

# **EXERCISE-INDUCED FATIGUE AND RECOVERY IN THE AGEING ATHLETE**

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**Doctor of Philosophy**

By

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*'I don't believe one grows older. I  
think that what happens early on in  
life is that at a certain age one  
stands still and stagnates.'*

T. S. Eliot

## **ABSTRACT**

There is a common belief among older athletes that intense training becomes more difficult with ageing. One of the reasons attributed to this performance limitation is an impairment of recovery processes that can prolong the time taken for the body to adequately adapt between training sessions or after competition. However, there has been limited research to address this assumption through the investigation of recovery of performance after training or competition in well-trained older athletes.

This thesis reviews the literature pertaining to ageing and exercise with particular reference to athletic performance, muscle damage and muscle repair/regeneration, with the intention of exploring the effects of ageing on training, overload and recovery from exercise in the well-trained ageing athlete. Two arguments are presented for an impaired recovery from training and competition in the older athlete. The first is that muscle damage after exercise is greater in the older athlete, and the second is that tissue repair is slower, both factors potentially prolonging recovery duration. The importance of adequate nutrition for recovery in athletes is recognised and discussed in regard to optimising recovery and to identify any specific dietary requirements or limitations that might be unique to the ageing athlete.

Therefore, the aims of this thesis were to:

1. describe the common beliefs and practices amongst athletes regarding ageing and recovery from intense training and competition demands,
2. assess and compare the nutrient intake of young and ageing athletes via the completion of diet records,
3. quantify any differences between well-trained young and ageing athletes, that were matched for fitness and training variables, in their performance

impairment, perceived physical impairment or rate of recovery after intense exercise.

In addressing these aims four studies are presented. The first utilised a brief questionnaire administered as a method of subject recruitment for future studies. Thirty six athletes under 30 years of age ( $24 \pm 3$  years) and sixty four athletes aged 30 years and above ( $41 \pm 8$  years) provided responses to a series of questions pertaining to training history, current training activities, post exercise symptoms of fatigue, perception of recovery duration, and the use of recovery strategies. Results indicated that there were significant differences ( $p < 0.05$ ) between the young and older groups for training frequency ( $9 \pm 3$  vs.  $7 \pm 3$  sessions per week), training volume ( $17 \pm 8$  vs.  $11 \pm 5$  hours per week) and recovery duration ( $10 \pm 9$  vs.  $16 \pm 14$  hours). There was also a significant positive correlation between recovery duration and training history ( $R = 0.28$ ,  $p < 0.01$ ). The majority of athletes surveyed indicated that they used specific strategies to promote recovery (76%).

The second study compared the nutrient intake of young and veteran athletes (veteran:  $>35$  years). The purpose of the dietary analysis was to establish if any apparent differences in recovery attributed to ageing could be a result of differing nutritional practices. Three-day diet record data from 13 young ( $24.0 \pm 4.8$  years) and 16 veteran ( $43.8 \pm 5.0$  years) athletes were collected and compared for differences in nutrient intake that might contribute to impaired recovery from exercise. Diet records were analysed by a qualified dietitian using the dietary analysis software Food Works (Xyris Software, Highgate Hill, Australia). Physical activity levels were assessed using the Baecke physical activity questionnaire. Energy expenditure was also estimated using the equations of Schofield and Harris-Benedict. The results indicated that there

were no significant differences between young and veteran athletes for overall energy intake. However, the veteran athletes had a significantly higher percentage of daily energy intake from fat than the young athletes ( $35 \pm 5$  vs.  $29 \pm 6$  g.day<sup>-1</sup>;  $p < 0.05$ ). The mean dietary intake of CHO for both age groups was substantially lower than the recommended guidelines for endurance athletes.

The third and fourth studies compared measures/markers of recovery in nine young ( $23.7 \pm 4.8$  years) and nine veteran ( $44.3 \pm 5.4$  years) cyclists and triathletes that were matched for training and performance. Recovery was measured over three days (T1 to T3) of intense exercise that replicated heavy training and/or competition demands. Functional performance measures included a progressive maximal test, thirty-minute time trial performance (TT30), leg power (countermovement jump), leg strength (maximal voluntary isometric contraction), sprint cycling performance (10 second sprint) and analysis of blood markers associated with exercise induced muscle damage (creatine kinase, lactate dehydrogenase). Perceptual and report of recovery (psychological recovery) was assessed using verbally anchored Visual Analogue Scales used to measure motivation, muscle soreness (SOR), ratings of fatigue (FAT) and the total quality recovery scale (TQR).

For the measures of functional performance there were no significant differences between the two age groups. Both groups maintained their time trial performance over the three days of intense endurance exercise. The average height jumped in the countermovement jump decreased slightly (2.6%,  $p < 0.05$ ) over the three days. There was also a significant decrease in average heart rate during the TT30 over the three days ( $\sim 3$  b.min<sup>-1</sup>) for both groups. In response to the testing protocols serum CK activity was significantly elevated for both age groups on days two and three (combined age data: T1-  $122 \pm 43$ , T2-  $178 \pm 90$ , T3-  $166 \pm 87$ ,  $p < 0.05$ ). For the perception and report of

soreness, fatigue and recovery, non-parametric statistics indicated that the veteran group reported a significant ( $P<0.05$ ) change in SOR ( $6.2 \pm 2.6$  to  $28.2 \pm 14.1$ ), FAT ( $1.7 \pm 1.2$  to  $2.2 \pm 0.09$ ), and TQR ( $15.8 \pm 2.5$  to  $13.8 \pm 2.1$ ) over the T1 to T3, while these changes in the young group were non-significant (SOR:  $15.5 \pm 15.5$  to  $24.2 \pm 17.1$ , FAT:  $1.7 \pm 1.1$  to  $2.2 \pm 0.9$  and TQR:  $16.3 \pm 2.6$  to  $15.1 \pm 2.9$ ). The change in muscle soreness was significantly ( $p<0.05$ ) greater in the veteran group than in the young group (Veteran,  $22 \pm 14$ ; Young,  $9 \pm 12$ ).

This investigation has provided the first comprehensive description of recovery from exercise in well-trained veteran endurance athletes. The common perception of a delayed recovery with ageing was supported by the longer reported duration required to recover between intense training and competition in athletes 30 years and older. This slower recovery does not appear to be due to major dietary differences between young and veteran athletes. In contrast to the perception of slower recovery repeated days of intense endurance cycling exercise was similarly tolerated by young and veteran athletes with respect to performance. However, there is a greater change in the perception of, muscle soreness and significant changes in fatigue and recovery in veteran athletes. This finding has implications for the effective monitoring of training load in the older athlete.

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## ABBREVIATIONS

|                           |   |
|---------------------------|---|
| <b>&lt;30</b>             | Less Than Thirty Years Old                    |
| <b>10ST</b>               | Ten Second Sprint Test                        |
| <b>30's</b>               | Thirty to Thirty Nine Years Old               |
| <b>30+</b>                | Thirty Years and Older                        |
| <b>40+</b>                | Forty Years and Older                         |
| <b>ABS</b>                | Australian Bureau of Statistics               |
| <b>ACC</b>                | Accusport/Accutrend Lactate Analyser          |
| <b>ADAPT</b>              | Automated Data Analysis for Progressive Tests |
| <b>ANOVA</b>              | Analysis of Variance                          |
| <b>AnT</b>                | Anaerobic Threshold                           |
| <b>ATP</b>                | Adenosine Tri-Phosphate                       |
| <b>BIA</b>                | Bioelectrical Impedance Analysis              |
| <b>BMI</b>                | Body Mass Index                               |
| <b>BMR</b>                | Basal Metabolic Rate                          |
| <b>CHD</b>                | Coronary Heart Disease                        |
| <b>CHO</b>                | Carbohydrate                                  |
| <b>CK</b>                 | Creatine Kinase                               |
| <b>CMJ</b>                | Counter Movement Jump                         |
| <b>CV</b>                 | Coefficient of Variability                    |
| <b>DEE</b>                | Daily Energy Expenditure                      |
| <b>DLW</b>                | Doubly Labelled Water                         |
| <b>Dmax<sub>mod</sub></b> | Modified D-max Anaerobic Threshold            |
| <b>DOMS</b>               | Delayed Onset Muscle Soreness                 |
| <b>DRI</b>                | Dietary Reference Intake                      |
| <b>ECG</b>                | Electrocardiogram                             |
| <b>EDL</b>                | Extensor Digitorum Longus Muscle              |
| <b>EI</b>                 | Energy Intake                                 |
| <b>FAT</b>                | Fatigue                                       |
| <b>FFQ</b>                | Food Frequency Questionnaire                  |
| <b>FI</b>                 | Final Increment                               |
| <b>g</b>                  | Gravity                                       |
| <b>GLUT-4</b>             | Glucose transporter-4                         |
| <b>GXT</b>                | Graded Exercise Test                          |

|                                    |   |
|------------------------------------|---|
| <b>H</b>                           | Height                                  |
| <b>HR</b>                          | Heart Rate                              |
| <b>LF</b>                          | Linear Factor                           |
| <b><math>\dot{V}O_2</math> max</b> | Maximal Oxygen Consumption              |
| <b>MRS</b>                         | Magnetic Resonance Spectroscopy         |
| <b>MVIF</b>                        | Maximal Voluntary Isometric Force       |
| <b>PCr</b>                         | Phosphocreatine                         |
| <b>RBE</b>                         | Repeated Bout Effect                    |
| <b>RDA</b>                         | Recommended Daily Allowance             |
| <b>RDI</b>                         | Recommended Dietary Intake              |
| <b>RER</b>                         | Respiratory Exchange Ratio              |
| <b>RPE</b>                         | Rating of Perceived Exertion            |
| <b>rpm</b>                         | Revolutions per Minute                  |
| <b>SD</b>                          | Standard Deviation                      |
| <b>SOR</b>                         | Soreness                                |
| <b>SPSS</b>                        | Statistical Package for Social Sciences |
| <b>t</b>                           | Time                                    |
| <b>T1, T2, T3</b>                  | Test Day 1, 2 and 3                     |
| <b>TEM</b>                         | Technical Error of Measurement          |
| <b>Tf</b>                          | Flight Time                             |
| <b>TQR</b>                         | Total Quality Recovery                  |
| <b>TT30</b>                        | Thirty minute cycling time trial        |
| <b><math>V_E</math></b>            | Ventilatory Volume of Expired Air       |
| <b>VJ</b>                          | Vertical Jump                           |
| <b>Wcom</b>                        | Watts Completed                         |
| <b>Wmax</b>                        | Maximum Watts                           |

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Finally, and most importantly, I dedicate this thesis to my very beautiful wife and children, Sue, Liam and Siena, who provided me with the inspiration to ‘get the job done’.

## **STATEMENT OF ORIGINALITY**

The work in this thesis has been completed by the candidate except where described in the thesis itself (dietary analysis and serum enzyme assays). This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published by another person except where due reference is made in the thesis itself.

.....

James Fell



# CHAPTER I:

## INTRODUCTION

### *Introduction*

The ageing process is accompanied by a decline in sports performance (59, 279, 412) and an anecdotal slowing of recovery mechanisms after physical training and competition (252, 327, 363). However, very little research evidence has been provided to support the view regarding the effects of ageing on recovery from exercise. The belief that older athletes require more time to recover between exercise sessions is regularly described in the popular media as evidenced in the information from internet training information websites (<http://www.sports-coach.net/prewp/schome-masters.html>; <http://www.runningtimes.com/issues/03dec/resurrected.htm>). However, despite this anecdotal information, the research evidence available to confirm this belief is scarce and equivocal.

A plausible argument in support of this common view is that the degree of substrate depletion and tissue damage that occurs as a result of exercise is greater in older persons (375), but this may not be entirely applicable to those that are or remain physically active into older age (112). Investigations on wound healing and bone repair indicate that tissue repair time is prolonged in muscle from older animals (373, 478). However, many physiological changes associated with the ageing process are similar to those associated with the detraining process caused by decreased levels of physical activity (174, 354). Thus a significantly prolonged repair rate in the elderly might be a product of the detraining process rather than ageing *per se*.

