovery
39 Specific Recommendations for Female Athletes. *Sports Medicine*, 41(10), 861-882.
- 40 Hawkins, S. A., Wiswell, R. A., & Marcell, T. J. (2003). Exercise and the master athlete--a model of successful
41 aging? *The journals of gerontology Series A, Biological sciences and medical sciences*, 58(11), 1009-
42 1011.
- 43 Heazlewood, I., Climstein, M., Walsh, J., Adams, K., Sevene, T., DeBeliso, M., . . . Munro, K. (2014). A
44 comparison of injury rates in Masters Athletes across different sports. *Journal of Science and Medicine*
45 *in Sport*, 18, Supplement 1(0), e107. doi: <http://dx.doi.org/10.1016/j.jsams.2014.11.388>
- 46 International Masters Games Association. (2013). from <http://www.imga.ch/>
- 47 Jurimae, J., Maestu, J., Purge, P., & Jurimae, T. (2004). Changes in stress and recovery after heavy training in
48 rowers. *Journal of Science and Medicine in Sport*, 7(3), 335-339.
- 49 Klein, C., Cunningham, D. A., Paterson, D. H., & Taylor, A. W. (1988). Fatigue and recovery contractile
50 properties of young and elderly men. *European Journal of Applied Physiology and Occupational*
51 *Physiology*, 57(6), 684-690.
- 52 Knobloch, K., Yoon, U., & Vogt, P. M. (2008). Acute and Overuse Injuries Correlated to Hours of Training in
53 Master Running Athletes. *Foot and Ankle International*, 29(7), 671-676. doi: 10.3113/fai.2008.0671
- 54 Korhonen, M. T., Cristea, A., Alen, M., Hakkinen, K., Sipila, S., Mero, A., . . . Suominen, H. (2006). Aging,
55 muscle fiber type, and contractile function in sprint-trained athletes. *Journal of Applied Physiology*,
56 101(3), 906-917. doi: 10.1152/jappphysiol.00299.2006
- 57 Korhonen, M. T., Heinonen, A., Siekinen, J., Isolehto, J., Alen, M., Kiviranta, I., & Suominen, H. (2012).
58 Bone density, structure and strength, and their determinants in aging sprint athletes. *Medicine &*
59 *Science in Sports & Exercise*, 44(12), 2340-2349. doi: 10.1249/MSS.0b013e318267c954

- 1 Kostka, T. (2005). Quadriceps maximal power and optimal shortening velocity in 335 men aged 23–88 years.
2 *European Journal of Applied Physiology*, 95(2/3), 140-145. doi: 10.1007/s00421-005-1390-8
- 3 Kreher, J. B., & Schwartz, J. B. (2012). Overtraining syndrome: a practical guide. *Sports Health*, 4(2), 128-138.
4 doi: 10.1177/1941738111434406
- 5 Kusy, K., & Zielinski, J. (2014). Aerobic capacity in speed-power athletes aged 20-90 years vs endurance
6 runners and untrained participants. *Scandinavian Journal of Medicine & Science in Sports*, 24(1), 68-
7 79. doi: 10.1111/j.1600-0838.2012.01496.x
- 8 Lanfranco, F., Gianotti, L., Giordano, R., Pellegrino, M., Maccario, M., & Arvat, E. (2003). Ageing, growth
9 hormone and physical performance. *Journal of Endocrinological Investigation*, 26(9), 861-872.
- 10 Latham, N. K., Bennett, D. A., Stretton, C. M., & Anderson, C. S. (2004). Systematic review of progressive
11 resistance strength training in older adults. *The journals of gerontology Series A, Biological sciences*
12 *and medical sciences*, 59(1), 48-61.