When the human body is exposed to intense, excessive or unaccustomed exercise (stress) a range of alterations to the functioning of physiological systems occurs

(241). Depending on the magnitude and nature of these changes there is a variable period of time before subsequent exercise can be performed to the same intensity (51). The time period required to reach full functional potential again is often referred to as the *recovery period*. However, according to Kellman (241) ‘..a clear and sufficient definition of recovery can rarely be found in the literature’. Similarly, while notable organisations such as the Australian Institute of Sport (AIS) have determined that recovery is an important component of athletic performance, it has also been acknowledged that recovery has not been well defined nor evaluated in any analytical way (191).

The recovery period after exercise is dependent upon many factors. Sporting performance is affected by numerous factors and consequently, adequate recovery should also consider such factors (191). These include training and competition, nutrition, psychological stress, lifestyle, health and environment (191). The time taken to recover can depend upon the amount of fatigue experienced and the rate of repair mechanisms working to return systems to normal functional levels.

Various factors have been proposed to either enhance and impede the recovery process (94). Adequate nutrients for substrate replenishment (eg. glycogen stores (223)) and moderate activity for removal of exercise by-products (eg. lactic acid (36)) have been shown to enhance recovery. Alternatively, hydration status (80), smoking (358), alcohol intake (83) and, paradoxically, the use of non-steroidal anti-inflammatory medications (312) have been associated with negatively influencing recovery from exercise.

Training for success is a balance between achieving peak performance and avoiding the negative consequences of overtraining (244). Inadequate recovery can lead

to decrements in physical performance which if unaddressed might lead to neuroendocrine complications, illness and overtraining (14, 241). However, while the importance of recovery from exercise is unequivocal, very little is known about the process of recovery and appropriate methods for measuring and monitoring recovery in athletes (191, 193, 241, 244).

Optimal recovery is relevant to all athletes, but for older athletes processes of recovery may be impaired in comparison with their younger colleagues. Master and Veteran athletes represent a growing population of athletes that compete in age categories deemed to be older than those at which normal peak performance would occur for a particular sport (88). The commonly held, but as yet unconfirmed, belief amongst these groups of older athletes that advancing age is associated with a prolonged duration for full recovery from exercise, and that impaired recovery has a direct and significant influence on athletic performance is the pivotal focus of this thesis.

### ***Statement of the Problem***

There is a paucity of literature on physical recovery from exercise, nutrition, or injury specific to the older athlete (Morley, 2000). This may be, in part, due to several challenges hindering the investigation of the impact of age on recovery duration in the older athlete.

Numerous anecdotal reports exist to suggest that muscle soreness is increased, and recovery of performance impaired/delayed after intense exercise in ageing athletes (326, 363). This raises the question as to whether such anecdotal observations have a physiological basis. Is the perception of impaired recovery a product of unavoidable deterioration of physiological systems (288) or is this merely an excuse for declines in training, motivation and performance? Alternatively, these observations may be due to

greater physical awareness, a more conservative outlook, or an altered psychological/perceptual phenomenon in these mature athletes. However, there are several unresolved issues with respect to the present literature available regarding these questions.

Prolonged recovery and reduced adaptation after eccentric exercise (McBride, 1995) and after immobilisation (478, 479) has been demonstrated in ageing rat muscle. Similarly, there may be a limited recovery potential from intense exercise due to impaired immune responses (435), and an increased risk of injury in the older athlete through slower tissue repair rates and decreases in flexibility of soft tissues (117, 373). While these factors may well be associated with a decline in physiological function and performance with age (139, 399), in humans such findings can often be confounded by individual subject variability, subject selection and study design (289).

The notion of impaired recovery affecting physical performance and training seems to be first described by athletes in the 30 to 40 year age bracket (326). However, a recent cross-sectional study found that although  $\dot{V}O_2$  max declines linearly across the ages of 25-75 years in sedentary men, it is maintained (no decline) in endurance-trained men up until approximately 50 years of age upon which the decline became faster than for the sedentary group (351). These authors reported that after 50 years of age there was an accelerated decline in  $\dot{V}O_2$  max in endurance-trained men that was significantly correlated with a decline in training volume ( $r=0.46$ ,  $p<0.0001$ ) (351). Consequently, much of the literature on the physiology of ageing and in particular ageing and recovery may not be transferable to a well-trained population of endurance athletes under 55 years of age.

When measuring recovery from exercise there is substantial debate in terms of validated markers of recovery (244), and whether commonly practiced methods for optimising the rate of physiological recovery are actually effective (434). While it is agreed that inadequate recovery can lead to accumulated fatigue and overtraining (277), there is less certainty regarding ideal measures of recovery, effect of training loads and successful methods for optimising recovery (244, 434). Adequate rest and optimal nutrition are clearly essential to successful recovery (244). Optimal nutrition, in particular, is paramount to the recovery process and must be taken into account when assessing recovery processes (76, 80, 84, 267). Unfortunately, the efficacy of many other current methods available to optimise recovery and the validity of measures used to assess whether an athlete is suitably recovered (not overreached/overtrained) are still equivocal (216, 244, 448).

If ageing athletes are experiencing greater 'wear and tear' as a result of their physical pursuits and/or experience a compromised rate of repair, then this group of athletes would stand to benefit the most from an improved understanding of training and recovery with particular reference to their population. Skeletal muscle and connective tissue have been shown to succumb to damage as a result of intense exercise (99, 150, 155, 270). However, several questions still remain to be addressed with respect to how such damage and recovery is affected by age and training:

- Is the damage caused by intense exercise greater in well-trained ageing athletes?
- If there is no difference in the amount of damage in both young and ageing athletes, are the rates of repair slower for the ageing individuals?
- What aspects of the ageing process contribute to delayed recovery, greater damage, delayed repair or both?

## ***Aims***

The aims of this investigation are to:

1. describe the common perceptions amongst an athletic population regarding the effect of age on recovery from exercise,
2. assess the nutritional status of the ageing athlete compared with physically matched younger athletes and the Australian Recommended Dietary Intakes.

and

3. quantify any differences between young and ageing well-trained athletes for performance impairment, perceived physical impairment or rate of recovery after intense exercise.

## ***Significance***

The time taken for the physiological systems to recover from an intense training/exercise session is individual and probably variable within individuals (241). Nonetheless, mean differences in rate of recovery between the young and ageing have been proposed but as yet not thoroughly investigated in an athletic population.

Regular physical activity is widely recommended as it elicits a number of favourable responses that contribute to healthy ageing (7), but it is arguable as to whether physical activity can allay the ageing process *per se* (210). Evidence of greater exercise induced damage or an impaired rate of recovery from exercise in older athletes would contribute to our understanding of the benefits of regular exercise in an ageing population.

While there is clear evidence that the nutritional requirements of the elderly are different from the rest of the healthy adult population (9, 141, 287) there is very little

literature as to whether this also applies to the ageing athlete (362). If so, what influence would these differences have on muscle damage and recovery from exercise? If specific nutritional deficiencies (such as in the antioxidant vitamins) contribute to greater damage and attenuated repair mechanisms from exercise, they may be most easily measured and alleviated in an ageing population where, due to senescent cellular functioning, optimal nutrient status may have the greatest impact. Maintenance of training regimes and lean body mass in ageing athletes provide a unique opportunity to investigate this hypothesis without the confounding effects of detraining.

Information regarding fatigue and recovery assists ageing athletes through the potential for improvement in athletic performance via an accelerated rate of recovery and enhanced training tolerance. New knowledge in this area may also assist the average ageing individual contemplating embarking upon an exercise regime, particularly if it can help to decrease the discomfort and delayed muscle soreness associated with unaccustomed exercise, and lead to accelerated improvement in fitness in response to undertaking a new exercise program.

With the increasing numbers of older members within the community there is an growing interest in anti-ageing strategies and exercise is one of the most strongly supported means to address age-associated declines (137, 390). 'As more individuals live longer, it is imperative to determine the extent and mechanisms by which exercise and physical activity can improve health, functional capacity, quality of life, and independence in this population.' (7). Consequently, this thesis will explore the interrelationships between the mechanisms of recovery from exercise and the influence of ageing on these processes.

## ***Hypotheses***

To address these issues the hypotheses tested are;

- i) Athletes over 30 years of age will report a perceived longer duration for full physical recovery from intense training or competition.
- ii) Differences in recovery between young and veteran athletes are, in part, associated with sub-optimal dietary practices for athletic performance and recovery.
- iii) Older athletes will demonstrate greater psychological and physiological changes in response to intense exercise, so that the return to pre-exercise levels for these parameters and for functional performance will be slower compared with a fitness matched group of younger athletes.

## ***Delimitations***

A plethora of parameters have previously been measured in an attempt to monitor training and recovery (169, 216, 345, 448, 452). However, the suitability of many of these markers is not clearly established (244, 450). Due to this limitation, a wide range of physiological, psychological and performance parameters were measured during the comparison of recovery between young and ageing athletes in order to provide insight into what tests are most appropriate for assessing recovery specifically in the older athlete.

## ***Limitations***

With all studies of ageing there are inherent problems with the methodology chosen. This study uses a cross-sectional design as opposed to a longitudinal design. There are two major confounders of cross sectional studies one being *cohort (generational) effects* and the other *selective mortality* (289). Although longitudinal



studies help address these confounders they rely on strictly controlling the study population over a long period of time, as well as the potential effects of repeated measurement having a direct influence on the measured variables. Therefore, 'provided the investigator is aware of the possible confounders, cross sectional studies are an effective approach for the study of ageing' (289).

Another limitation is in the number of well-trained young and middle-aged athletes targeted in this study willing to volunteer their time and bodies to research. The study required the subjects to modify their normal training regimes, a commitment that many serious athletes are not prepared to make. As such the number of subjects recruited contributes to the limitations of the study due to the restriction on the power of the statistics used.

Finally, the older age-groups investigated in this study were still relatively young (less than 60 years) in terms of ageing. Thus the research is limited in that the findings may be relevant only to athletes within this age range, and may not be validly generalized to the wider ageing athletic community.

## **CHAPTER II: REVIEW OF THE LITERATURE**

### ***Introduction***

The ageing process is accompanied by significant declines in physical functional capacity (13) and athletic performance (170, 279, 316). There is a common belief amongst ageing athletes that recovery from exercise is impaired with age (363). However, the manner in which the rate of recovery from exercise might affect these declines in physical function in an ageing athletic population has not been described. The concept of an age-related impairment in physiological recovery from exercise is not a recent phenomenon. Early work by Ermini et al. (147) suggested that the restoration of adenosine triphosphate (ATP) after exhaustive swimming exercise was impaired in older rats due to a low resting muscle phosphocreatine level. However, the application of research findings taken from studies using sedentary rodents to athletic humans is quite clearly limited.

The purpose of this literature review is to explore the scientific evidence for an impaired recovery process in the ageing athlete. Ageing can refer to developmental stages, times of neutral (no) change and processes of decline from conception to death (289). Ageing or older athletes can be defined as those that qualify to compete in veteran and master sporting events, and deterioration of sporting performance has been argued to begin at 35 years of age (59). In this review the terms ageing, older, senior, master and veteran athlete are taken to apply to athletes that have reached an age deemed to be after that at which normal peak performance would occur for a particular

sport. Furthermore, in this thesis the terms ‘ageing’ and ‘older’ are considered to be relative terms and therefore refer to any age where there is the inference that an age-associated decline in ‘normal’ physiological function may exist.

The available literature is limited with respect to measuring recovery in ageing athletes. Therefore, much of the research presented hereafter uses healthy, but sedentary animals and humans ranging from middle-aged to senescent. Thus there are two limitations to this review of the literature with respect to the research aims of this thesis. The first is that any reported difference in physiological recovery between young and ageing animals and humans that are sedentary may not be relevant to well-trained athletes. Secondly, the ages of the ‘ageing’ groups in many of the studies varies considerably and thus apparent differences in recovery of ‘very old’ animals and humans may not be applicable to a group of middle-aged (40-59 years) athletes. Nonetheless, the review of the literature is intended to demonstrate to the reader the possible arguments for a delayed recovery as a result of ageing and the obvious lack of research that is specific to the many dedicated athletes in the 30 years and older age bracket ‘deemed’ as ageing by their respective sporting organisations.

It must also be acknowledged that the recovery process is both physiological and psychological. However, as the main goal of this manuscript is to investigate physiological recovery, this review will be mostly limited to literature pertaining to the physiology of ageing, fatigue and recovery.

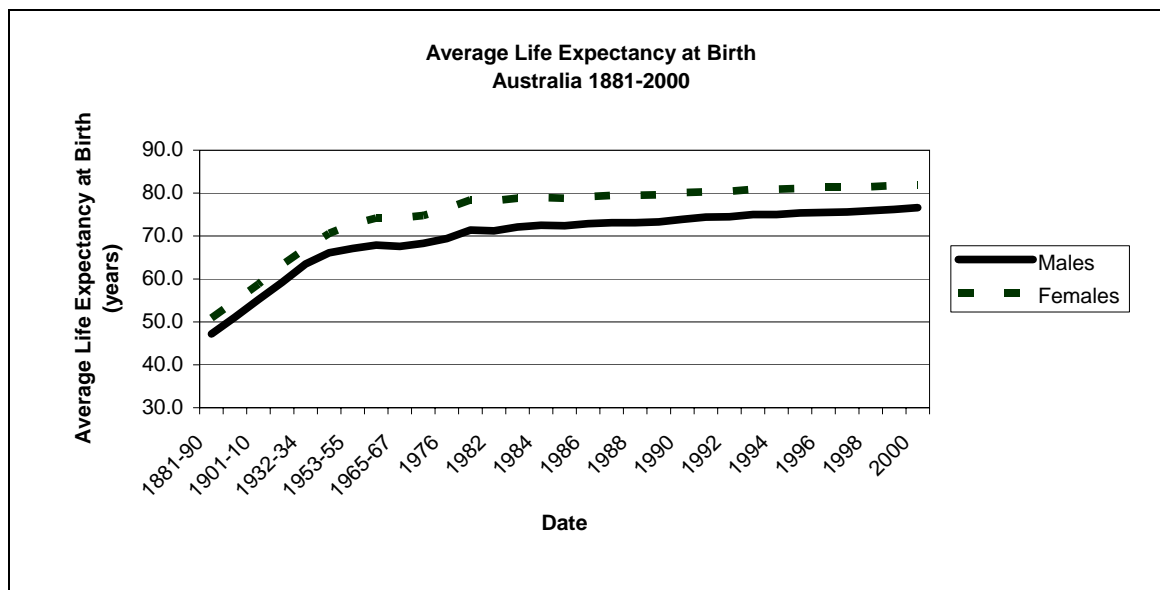
The review will begin by discussing the current trend for an increase in the population of elderly people in western societies and consequential growth in numbers of ageing athletes. The physical training model, which incorporates the processes of fatigue and recovery, will be presented and how ageing might affect this model

proposed. Literature that has addressed aspects of physical recovery in young and ageing animals and humans will be presented and critically discussed with particular reference to age-associated changes to skeletal muscle. Nutrition plays a crucial role in athletic performance and recovery (8, 76, 78) and there is also growing evidence that the nutritional needs are altered with the ageing process (141). Consequently, a review of nutritional studies of the ageing athlete will be presented. Finally, an overview relating to the measurement of recovery and some commonly suggested methods for promoting recovery from exercise will be provided in order to highlight the difficulties encountered for research measuring, monitoring and enhancing recovery from intense exercise (191).

### ***The Ageing Population***

The significance of the ageing process to this investigation into ageing and recovery is emphasised by two main factors. The first is due to the growing population of elderly people due to changes in average life expectancy in developed countries during the last century (198). Secondly, it can be assumed that older athletes are experiencing elements of the ageing process, a chronological inevitability, of which one aspect may be a delayed recovery period after exercise. How the ageing process might affect recovery time in the ageing athlete has not yet been addressed.

Over the past 100 years the average life expectancy at birth in developed countries such as the United States has increased from less than 50 years in 1900 to almost 80 years in 1996 (344). Figure 2.1 is a representation of these figures for Australia over the past 100 years (1). Life expectancy of humans from birth and median length of life, which can be ascertained from survival curves, increased throughout the course of the twentieth century.

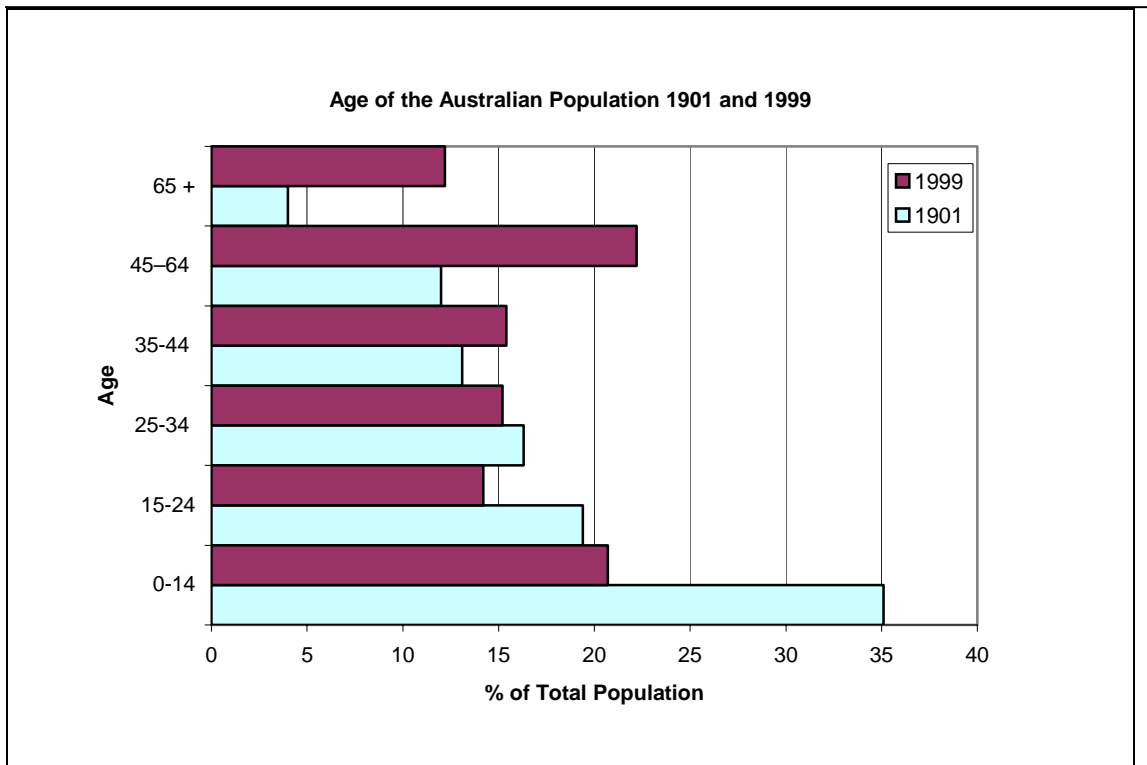


**Figure 2.1: Life expectancy at birth 1886-1998 (1)**

Source: Australian Demographic Trends 1997 (ABS Cat. no. 3102.0) (for years 1881 - 1994)

Deaths, Australia (ABS Cat. no. 3302.0) (various issues) (1995 - )

An implication of the increasing average age of mortality is the growing population of elderly people (Figure 2.2). In Australia the population over 65 years of age in 1976 was 1.3 million representing nine percent of the total population. However, it is anticipated that by the year 2016 the percentage of individuals over 65 will be close to 3.6 million accounting for approximately 16% of the population (<http://www.wesleymission.org.au/publications/ageing/introduction.htm> - retrieved 24/6/02). Figures from the United States show an 87.6% increase in the 65+ age group from 1960 to 1990 while the total population increased by only 38.7% during this same period (97).



**Figure 2.2: Population distribution of Australia in 1901 and 1999 (2)**

This rapidly expanding demographic group is becoming increasingly interested in ways to extend the length, or at least improve the quality of their lives. Whilst there are a number of purported interventions to improve average life expectancy at birth or maximal life span (475), one of most widely promoted methods of impeding the rate of senescence is participation in regular physical exercise (144, 357). This view is reinforced in position stand by the American College of Sports Medicine (7) which states 'Participation in a regular exercise program is an effective intervention/modality to reduce/prevent a number of functional declines associated with ageing'.

No longer content to limit their daily dose of exercise participation to low intensity exercise such as lawn bowls, golf, leisurely walks or armchair aerobics, many athletes refuse to give up their competitive sport or are turning to new sporting challenges later in life (161, 439). This trend has lead to a sudden increase in the

number of participants in masters and veterans sport, with these sport categories amongst the fastest growing areas of sports participation in Australia (221).

In parallel to the growing participation by older individuals in intense physical activity and sport, interest in the interplay between exercise and ageing from both participants and researchers has also evolved. Unfortunately, the ageing athlete is a research subject for which there is a relative paucity of literature available. As well as a desire by many ageing athletes to find out more about their fitness and performance, research on ageing athletes also provides an invaluable resource with respect to the study of the ageing process. Older athletes (particularly those that have continued intense training throughout life) provide researchers with excellent opportunities to investigate the long-term effects of regular exercise on biological systems in humans without the complication of the detraining effect due to an increasingly sedentary lifestyle (59).

## The Ageing Athlete

A growing number of individuals choose to continue intense exercise into older age. Referred to as 'Masters Athletes', 'Veteran Athletes', 'Senior Olympians', 'Golden Oldies' and a host of alternative names and acronyms (88), individuals from these groups produce athletic feats that often defy the normal behaviour of the elderly (317). Within these groups of dedicated ageing athletes there is a strong belief that one of the major limiting restrictions on continued training and performance gains is an impairment of recovery. In the second edition of his book 'Lore of Running', Noakes bemoans the fact that in only a few short years from his thirties to forties he had to modify his training regime to cope with slower recovery from exercise (326). Noakes is

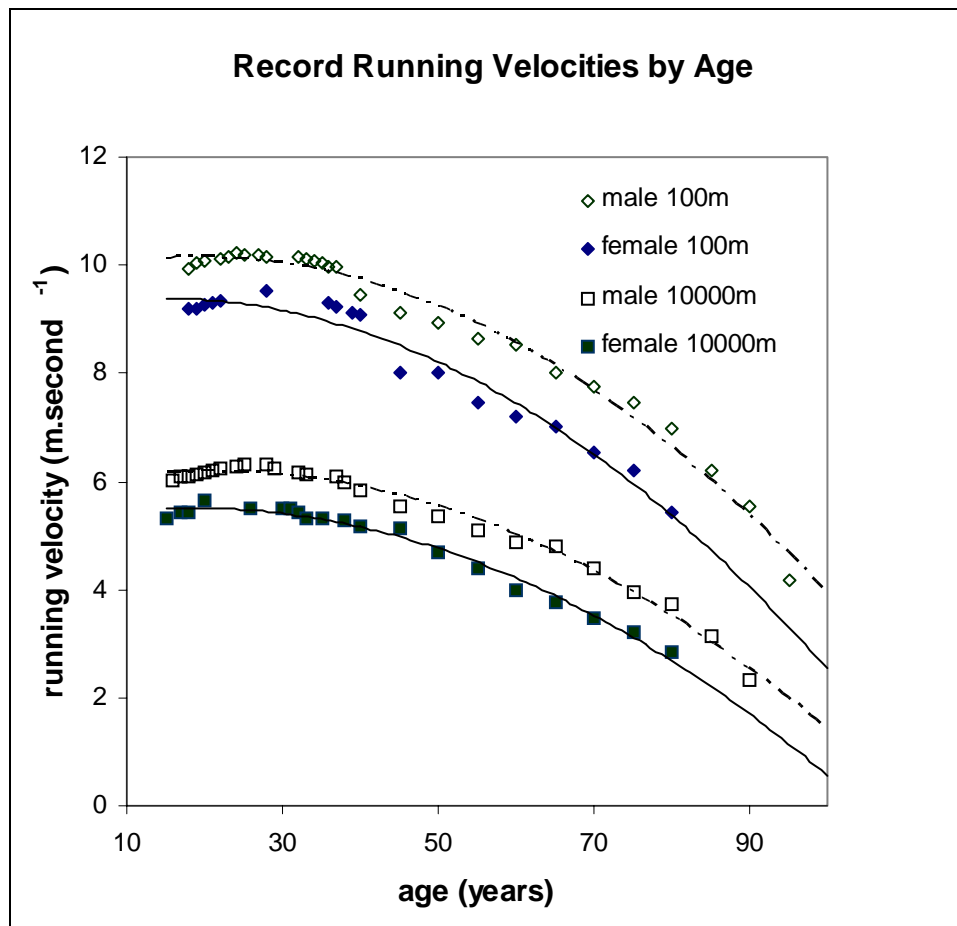
not alone in his views and the phenomenon of impaired recovery with age appears to be widely held and described by other researchers (252, 363).