- 13 Lepers, R., Rust, C. A., Stapley, P. J., & Knechtle, B. (2013). Relative improvements in endurance performance
14 with age: evidence from 25 years of Hawaii Ironman racing. *Age (Dordr)*, 35(3), 953-962. doi:
15 10.1007/s11357-012-9392-z
- 16 Leti, T., & Bricout, V. A. (2013). Interest of analyses of heart rate variability in the prevention of fatigue states
17 in senior runners. *Autonomic Neuroscience*, 173(1-2), 14-21. doi: 10.1016/j.autneu.2012.10.007
- 18 Louis, J., Hausswirth, C., Bieuzen, F., & Brisswalter, J. (2009). Muscle strength and metabolism in master
19 athletes. *International Journal of Sports Medicine*, 30(10), 754-759. doi: 10.1055/s-0029-1231046
- 20 Louis, J., Hausswirth, C., Easthope, C., & Brisswalter, J. (2012). Strength training improves cycling efficiency
21 in master endurance athletes. *European Journal of Applied Physiology*, 112(2), 631-640. doi:
22 10.1007/s00421-011-2013-1
- 23 Macgregor, C., Reaburn, P. R., & Climstein, M. (2013). The Effect of Age on Training Practices in Veteran
24 Cyclists: An Australian Study. *Medicine & Science in Sports & Exercise*, 45(5S), 1-720
- 25 MacRae, B. A., Cotter, J. D., & Laing, R. M. (2011). Compression Garments and Exercise Garment
26 Considerations, Physiology and Performance. *Sports Medicine*, 41(10), 815-843.
- 27 McKean, K. A., Manson, N. A., & Stanish, W. D. (2006). Musculoskeletal Injury in the Masters Runners.
28 *Clinical Journal of Sport Medicine*, 16(2), 149-154.
- 29 Menzies, P., Menzies, C., McIntyre, L., Paterson, P., Wilson, J., & Kemi, O. J. (2010). Blood lactate clearance
30 during active recovery after an intense running bout depends on the intensity of the active recovery.
31 *Journal of Sports Sciences*, 28(9), 975-982.
- 32 Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2012). Recovery in Soccer: Part I -
33 Post-Match Fatigue and Time Course of Recovery. *Sports Medicine*, 42(12), 997-1015.
- 34 Neder, J. A., Jones, P. W., Nery, L. E., & Whipp, B. J. (2000). The effect of age on the power/duration
35 relationship and the intensity-domain limits in sedentary men. *European Journal of Applied*
36 *Physiology*, 82(4), 326.
- 37 Nybo, L., Girard, O., Mohr, M., Knez, W., Voss, S., & Racinais, S. (2013). Markers of muscle damage and
38 performance recovery after exercise in the heat. *Medicine & Science in Sports & Exercise*, 45(5), 860-
39 868. doi: 10.1249/MSS.0b013e31827ded04
- 40 Ogawa, T., Spina, R. J., Martin, W. H., 3rd, Kohrt, W. M., Schechtman, K. B., Holloszy, J. O., & Ehsani, A. A.
41 (1992). Effects of aging, sex, and physical training on cardiovascular responses to exercise.
42 *Circulation*, 86(2), 494-503.
- 43 Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P., B. (2010a). Effect of a 5-min cold-water
44 immersion recovery on exercise performance in the heat. *British Journal of Sports Medicine*, 44(6),
45 461-465.
- 46 Peiffer, J. J., Abbiss, C. R., Chapman, D., Laursen, P. B., & Parker, D. L. (2008). Physiological characteristics
47 of masters-level cyclists. *Journal of Strength and Conditioning Research*, 22(5), 1434-1440. doi:
48 10.1519/JSC.0b013e318181a0d2
- 49 Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., . . . Newton, R. U. (2010b). Strength and
50 functional characteristics of men and women 65 years and older. *Rejuvenation Res*, 13(1), 75-82. doi:
51 10.1089/rej.2009.0916
- 52 Pimentel, A. E., Gentile, C. L., Tanaka, H., Seals, D. R., & Gates, P. E. (2003). Greater rate of decline in
53 maximal aerobic capacity with age in endurance-trained than in sedentary men. *Journal of Applied*
54 *Physiology*, 94(6), 2406-2413.
- 55 Ploutz-Snyder, L. L., Giamis, E. L., Formikell, M., & Rosenbaum, A. E. (2001). Resistance training reduces
56 susceptibility to eccentric exercise-induced muscle dysfunction in older women. *The journals of*
57 *gerontology Series A, Biological sciences and medical sciences*, 56(9), B384-390.
- 58 Ransdell, L. B., Vener, J., & Huberty, J. (2009). Masters Athletes: An Analysis of Running, Swimming and
59 Cycling Performance by Age and Gender. *Journal of Exercise Science & Fitness*, 7(2, Supplement),
60 S61-S73. doi: [http://dx.doi.org/10.1016/S1728-869X\(09\)60024-1](http://dx.doi.org/10.1016/S1728-869X(09)60024-1)

- 1 Reaburn, P., & Dascombe, B. (2009). Anaerobic performance in masters athletes. *European Reviews of Aging &*
2 *Physical Activity*, 6(1), 39-53.