Research into the area of age and exercise performance is not a recent phenomenon. Astrand (21) published an early cross-sectional study reporting on physical work capacity across a range of age groups. An early study by Dill, Robinson and Ross (136) reported on the fitness of champion runners over time, and Moore (316) reported on track and field records related to age and running speed. Numerous subsequent studies have gone on to investigate various aspects of physiology and ageing and there have been many quality publications. There have also been several publications specifically for the ageing athlete, and the reader is directed to works by Sutton and Brock (418), Menard and Stanish (307), and Shephard (400).

Much of the ageing literature has identified that the ageing process is characterised by a steady decline in functional (12, 13, 34, 462) and physical work capacities (10, 58, 420). However, there is some evidence indicating that lifetime athletes can significantly slow these declines compared with non-exercising subjects (185, 237, 355, 370, 442). It has even been suggested by some researchers that this decline is not inevitable and may, to an extent, be avoidable (279, 354). In contrast, others have challenged the concept that regular exercise is an effective panacea for slowing the rate of physiological decline with age (157, 201, 419, 471). These authors have reported a similar or faster decline in aerobic fitness for those maintaining a physically active lifestyle in comparison with sedentary subjects. Adding further confusion to this debate is the possibility that many of the reported health benefits for the elderly associated with participation in athletic competition may simply reflect a healthier lifestyle overall (401).



Whether inevitable or preventable, physiological decline does occur. Changes to the cells, tissues and organs of the body all occur with age, and as a consequence, most biological functions show a progressive, age-related deterioration (288, 289, 399, 400). This is particularly evident when considering the effects of age on physical performance as determined by sporting world records. The male world record running speed for the 100 metres and 10,000 metres (Figure 2.3) decline by  $0.06 \text{ m.s}^{-1}.\text{yr}^{-1}$  and  $0.05 \text{ m.s}^{-1}.\text{yr}^{-1}$  respectively (317).



**Figure 2.3: Record running velocities by age and gender for the 100 and 10000 metres events.**

Similar progressive declines in performance are evident for other sports with the rate purportedly largest for events reliant on strength, speed and power, ‘as the distance increases the rate of performance decline decreases’ (279). However, there is need for

caution when making inferences about whether the deterioration with age is greater in sprint than longer events using absolute or relative change in time or velocity. For purposes of comparing absolute change across events Stones and Kozma (415) converted the dependent performance variable across a range of studies to a logarithmic scale and concluded that deterioration with age is greater for events beyond sprint distance. Several other researcher have found relative decline to be slower in sprints than the longer distances at older ages (59, 139, 420).

The association between ageing and decline in physiological systems or sporting performance has been suggested to be both linear (351) and non-linear (200, 306). A recent meta-analysis of published studies investigating the reported declines in physiological systems with age concluded that there was a linear decline (as opposed to the data presented in Figure 2.3) for most physiological systems (397), although this may depend upon whether subjects are trained or sedentary (351).

Changes in physiological functions as a result of ageing include; the widely reported decline in maximal heart rate (208), an apparent loss of muscle mass with selective loss of type II fibres (116), changes in structure and function of connective tissue (446, 451), loss of nervous tissue and deteriorating nervous function (384, 385, 406), potentially higher incidence of injury (134, 235) and a suggested delay in healing and recovery rate (102, 109, 117, 299). The reasons for these changes are not entirely clear and may be partly attributed to increasingly sedentary lifestyle, particularly in humans. Although much of this research has not been undertaken on trained subjects it is reasonable to suggest that these age-related declines in physiological function would contribute to the demonstrated decline in athletic performance.

The mechanisms underlying the ageing process are not well understood and how these mechanisms may influence recovery in an ageing athletic population is as yet unknown. It is necessary to consider the currently available evidence for a delayed recovery or impaired adaptation in older muscle in order to propose possible mechanisms for a delayed recovery from exercise. In order to investigate the influence of impaired recovery on the decline in sporting performance presented above, it is necessary to understand the 'physical training model' and the possible influences that ageing could have on this model.

### ***The Physical Training Model***

#### **Overload and Recovery**

Since the purpose of physical training is to unbalance the homeostasis of an individual's functional systems, the natural consequence is some degree of fatigue (407). Theoretically, this fatigue stimulus should lead to physical and psychological adaptations that will prepare the individual for future physical insult and enhance subsequent performance. The principles of training include *overload* and *recovery* (380) and it is essential that a balance between these variables is achieved in order to provide an optimal training effect without impaired adaptation that could lead to maladaptation and/or underperformance (75).

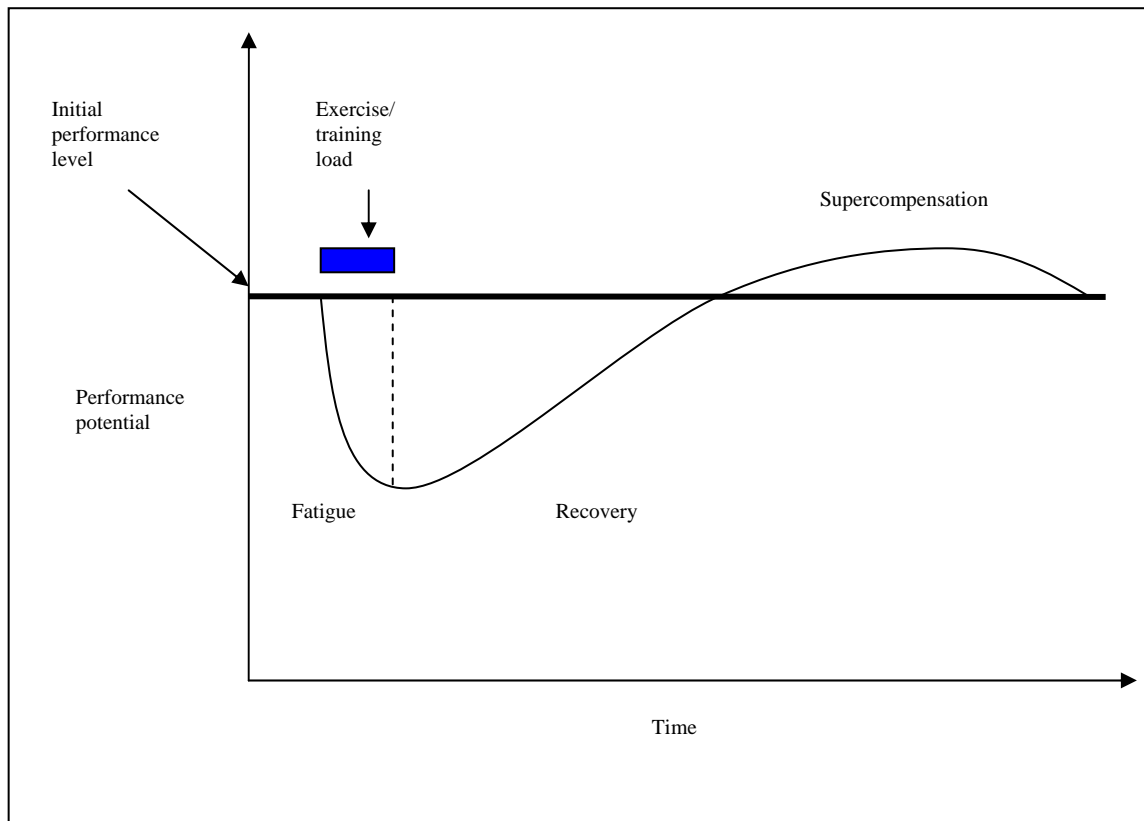
Smith and Norris (407) identified four training loads and approximate recovery times relative to each load. These included; acute training stress, unaccustomed exercise, training overload and excessive training overload. Recovery intervals corresponding to each of these training loads ranged from less than 24 hours to greater than 28 days. Recovery can take as little as the few minutes it takes to replenish

muscular phosphocreatine stores (304) or the weeks taken to recover muscular force after eccentric exercise (388).

While we can monitor the training effect through techniques such as blood samples and muscle biopsies, due to the complexity of the biological adaptive processes (recovery) these measures may not help in predicting performance (450). Several studies have investigated the recovery time course of various physiological parameters after acute training loads (50, 107, 437, 472), and more recently a large amount of research has investigated the effects of excessive training load with respect to overreaching and overtraining (180, 199). Unfortunately, relatively little research has considered recovery from normal day-to-day training, although this topic is beginning to generate substantial interest (191). Sporting performance or physical fitness depends upon the quality and quantity of the training overload and the degree of recovery (407). However, like many aspects of sporting performance, the degree of recovery is hard to quantify due to biological and methodological variability (217, 220).

The process of adaptation is the result of the interplay between fatigue and recovery, and can be represented using the single-factor model (Figure 2.4). A two-factor model has been suggested to better represent the interplay between fitness and fatigue with the fitness and fatigue impulse generated from a single training session converging and diverging over time, so that at any time point the predicted performance is equal to fitness minus fatigue (407). However, the single factor model represented below provides a useful reference point for presenting the possible effects of age on fatigue and recovery. In this model there is period of decreased physical performance potential in response to a single training bout that stimulates adaptation processes, ultimately leading to supercompensation (for example muscle glycogen depletion

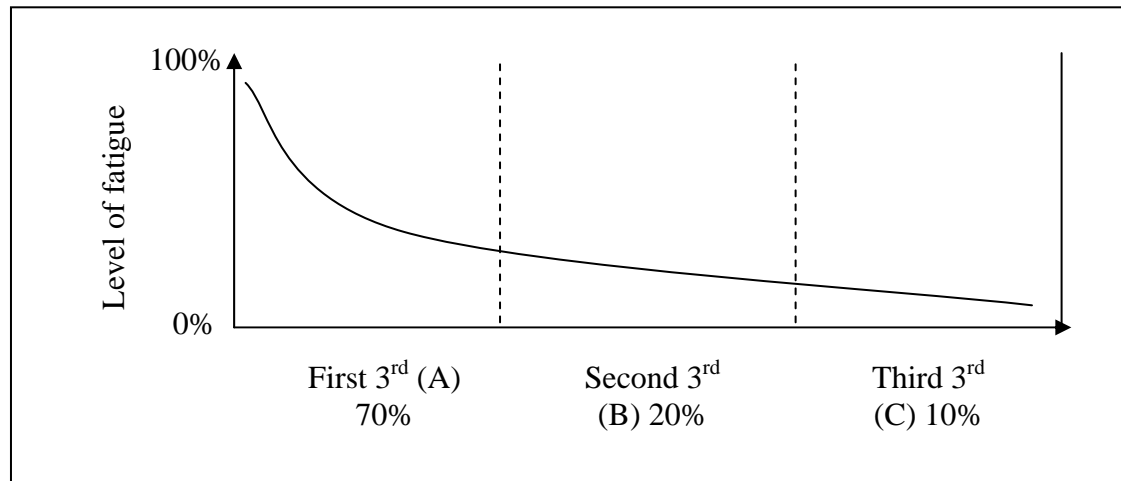
followed by super-compensation) and improved performance potential. Excessive training (overtraining) or impaired recovery processes (eg. malnutrition) would impede this adaptive response and limit potential performance gains.



**Figure 2.4: Theoretical model of shock, reaction and supercompensation associated with a single exercise bout (adapted from the work of Hans Selye described in Rushall and Pyke (380)).**

Fitness and fatigue in response to a training load is dependent upon processes of recovery. Based on the work of Florescu, Dumitrescu and Predescu (1969), Bompa (51) presents a model of a recovery curve in a chapter dedicated to Rest and Recovery. This recovery curve is divided into three sections (Figure 2.5). Initially the curve drops dramatically as biological parameters such as heart rate and blood pressure return to normal within 20-60 minutes following the work. Recovery during the next two stages is much slower requiring the restoration of muscle glycogen, fats, protein, vitamins and

enzymes that may take in excess of 24 hours. It is within this period of 12 to 36 hours where total recovery may not be complete but subsequent training activities might be undertaken which is the focus of this thesis.



**Figure 2.5: Dynamics of the recovery curve. A is initial muscle fuel replenishment (~30 min to 6 hr); B is full replenishment of fuels in the entire organism (~6 hr to 24 hr); and C represents recovery of neural sphere CNS + A + B, or 24 hr' (From Bompa, (51))**

The manner in which ageing impacts upon the above recovery process has received very little research attention. Studies comparing the recovery of physiological parameters after acute recovery from exercise between ageing and young subjects have included the measurement of gas exchange variables and heart rate (109), muscle contractile properties (246), muscle energy metabolism (408) and muscle oxygenation (256). In general, these investigations have reported differences between young and elderly subjects for acute recovery of physiological parameters from fatiguing exercise. This suggests that for the same training load, a longer recovery period might be required before the elderly return to baseline levels. However, due to the sedentary or 'recreationally active' nature of the subjects used in these studies, the increased recovery time may not apply to well-trained older individuals (130). The following section will explore the theoretical effects of age on recovery from acute exercise and

present the limitations of much of this research due to the influence of declines that occur with ageing in the level of physical activity engaged in by both humans and animals.

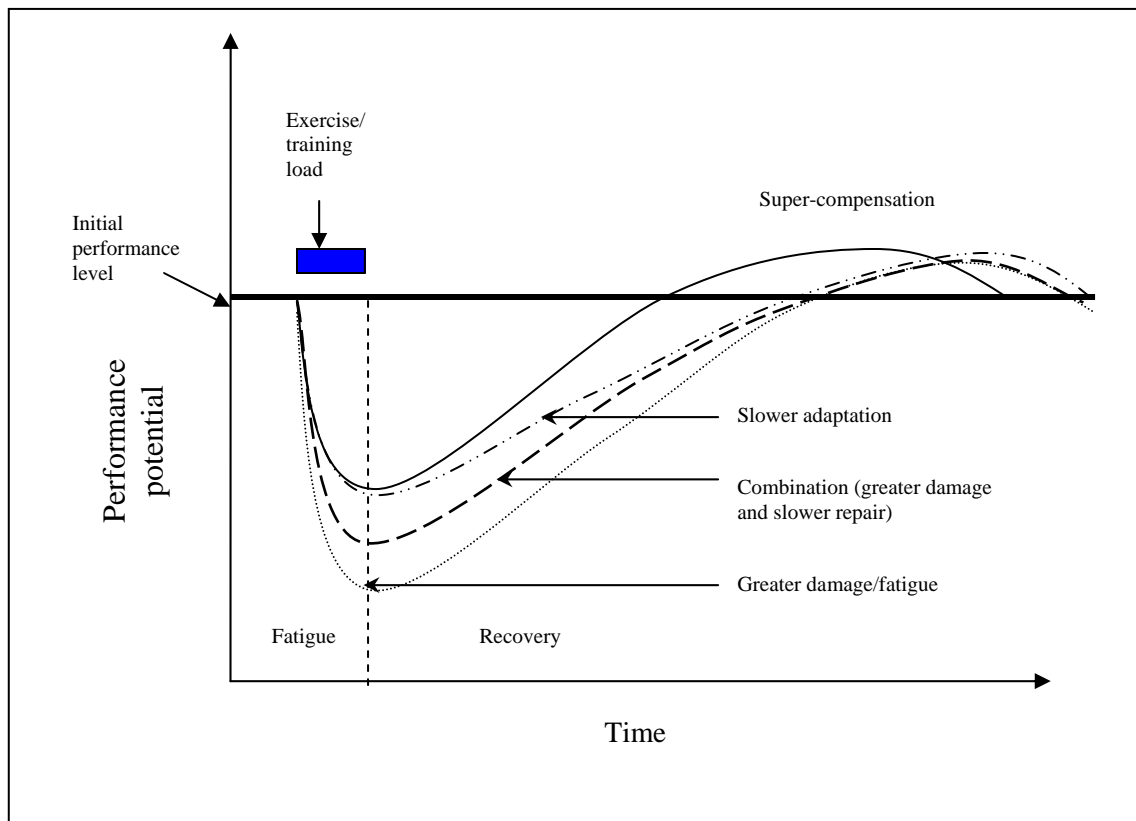
### ***Ageing and Recovery***

The principal question to be addressed in this section is, 'do older athletes take longer than younger athletes to return to pre-exercise performance potential after a single bout of exercise?' Two potential arguments for a delayed recovery in older athletes are;

1. A greater amount of exercise induced fatigue/damage.
2. An impaired rate of adaptation and repair following a fatiguing exercise bout.

Both of these scenarios are represented in Figure 2.6, which demonstrates the single-factor theoretical model of the time course of physical recovery from a workout previously presented in Figure 2.4.

Similar fatigue and recovery patterns may be evident for a variety of physiological variables although they will also be influenced by an individual's state of training and the extent of the training load applied. From this model the impact of delayed recovery for an older athlete can be emphasised when considering the timing of any subsequent exercise bout. If a further exercise/training load was to be delivered prior to the curve returning to pre-exercise levels then the fatigue effect may be compounded increasing the potential for maladaptation and overtraining.



**Figure 2.6: Theoretical model of the time course of adaptation (fatigue and recovery) after an exercise impulse. Bold line denotes normal model, broken lines represent proposed models for an older athlete experiencing greater damage or slowed recovery.**

It has been suggested that older athletes may be more susceptible to overtraining due to greater exercise-induced muscle damage and impaired recovery (432). The following quote by Kraemer and Nindl (252) supports the view that the ageing athlete is more susceptible to overtraining;

*As one ages the recovery process also slows down, and overtraining may be even more frequent in master athletes who have not modified their progression formats from their younger years. This could be due in part to an altered hormonal environment that does not support the remodelling of muscle and connective tissue as quickly as the hormonal environment of younger athletes. This is especially true as one goes from the fourth to the sixth decade of life.*



However, others have argued that young athletes may actually be more susceptible to overtraining due to incomplete developmental processes (241). Unfortunately, most overreaching/overtraining research has been conducted using young adult and adolescent athletes. At present no research on overtraining has used ageing athletes as subjects to confirm or refute these beliefs.

Smith and Norris (407) suggest that while models such as the above fatigue and recovery example provide visual representation of the effects of an exercise session, the principle of individualisation confounds generalising this response to a group of athletes. Empirical performance data must be obtained in order to allow athletes to be sub-grouped on performance changes and recovery rates when applying this model. Although this suggests problems due substantial individual variability in fatigue and recovery for athletes, because the common belief is that greater damage and slowed recovery is more prevalent for older individuals, they can thus be classified as an 'impaired recovery rate' sub-group. However, whether impaired recovery and greater susceptibility to overtraining is a group characteristic in well-trained older athletes is yet to be determined. Based on the above relationship between fatigue and recovery, if there is a change in the stress-repair process in the ageing athlete then to avoid overtraining they would be required to either decrease the training load or increase the recovery duration. Either option would have a negative impact on training and performance gains.

In support of the argument for impaired recovery in ageing individuals, several studies have used skeletal muscle from rats and mice to investigate the effects of age on muscular function and recovery after fatiguing or damaging contraction protocols (68, 69, 72, 182, 299, 481). Several authors have also undertaken comparisons in muscle

damage and repair for humans of different ages (4, 112, 375, 377). Although there are conflicting findings from these studies, they highlight the important potential role of age-related changes in skeletal muscle structure, function and adaptability on recovery from exercise in the ageing athlete.

## Physiology of Ageing Muscle

Declines in physical performance with ageing are often attributed to age-related changes to skeletal muscle (361). Morphological and biochemical alterations to ageing muscle that can negatively impact upon muscle function have been repeatedly demonstrated (54, 71). The overall systemic decline with age may contribute via a variety of pathways to performance decrements (59), increased muscle damage (375) and impaired recovery (68). Although skeletal muscle maintains a high degree of plasticity throughout the lifespan in response to training or damage (185, 233, 440, 441), there are numerous age-related structural and functional changes that have been reported that can have a deleterious impact upon muscle function (296). However, there is also continued debate as to the extent that many of these changes may be prevented by regular physical training (187, 222).

Some of the reported changes in skeletal muscle associated with ageing include; a progressive decline in total skeletal muscle mass (379), a selective atrophy and loss of type II muscle fibres (115), a reduced number of motor units with more fibres per unit (275), and a decrease in the quality of muscle as evidenced by a decrease in the force per unit of muscle (166). However, the extent to which each of these age-related changes might influence recovery from exercise in well-trained athletes has not previously been reported. Furthermore, the chronic physical training undertaken by

many ageing athletes may in itself contribute to some of the changes presented above without necessarily negatively impacting on function (156, 424).

Age-related changes in total body mass have been well documented with the majority of studies reporting a gradual increase in body mass up to approximately 55 years of age, after which it decreases (211). Based on the findings of both cross sectional and some longitudinal studies this pattern of change for body mass is not always present in ageing athletes. Data taken from a number of studies on young and ageing athletes, has shown body mass to be similar in both ageing and young endurance-trained men (67.8 vs 68.1 kg) (211). Longitudinal studies have found body mass to either remain stable (371) or decrease only slightly over 8-10 years (354) in the same athletes. However, there are some problems with making inferences from the literature on age and body mass due to limited longitudinal data (202) and the inherent problems with cross sectional data due to birth-cohort effects on body size, sampling bias and/or survival (211).

One of the main reasons proposed for the age-related decline in body mass with increasing age in sedentary individuals is the loss of skeletal muscle and an increase in fat mass compared to fat free mass (149). The age-related decrease in muscle mass is referred to as 'sarcopenia' (379). Accompanying this decrease in skeletal muscle volume is a reduction in muscle strength (6, 166), and studies have reported declines in both muscle volume and muscle strength with age in both sedentary and active ageing individuals (6, 115, 379, 443). However, muscle size, strength and function can actually still be improved in the elderly through participation in progressive resistance training programmes (441).

As well as the decline in muscle strength and function due to loss of muscle volume with age (457), there is evidence of declines in muscular strength that cannot be entirely explained by decreases in cross sectional area (71, 336, 431). This qualitative decline in muscle strength with age is evident as a decrease in specific force (force per unit of muscle cross-sectional area) and has been attributed to factors such as the selective atrophy and overall decrease in the type II fast twitch muscle fibres (260), the denervation of motor units (447), and structural changes to myosin molecules (248) that may reduce the number in the strong binding structural state during contractions (273). It has even been suggested that some functional changes may be present as early as the fourth decade (411). However, there remains some contention as to how much this atrophy is directly a consequence of ageing, or due to detraining processes as a result of a reduction in physical activity that often accompanies ageing (152, 279, 300, 365).