- 3 Reaburn, P. R., Macgregor, C., & Climstein, M. (2013). *Poor Use Of Post-exercise Recovery Strategies In*
4 *Veteran Cyclists: An Australian Study*. Paper presented at the Medicine & Science in Sports &
5 Exercise.
- 6 Sabapathy, S., Schneider, D. A., Comadira, G., Johnston, I., & Morris, N. R. (2004). Oxygen uptake kinetics
7 during severe exercise: a comparison between young and older men. *Respiratory Physiology &*
8 *Neurobiology*, 139(2), 203-213. doi: 10.1016/j.resp.2003.09.008
- 9 Sachdev, S., & Davies, K. J. (2008). Production, detection, and adaptive responses to free radicals in exercise.
10 *Free Radical Biology and Medicine*, 44(2), 215-223. doi: 10.1016/j.freeradbiomed.2007.07.019
- 11 Siegler, J. C., & Robergs, R. A. (2005). Metabolite accumulation & subsequent recovery from short-term,
12 intense exercise to exhaustion: A review. *Journal of Exercise Physiology Online*, 8(3), 1-10.
- 13 Simoes, R. P., Bonjorno, J. C., Jr., Beltrame, T., Catai, A. M., Arena, R., & Borghi-Silva, A. (2013). Slower
14 heart rate and oxygen consumption kinetic responses in the on- and off-transient during a discontinuous
15 incremental exercise: effects of aging. *Revista Brasileira de Fisioterapia*, 17(1), 69-76.
- 16 Steib, S., Schoene, D., & Pfeifer, K. (2010). Dose-response relationship of resistance training in older adults: a
17 meta-analysis. *Medicine & Science in Sports & Exercise*, 42(5), 902-914. doi:
18 10.1249/MSS.0b013e3181c34465
- 19 Stockwell, T. B., McKean, M. R., & Burkett, B. J. (2012). Response to Constant and Interval Exercise Protocols
20 in the Elderly. *Journal of Exercise Physiology Online*, 15(2), 30-39.
- 21 Stone, M. H., Sands, W. A., Carlock, J., Callan, S., Dickie, D., Daigle, K., . . . Hartman, M. (2004). The
22 importance of isometric maximum strength and peak rate-of-force development in sprint cycling.
23 *Journal of Strength and Conditioning Research*, 18(4), 878-884.
- 24 Sultana, F., Abbiss, C. R., Louis, J., Bernard, T., Hausswirth, C., & Brisswalter, J. (2012). Age-related changes
25 in cardio-respiratory responses and muscular performance following an Olympic triathlon in well-
26 trained triathletes. *European Journal of Applied Physiology*, 112(4), 1549-1556. doi: 10.1007/s00421-
27 011-2115-9
- 28 Tanaka, H., & Seals, D. R. (2008). Endurance exercise performance in Masters athletes: age-associated changes
29 and underlying physiological mechanisms. *Journal of Physiology*, 586(1), 55-63. doi:
30 10.1113/jphysiol.2007.141879
- 31 Torres, R., Pinho, F., Duarte, J. A., & Cabri, J. M. H. (2013). Effect of single bout versus repeated bouts of
32 stretching on muscle recovery following eccentric exercise. *Journal of Science and Medicine in Sport*,
33 16(6), 583-588.
- 34 Vaile, J., Halson, S., & Graham, S. (2010). Recovery review--science vs. Practice. *Journal of Australian*
35 *Strength & Conditioning*, 18(S2), 5-21.
- 36 Venter, R. E. (2012). Role of sleep in performance and recovery of athletes: A review article. *South African*
37 *Journal for Research in Sport, Physical Education & Recreation*, 34(1), 167-184.
- 38 Venter, R. E., Potgieter, J. R., & Barnard, J. G. (2010). The use of recovery modalities by elite South African
39 team athletes. *South African Journal for Research in Sport, Physical Education & Recreation*, 32(1),
40 133-145.
- 41 Versey, N., Halson, S., & Dawson, B. (2013). Water Immersion Recovery for Athletes: Effect on Exercise
42 Performance and Practical Recommendations. *Sports Medicine*, 43(11), 1101-1130.
- 43 Vigorito, C., & Giallauria, F. (2014). Effects of exercise on cardiovascular performance in the elderly. *Frontiers*
44 *in Physiology*, 4/5, 1-8. doi: 10.3389/fphys.2014.00051
- 45 Wagstaff, C. R. D. (2014). Emotion Regulation and Sport Performance. *Journal of Sport & Exercise*
46 *Psychology*, 36(4), 401-412.