There is a suggestion that reduced physical activity levels should be considered as a normal consequence of ageing as the tendency to be less active in old age is, 'a universal biological phenomenon, occurring in species as diverse as fruitflies, roundworms, mice, monkeys, and humans' (465). Decreased physical activity with ageing has been proposed as a key factor involved in producing sarcopenia (319). However, it is also argued that reduced activity may be more a result of sarcopenia than a primary cause (465). At present it is not explicit that a reduction in physical activity with age, and the associated physiological decline, is unavoidable. Recent research by Bronikowski and colleagues (67) emphasises the potential benefits of lifelong physical activity and challenges the absolute inevitability of many of the age-related declines in muscle tissue. These researchers reported that regular high levels of voluntary exercise in male mice reduced many of the age-related gene expression changes that were observed in the heart muscle of sedentary animals. Skeletal muscle may well behave

similarly in response to lifelong vigorous exercise, with recent evidence that strength can be preserved up until the eighth decade in endurance-trained athletes (424). Rosa et al. (372) have very recently reported that life long treadmill exercise in mice, up to the age of 18 months, leads to a preservation of gastrocnemius muscle fibre cross sectional area when compared with young (3 month) and older sedentary animals.

Taking into account the two proposed potential causes of impaired recovery in the ageing athlete (Figure 2.6) it is pertinent to review the literature relating to the effect of ageing on exercise-induced muscle damage and the repair or adaptation of skeletal muscle in response to exercise. A substantial quantity of research literature has been published describing age-associated effects on damage and repair in skeletal muscle (102). Faulkner et al. (152) suggested three critical changes that occur in the skeletal muscles of ageing animals that may contribute to muscle atrophy and weakness with ageing. These included a greater susceptibility to contraction-induced injury (481), less successful regeneration of muscle fibres (103), and incomplete structural and functional recovery (68). Unfortunately, much of the available literature presents research conducted on animals and humans that are very old or senescent. Many of the changes that occur with age may initially be present in middle-aged or moderately-aged humans and animals (477, 483). As a result more ageing research is now being directed at 'younger' age groups, although still often not matched for physical activity.

The participants in the current study are classified as middle-aged, well-trained cyclists, and as such, may not correlate with 'normal' models of skeletal muscle ageing. Consequently, it is acknowledged that there are limitations to the inferences that might be drawn from the following research presented to the specific population targeted in the current investigation.

## Exercise-Induced Skeletal Muscle Damage and Ageing

It has been well documented that the skeletal muscles of older rodents are more susceptible to contraction-induced damage than muscles of young rodents (70, 114, 481). However, few studies have been performed that have investigated the susceptibility of muscles of older humans to exercise-induced muscle damage (114), and the findings have not been consistent (112, 280). In those studies that have used humans as subjects there have been conflicting findings with some studies reporting no notable differences in muscle damage between young and ageing subjects when assessed by decreases in isometric force (112), or via electron microscopy (377), and other studies finding significantly greater damage in ageing muscle (280, 375).

A possible argument for the opposing findings in the above studies may be the effect of gender on exercise-induced muscle damage (432), with similar investigations from the same researchers producing contrasting results (375, 377). For example, while the amount of muscle damage caused by high-volume, heavy resistance training was no different for younger (20-30 years) and older men (65-75 years)(377), 65-75 year old women exhibited higher levels of muscle damage than their 20-30 year old younger counterparts (375). This latter study is also in contrast to the findings of Clarkson and Dedrick (112) who reported similar muscle damage and repair processes in both college aged ( $23.6 \pm 3.3$  years) and elderly ( $67.4 \pm 5.3$  years) females after a bout of lengthening muscle contractions. Roth and colleagues (375) were at odds to explain the different findings for males and females suggesting the potential role of oestrogen in protecting against muscle damage (26-28). However, more recent research has challenged the relationship between estradiol levels and post-exercise plasma creatine kinase activity, reporting no relationship when comparing pre-menstrual, menstrual and post menopausal women after exercise-induced muscle damage (17).

There are two alternative arguments for the conflicting findings regarding the effects of ageing on muscle damage in the above studies. The first involves the methods that are commonly employed to quantify muscle damage. Creatine kinase (CK) activity in the blood is regularly reported as a reliable indirect marker of exercise-induced muscle damage (110, 238, 262). However, using light and electron microscopy, Manfredi et al., (280) reported significantly greater exercise induced muscle damage (90% vs. 5-50% damaged fibres) in ageing (59-63 yr old) compared with young (20-30 yr old) males with no differences in plasma CK activity. Other indirect measures of muscle damage that have been reported include elevated plasma activity of a variety of muscle enzymes (myoglobin, lactate dehydrogenase), the presence of markers of oxidative damage (malondialdehyde), decrements in force/strength/power, areas of inflammation observed through the use of computer tomography or magnetic resonance imaging, muscle soreness, swelling and changes in range of motion (331). A recent review by Warren, Lowe and Armstrong (463) concluded that functional measurements such as the ability to produce force or torque provided a better indication of muscle damage due to the high variability and measurement bias of methods such as serum activity of muscle enzymes and histology. Range of motion was also suggested as a valuable tool in studies on humans. These measurements have the added benefit of providing athletes with a measure of physical impairment which may be related to exercise performance.

The second possible cause for the contradictory results in the study of ageing and muscle damage may be due to the training status of the participants. Tiidus (432) proposed that there are clear age-related differences in the susceptibility of skeletal muscle to exercise-induced muscle damage, supported by the lower number of lengthening contractions required to elicit structural and functional damage in older

animals (481). However, Tiidus also acknowledged that training status could be an important factor in reducing the degree of post-exercise damage in elderly human muscle. While several studies on animals have concluded that exercise-induced damage is greater in ageing muscle (68, 299, 481), none of these studies have taken into account training status or activity levels, thereby neglecting to consider that differences in muscle damage may be associated with decreases in habitual physical activity (174).

Clarkson and Dedrick (112), in their comparison of muscle damage between young and ageing women concluded that the muscle damage process takes a similar course for young and old women, and that the repair process is equally effective, with older muscle demonstrating the same ability to adapt to damage as young muscle. However, the researchers noted that the older subjects in their study were very active, regularly participating in sport, exercise, or strenuous work. In support of this finding, Ploutz-Snyder et al. (353) resistance trained a group of older women ( $63 \pm 5$  years) for twelve weeks and reported that after the training intervention, these women displayed no difference to younger untrained women ( $23 \pm 4$  yr old) in muscle damage following a series of lengthening contractions as indicated by loss of strength and magnetic resonance imaging. Thus there is strong evidence that training status is a more important determinant of the degree of muscle damage caused by a single bout of exercise than is age.

The influence of prior training on muscle damage is also highlighted by a study using mice (72). Repeated weeks of pre-conditioning lengthening contractions in adult (7 months) and ageing (22 months) mice lead to smaller force deficits and less morphological damage in the pre-conditioned muscles compared with unconditioned muscles for both adult and old animals (72). The pooled data from both age groups



demonstrated that the force deficit in the conditioned dorsiflexor muscles was less than half that of unconditioned muscles ( $11.2 \pm 4.6\%$  vs.  $27.4 \pm 5.4\%$  respectively). Additionally, the conditioned muscles displayed a significantly reduced proportion of damaged fibres (2%) than the non-conditioned muscles (10%). Preconditioning of an ageing muscle with exercise may prevent subsequent exercise-induced damage due to the regeneration of muscle fibres that occurs following the exercise stimulus. Devor and Faulkner (135) demonstrated that after exposure to damaging bupivacaine injections the regenerated muscle fibres were equally protected from damage induced by lengthening contractions in both young and old rats. Consequently, the role of training in providing a protective stimulus for skeletal muscle is substantial, and cannot be discounted when investigating the influence of age on skeletal muscle damage and repair.

A recent study by Rosa et al. (372) suggests that habitual exercise may protect muscle tissue against the effects of ageing. The authors examined the effect of lifelong aerobic training on skeletal and cardiac muscle adaptations in mice. They trained a group of mice from the age of 3 to 18 months for one hour each day at a treadmill speed that equated to 60% of their 3 months  $\dot{V}O_{2\max}$ . Compared to young adult (3 months) and untrained ageing (18 months) mice, the trained animals achieved a maximal treadmill velocity during an incremental exercise test of approximately 30% greater than the young animals which in turn were approximately 25% better than those observed in the old untrained animals. Unlike the untrained old animals, the trained mice exhibited preservation of gastrocnemius muscle fibre cross-sectional area with the mean cross-sectional area actually exceeding that of the young animals, although this was not significant. The levels of malondialdehyde (MDA), a marker of oxidative stress

in the lipid membranes, were higher in the untrained elderly than the young animals. However MDA, was lower in the trained animals than either the young or untrained elderly group in both skeletal and cardiac muscle indicating a reduction in oxidative damage during the incremental exercise test in this group. This latter finding is consistent with other work (250) suggesting that regular exercise training imbues protection from exercise-induced oxidative damage.

Age-associated differences in the degree of muscle damage after exercise in well-trained humans have yet to be clearly demonstrated in the literature. Difficulties associated with the accurate quantification of muscle damage (particularly in humans), confusion regarding the effects of gender on muscle damage indices, and the effect of training status (or in the case of ageing, detraining status) makes it difficult to unequivocally conclude that ageing muscle is more susceptible to exercise-induced damage. Furthermore, the exercise protocols used in many studies of muscle damage often use lengthening contractions that are extreme and unrealistic to most muscle training regimens.

Lengthening contractions are widely used to induce muscle damage in studies designed to investigate damage, repair and recovery. Typically these lengthening contraction protocols involve a large number of contractions performed at extremely high loads. While this is effective in inducing muscle damage it is not representative of normal athletic training. Athletes may incorporate resistance training into a training regimen, however this is typically at resistances less than one repetition maximum (1RM). The course of damage and recovery from the lengthening contractions typically used in these studies may differ from that which occurs during normal physical training and recovery. The above factors clearly indicate that there is a need for further research

in this area, with particular attention paid to the protocol used to elicit muscle damage, the measurement of the damage, and the training status of the participants.

### Ageing, Recovery, Repair and Adaptation of Skeletal Muscle

The second argument presented for a delayed recovery in the ageing athlete is the likelihood of a longer repair and adaptation time for damaged/fatigued skeletal muscle. If the skeletal muscle of both young and ageing athletes experience similar amounts of exercise-induced damage but the kinetics of recovery are slowed with age, then the time period before full performance recovery after exercise would be extended as we age. Moreover, if exercise-induced damage is in fact greater in ageing skeletal muscle, then this in itself may also contribute to further impair recovery processes (335).

Investigating differences in the recovery kinetics of young and ageing muscle can be achieved by the comparison of variables such as the time taken for replenishment of energy substrates or for the repair of structural and/or functional changes induced by exercise. The duration required for training adaptations to occur in response to an exercise stimulus may also be considered as an indicator of these recovery and repair processes. However, the literature which has compared the recovery, repair and adaptation processes in the skeletal muscle of young and ageing animals and humans has failed to clearly demonstrate age-associated differences (234, 346, 394). Again, this may be due to the exercise protocol employed to elicit damage/fatigue of the exercising muscle influencing the recovery and repair processes.

Recovery from metabolic fatigue will involve very different recovery mechanisms to recovery from contraction-induced muscle damage. While some studies have demonstrated clear differences between young and ageing muscle in the recovery

of functional parameters after exercise (68, 298, 299), others have reported that age does not negatively affect recovery duration (4, 182). In the above studies there appears to be a clear effect of age on recovery from lengthening contraction-induced injury but not necessarily from fatigue (presumably without injury). Therefore, for the purpose of comparing recovery between young and ageing muscle it is important to keep in mind whether the exercise-induced damage or fatigue protocol used is representative of 'normal' athletic pursuits in human beings.

### **Glycogen recovery**

Long duration exercise can deplete muscle glycogen stores which can negatively impact upon muscle function and athletic performance (409). While there is evidence that ageing muscle may have lower resting levels of both high energy phosphates (313, 422) and glycogen (104), it is likely that in humans this is largely due to a more sedentary lifestyle, as training has been shown to restore resting levels towards that of young muscle (104, 308). Greater levels of depletion and/or impaired restoration of glycogen after exercise in ageing muscle would be detrimental to recovery and subsequent exercise performance.

With respect to glycogen recovery, both of the proposed mechanisms for a delayed recovery in older skeletal muscle, greater damage and/or slower recovery, may actually work together in a cumulative manner. Exercise-induced muscle damage has been shown to impair post-exercise muscle glycogen resynthesis (125). Glycogenesis impairment after lengthening contractions has been attributed to transient decreases in glucose transport protein-4 (GLUT-4) content (19), but the same mechanism was not associated with impaired recovery of muscle glycogen post-marathon (20). In the latter study GLUT-4 translocation to the sarcolemma may have been affected by the marathon however this variable was not measured. Any impairment of glucose transport and

glycogenesis post-exercise could contribute to delayed recovery and decrease subsequent exercise capacity if performed prior to complete recovery of glycogen stores (18).

Muscle GLUT-4 levels have also been suggested to decrease with ageing (189). A combination of ageing and damaging exercise therefore may impair post-exercise glycogenesis to a greater extent than would be seen by either of these factors individually. However, Cox et al. (128) found that even short term exercise training (7 days) could improve glucose uptake via increased muscle GLUT-4 concentration equally in both young (18-30 yr old) and older (50-70 yr old) sedentary subjects, with no differences between groups either before or after training. This has also been demonstrated in rodents where GLUT-4 concentrations have been shown to be ~50% higher in adult rats (10 months) with access to running wheels than controls (188). While the same study did not demonstrate the equivalent training-induced adaptations in GLUT-4 levels in an older group of exercised rats (25 months), the lesser adaptation was attributed to a markedly reduced daily training volume in the older animals compared with the adults (<50%). Thus although it is possible that this finding suggests a reduced adaptability in old age it may simply reflect the effects of decreased training (104).

Clearly the physical activity levels of research subjects must be considered when drawing conclusions from much of the existing research relating to post-exercise recovery of muscle glycogen. Future studies may resolve some of these questions by comparing glycogen resynthesis after exercise in young and ageing athletes matched for training and performance.

## **Musculoskeletal tissue recovery and repair**

The adaptive potential of muscle tissue (and other associated systems) limits the gains that can be realised through training. The rate that a tissue can repair from, and prepare for future, exercise-induced stress will govern how often and how intensely the tissue can be stressed. If this rate is reduced by ageing, then the adaptive potential will decrease due to reduced capacity for frequent and intense physical training. If increased damage and delayed recovery are products of inactivity as much as they are consequences of ageing, what implications does this have regarding the potential for old muscle to adapt to physical training?

Slower adaptation in response to various conditioning exercises has been reported with ageing in rodents (72, 299). Adaptation (protection from injury) from an initial bout of lengthening muscle contractions was less in the muscle of ageing rats (32 months) than that of young (6 months) rats when exposed to the same exercise two weeks later (299). Clarkson and Dedrick (112) used two bouts of lengthening contractions to induce muscle damage and then to investigate the effect of age on repair and adaptation in humans. In contrast to the findings of McBride et al. (299) they found that the damage and repair processes in response to the first and second bouts, seven days apart, were the same for the elderly as for the young participants. The highly active training status of the older women in the study of Clarkson and Dedrick may have contributed to the different results.

Brooks et al. (72) reported that while a period of pre-conditioning exercise training could provide protection from skeletal muscle injury induced by lengthening contractions, this protective effect took six weeks to develop in older mice compared with only four weeks in young mice. Hence, although the pre-conditioning exercise

helped reduce the degree of subsequent exercise-induced muscle damage, the time taken to condition the muscles of the old mice was significantly longer than for the young animals. This finding suggests that older muscle may experience slower, but equivalent adaptation to exercise compared with young muscle, and also provides evidence for the hypothesised prolonged recovery duration in older athletes due to slower adaptation mechanisms. However, it cannot be discounted that the longer conditioning period could be due to reduced habitual activity in older rodents (315) prior to the initial bout of lengthening contractions.

Recently, treadmill training has been found to protect against force deficit caused by lengthening contractions equally in the muscles of both young (3 months) and old (23 months) rats (184). The researchers reported that ten weeks of treadmill training reduced the loss of isometric force after lengthening contractions in old trained rats compared with old control rats from 28% to 13% and that this was comparable to the adaptation in the young rats (26% to 13%). Similar evidence of adaptation to muscle contraction has been demonstrated by other researchers. Pette and Skorjanc (346) reported that ageing rats (101-108 weeks) demonstrated the same alterations in fibre type composition, myosin heavy chain isoform pattern, and enzyme activities as young adult rats (15-22 weeks) in response to 50 days of chronic (10 hours per day) low frequency stimulation. Unfortunately, neither of these studies investigated the time course taken for these adaptations to occur in the young and old animals. Nonetheless, these two studies indicate a similar potential for muscle to adapt to physical training in both older and younger animals.

It has been suggested that ageing human muscle retains plasticity and has the ability to adapt to physical training, with gains in both strength and size being reported

as a consequence of resistance training (165, 440). Physical activity may also ameliorate, or mask mitochondrial 'ageing' in muscle (66). Consequently, both endurance and strength training are recommended forms of physical activity for ageing people (7). However, is the adaptive potential the same for both young and old muscle? A number of recent studies have examined the adaptive potential of ageing human skeletal muscle, as indicated by satellite cell number and activity (376, 378). Initial results suggest that, in contrast to findings from animal models (29), satellite cell populations are not significantly lower in healthy, sedentary older compared to young adult men and women (376). In a follow-up study (378), nine weeks of strength training was found to elicit significant increases in satellite cell proportion (from 2.3 to 3.1%) and in the number of active satellite cells (31% up from 6-7%) in both young (20-30 years) and old (65-75 years) men and women. Similarly, after six months of strength training, there were significant and similar increases in thigh and quadriceps muscle volume in both young and old males and females, leading to the conclusion that neither age nor gender affects muscle volume response to whole-body strength training (374).

From the research presented, it seems likely that exercise training leads to muscle adaptation and can impart a protective effect on skeletal muscle in the elderly. However, the impact this has on functional recovery is still to be elucidated. The optimisation of recovery for a subsequent bout of exercise is important to the athlete as alterations in the rate of recovery may affect subsequent performance and adaptation. Consequently, the effect of ageing on recovery from exercise and subsequent performance needs to be explored.



A major goal of the training process regardless of age is to maintain or improve functional performance in the chosen sport. While the training model aims to elicit progressive overload leading to positive functional adaptations and improved performance, the concern for the older athlete is that if recovery processes are impaired there is a greater risk of inadequate recovery whereby training actually leads to progressive overreaching. Progressive overreaching involves a gradual decline in functional performance despite maintenance of training load, due to insufficient recovery.

A recent study by Pimentel et al. (351) found that there was no notable decline in training volume, cardiovascular fitness or athletic performance up to 50 years of age in well-trained athletes. However, beyond the age of 50 all these variables begin to decline rapidly. What cannot be ascertained from this research is whether the decrements in performance and cardiovascular fitness are due to declines in training volume or vice versa. This raises the question as to whether the older athlete voluntarily reduces their training volume due to age-related declines in rate of recovery, or alternatively by attempting to maintain training volumes, functional performance declines due to inadequate recovery (progressive overreaching). This conundrum may be further complicated by evidence that mechanisms of perceived effort and pain may also be influenced by ageing (5, 178) and it is these perceptual feedback mechanisms that athletes may use to monitor training load and recovery (216). Consequently, how the perception of recovery may be altered in the ageing athlete and how this may affect training also merits investigation.

The suggested physiological mechanisms that may contribute to impair recovery from exercise in the well-trained ageing athlete have not yet been confirmed. A potential reason for the limited literature regarding recovery in the well-trained ageing

athlete may be due to difficulties encountered in monitoring recovery from training and competition in general.

### ***Recovery from Training and Competition***

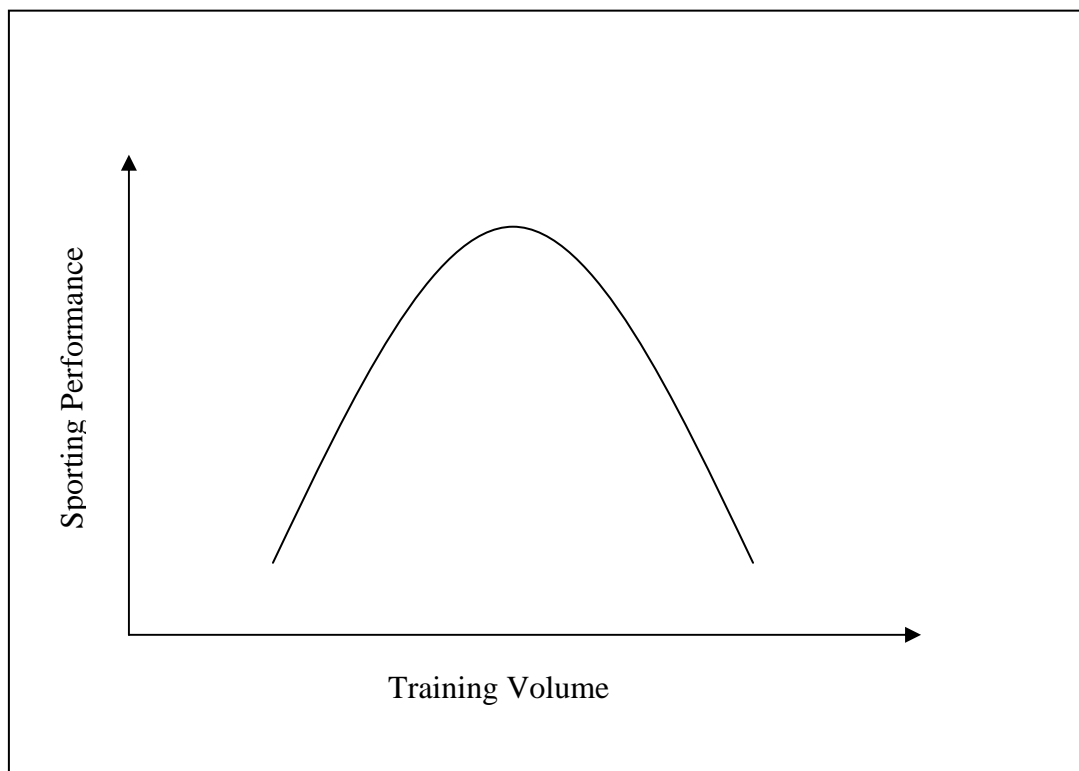
There is limited published research addressing recovery from training and competition, particularly in well-trained athletes. Of the literature available there has been a focus on either acute recovery from a single exercise bout (171) or, more recently, the monitoring of athletes for symptoms of overtraining during typical training activities (215). The latter monitoring of recovery is considered most relevant to the present investigation. The focus of this review of the literature is on the ability for the ageing athlete to recover between bouts of normal physical training and competition in order to achieve optimal performance. Consequently, the following section will address the importance of recovery in the physical training process, problems associated with inadequate recovery, the measurement of physical recovery, and methods commonly used to accelerate recovery after exercise.

### **Training, Recovery, Overreaching and Overtraining**

Recovery from exercise is as essential as the exercise itself to subsequent health and athletic performance. The simplified dose-response curve (Figure 2.7) represents that the response of the body to physical training is dependent upon the amount of training, or 'optimal training' (255). Training volumes which are less than what can be considered optimal do not result in the desired adaptation (greatest performance gains), whereas when the amount of training exceeds the optimum, performance could decline because of the fatigue induced by 'over-solicitation' (89).