- 47 Walsh, J., Climstein, M., Heazlewood, I. T., DeBeliso, M., Kettunen, J., Sevene, T. G., & Adams, K. J. (2013).
48 Masters athletes: No evidence of increased incidence of injury in football code athletes. *Advances in*
49 *Physical Education*, 3(01), 36.
- 50 Wiltshire, E. V., Poitras, V., Pak, M., Hong, T., Rayner, J., & Tschakovsky, M. E. (2010). Massage impairs
51 postexercise muscle blood flow and "lactic acid" removal. *Medicine & Science in Sports & Exercise*,
52 42(6), 1062-1071. doi: 10.1249/MSS.0b013e3181c9214f
- 53 Woo, J. S., Derleth, C., Stratton, J. R., & Levy, W. C. (2006). The Influence of Age, Gender, and Training on
54 Exercise Efficiency. *Journal of the American College of Cardiology*, 47(5), 1049-1057. doi:
55 <http://dx.doi.org/10.1016/j.jacc.2005.09.066>
56
57

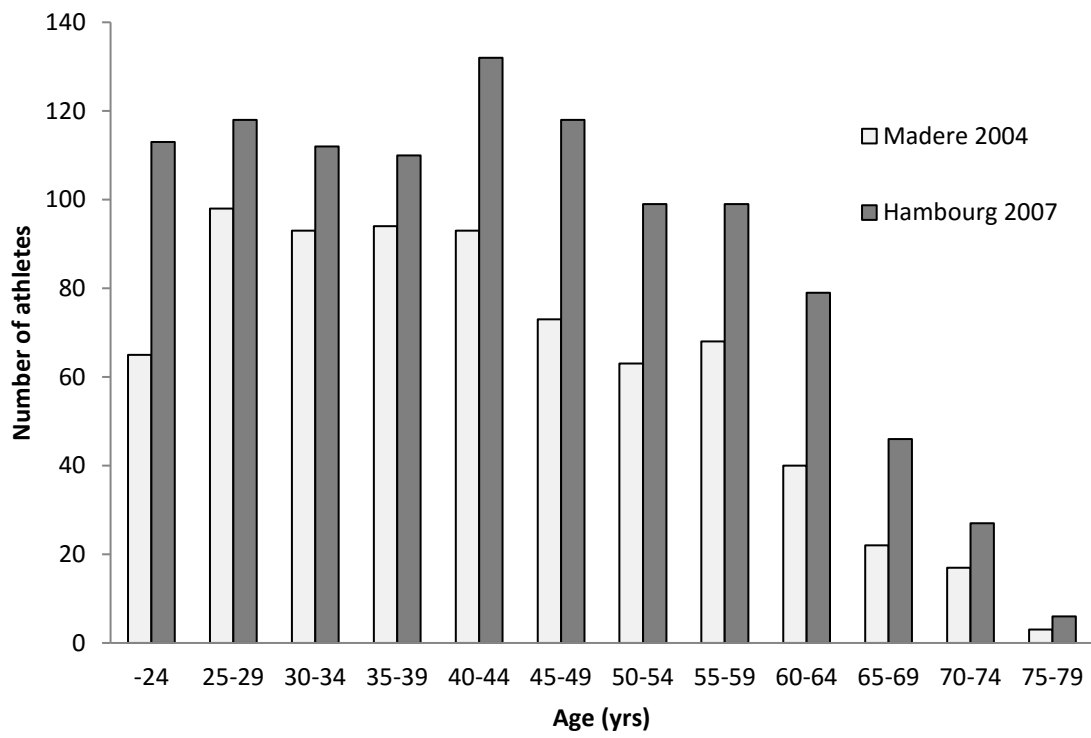


Figure 1 Completion rates of Triathlon World Championships in age groups. Figure adapted from Bernard et al., (2009)

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, VO _{2max} , \dot{V} VO _{2max} , \dot{V} VT1, \dot{V} VT2 & running economy.	Pre, 24 hr post	Significantly slower 24hr post \dot{V} VT2 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 _M	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; DE = Delta Efficiency