Accumulation of large amounts of intensive exercise with insufficient recovery between training bouts can lead to a transient decrease in performance. Where a

reduction in training load can reverse performance declines the condition has been termed overreaching (193). However, sustained overreaching could lead to a gradual transition to more a long-lasting stage of fatigue, a condition usually referred to as the ‘overtraining syndrome’, ‘staleness’, or ‘burnout’ (244). Overreaching and/or overtraining present as a decrease in performance (exhaustion phase), which can take from days to many months to recover from (193).



**Figure 2.7: Simplified ‘inverted-U’ dose-response curve of training and performance**

Over recent years much research has been undertaken addressing overtraining in athletes (169, 212, 277, 450). Although the causes and identification of overtraining are complex, adequate recovery is unequivocally one of the most important elements in preventing overtraining. It has been stated that overtraining is due to an imbalance between stress and recovery (264) and that under-recovery is the precursor/cause of overtraining (241).

The supercompensation principle described earlier (Figures 2.4 & 2.6) relies on a suitable period for recovery before performance gains can be realised. Using a systems model to investigate the effect of an increase in training frequency (i.e. reduced recovery time between bouts) on exercise-induced fatigue, Busso et al (90) found that when training frequency was high there was an increase in magnitude and duration of fatigue induced by a single training bout. Training induced fatigue was reported as the time needed to recover performance after a physical training session, and increased from 0.9 +/- 2.1 days at the end of a low-frequency training period to 3.6 +/- 2.0 days after a high-frequency training regimen. Additionally, maximal gain in performance for a given training load decreased during high frequency training. Consequently it was concluded that shortening recovery time between training sessions progressively yielded a more persistent fatigue induced by each training effort. Accordingly, the importance of adequate recovery from training and competition for maximising performance gains is widely acknowledged (214, 216, 244).

Kellman (241) recently emphasised the importance of recovery stating that 'the key to prevent overtraining is an active and proactive enhancement of recovery'. However, apart from the use of appropriate nutritional practices, there is surprisingly little empirical research published that validates the putative methods of improving recovery in an athletic population. Clearly, adequate rest is essential, but additional strategies that can be undertaken between training sessions to promote repair and assist the body to adapt in readiness for the next session should help improve performance by: 1) enabling a better quality of physical training through being able to maintain a higher training intensity, and/or 2) allowing an increased frequency of training sessions.

During periods of intensified training such as that performed in overreaching studies, athletes demonstrate reductions in physical performance and increased ratings of fatigue and soreness with more negative mood state profiles (168, 192, 277). However, as per the definition of overreaching, a short period of rest or recovery training may lead to restoration of performance capacity (193). There is some evidence that overreached athletes can demonstrate greater improvements after a brief taper period than well trained athletes (127), which may lead to athletes and coaches attempting to deliberately overreach prior to major competition. A recent study addressing intense training in junior elite rowers proposed that overreaching is an integral part of successful training regimens (414). Consequently, monitoring recovery can be problematic during intensified training periods where temporary performance decrements might be routinely expected. Kenttä and Hassmén (244) suggest that an athlete failing to recover within 72 hours is presumably negatively trained or in an overreached state. Therefore, the challenge of any training regime is to finely balance the relationship between training load and successful recovery so as not to overstress the body to the point beyond which a rapid and full recovery cannot be achieved.

In order to achieve an optimal balance between physical training and recovery a logical process is to attempt to hasten recovery and also to monitor training induced fatigue so that recovery can be quantified. Research has attempted to identify effective means by which recovery can be accelerated (191). However, while substantial anecdotal evidence for various recovery techniques exist (94), the research literature is less convincing, largely due to limitations in accurately monitoring the physical training responses and recovery from exercise (176).

## Monitoring and improving recovery from exercise

Inadequate recovery after training, competition, between training seasons, or after rapid increases in training load, may result in overtraining syndrome (277). To avoid overtraining there is a need for recovery to be included as an integral component of the training plan (94, 244, 277). However, activities aimed at promoting physical recovery should be carefully selected based on confirmed efficacy which can only be established using valid and accurate monitoring techniques.

### Measuring Recovery

One of the challenges confronting research into measuring and enhancing recovery is the absence of validated markers of recovery to enable monitoring of training and recovery (244). Various measures of recovery have been employed with a mixture of success. In the investigation of overreaching and overtraining in athletes researchers have attempted to identify methods of monitoring training and recovery (450), but as yet no specific, simple, and reliable parameters are known to diagnose overreaching and overtraining in the earliest stage (255). Recent reviews on the topic of overtraining and overreaching have consistently identified some of the problems with monitoring athletes for signs of overtraining (193, 277), reinforcing the difficulties associated with quantifying recovery from exercise.

The identification of athletes with lasting residual fatigue from training and the requirement for monitoring is not a recent area of research. Early work by Forbes Carlile identified performance decrements in elite swimmers during intensified training periods. These observations subsequently lead to the measurement of variables such as brachial pulse wave, electrocardiogram, body mass, and haemoglobin levels in an attempt to objectively measure signs of 'strain' (100, 101). Coaches and scientists have

continually sought to establish reliable and objective markers to identify excessive strain in athletes in an attempt to optimise training and avoid any negative consequences of overtraining. Recently, psychological measures such as the recovery-stress questionnaire (242), changes in blood cortisol (22) and catecholamines (278), changes in immune system variables such as glutamine/glutamate ratio (194), alterations in the relationship between perceived exertion and heart rate (285), or perceived exertion and blood lactate (61, 175), have all been suggested as useful tools, with varying levels of validity, for monitoring training and recovery in order to provide early diagnosis of overtraining. As there is no clear diagnostic test for overtraining (193), there is a general consensus that physical performance is the only 'gold standard' for measuring recovery from training and identifying maladaptation in athletes (413). Halson and Jeukendrup (193) suggest that it is essential that these alternative indicators only be considered in relation to changes in physical performance and not separately due to uncertainty in many of these markers of overreaching and overtraining.

While it is evident that performance is the preferred method of monitoring training and recovery responses, there are a variety of ways that performance can be measured. The selection of a performance measure is dependent upon the athlete being investigated. Time trials (213), measurement of maximal aerobic power (231), time to fatigue (449), jumping ability (127) and maximal force (167) are among the various performance tests that have been used to diagnose overtraining in athletes or to monitor fatigue and recovery. Research into methods for improving recovery have often utilised both performance measures and a variety of non-performance related variables. The main aim for the researcher should be to ensure that the measurement technique specifically reflects the performance requirements of the sport, the 'gold standard' of overtraining syndrome diagnosis (450). As a minimum requirement a test should at least

measure physiological changes that may have a detrimental impact upon sporting performance.

The difficulties in accurately quantifying training, recovery and overtraining complicate the investigation of practices designed to improve recovery. The measurement technique selected to assess the efficacy of a particular recovery intervention may influence whether the intervention is found to be worthwhile, of no benefit or detrimental to recovery. Consequently while numerous techniques have been utilised and even vigorously promoted by athletes and coaches over the years there is limited scientific support for many of these techniques (191).

### **Enhancing recovery**

Monitoring and balancing training stress and recovery to optimise performance gains is a continual challenge for coaches and athletes (242). By facilitating rapid recovery the best possible performance gains from physical training can be realised. However, questions remain with regard to what strategies promote recovery and how can we accurately monitor recovery?

Recovery strategies can be divided into two broad categories. Passive (sleep/rest) and proactive (massage, stretching, hydro/aqua-therapy, diet and fluid replacement, dietary supplements, low volume/intensity training and electrotherapy) recovery strategies are all intended to assist the body to adapt to the training stimulus as rapidly as possible. The importance of rest for recovery is self-explanatory and clearly essential to the training process. However, the possibility of speeding the rate of recovery above what would normally occur with passive strategies alone by using active techniques is appealing to most coaches and athletes.



Bompa, (51) allocates an entire chapter to recovery describing in detail several methods of promoting physiological recovery from exercise. Physiotherapeutic means of recovery proposed by Bompa include; massage, heat or thermotherapy, cold or cryotherapy, contrast baths, oxygenotherapy, aerotherapy, altitude cure, reflexotherapy-acupuncture and acupressure, vagal-reflexotherapy and chemotherapy. However, amongst the description of these techniques and their suggested effects there is no single reference to a controlled study that has demonstrated enhanced recovery and athletic performance. Many of these commonly practiced recovery modalities may only provide a placebo effect for the athlete. From the available literature on many of these recovery strategies there are conflicting findings and at this stage it is difficult to confirm the benefits of any one technique.

A recent comprehensive report on recovery in elite athletes highlights the limited literature available regarding proactive recovery activities (191). In this report recovery modalities were rated as low, medium or high based on both scientific research and current usage. A high rating could be given to a specific recovery modality if there was; a) sufficient scientific evidence to support its usage, or b) if large numbers of athletes used the modality and there was no scientific evidence suggesting it is detrimental to performance. The argument given for the second category was the limited published scientific evidence in the area. The report allocated a high rating to several recovery modalities including compression garments, contrast therapy (alternating hot and cold exposure), ice therapy/cryotherapy/cold water immersion, and stretching, but acknowledged the need for further research into many of these modalities.

In contrast to many of the above recovery interventions, the potential for optimal nutritional practice between training sessions to improve performance has been reported comprehensively in the literature (76, 80, 98, 268). The importance of post-exercise nutrition for recovery in athletic performance is unequivocal, and has been demonstrated by research that has shown aerobic performance following recovery is related to the degree of muscle glycogen replenishment (223). The timing and composition of post-exercise nutrient intake is also critical in order to optimise performance potential in subsequent exercise activities (80, 204, 268). Consequently, when researching the influence of ageing on recovery, the dietary intake of the athletes investigated may well be a critical variable that must be considered.

### ***Nutrition Intake and the Ageing Athlete***

A crucial aspect of physical training and recovery is the supply of adequate nutrients for optimal nutrition and performance (196, 324). In order for any organism to survive, energy input must equal energy expenditure and regular exercise increases energy expenditure. Consequently, dietary intake should change in order to meet the increased demand. As a result there has been a substantial amount of research performed on the dietary needs of athletes (79, 98, 416, 454), and the topic of sports nutrition continues to generate debate and play a major role in exercise-focussed research.

In contrast, there is a limited availability of published research addressing the nutritional requirements of the ageing athlete. Several recent reviews highlight the distinct lack of empirical research that specifically addresses the dietary behaviours and needs of ageing athletes and the potentially unique dietary requirements created as a result of the combined effects of intense physical exercise and ageing (95, 279, 362,

383). The physiological changes in the ageing athlete identified in the previous sections infer potential modifications in the nutritional requirements for this group. Declining lean body mass, changes in immune function, reduced sensitivity of chemoreceptors (taste, smell), changes to bone mineral density, compromised cardiovascular function, altered gastrointestinal function and impaired thirst sensitivity are some of the proposed, but far from conclusive, arguments for differing nutritional requirements for the ageing athlete (9, 290, 292). Unfortunately, due to the paucity of literature specifically addressing these issues much of the information can only be inferred from research on younger athletes and from sedentary ageing populations.

Recommended Dietary Intake (RDI) and Recommended Daily Allowance (RDA) are the levels identified as the amounts of micro- and macronutrients necessary for healthy living. Evidence exists that ageing contributes to deficiencies in meeting RDI for a range of micronutrients (25). Furthermore, a recent report by the American Dietetics Association (9) has confirmed that older adults have specialised requirements for a variety of nutrients because of the impact of ageing on absorption, utilisation and excretion. However, this report does not provide specific recommendations regarding the nutrient requirements for the ageing athlete. Dietary recommendations for the average sedentary older person may be quite inappropriate for the highly trained active ageing athlete. The specialised requirements identified for the ageing sedentary individual could be magnified by the intense physical training undertaken by many ageing athletes. There is an immediate need for more research specifically addressing whether current nutritional guidelines are suitable for the ageing athlete. From the few published investigations into the dietary intake of ageing athletes the results reported have suggested potential specific nutritional deficiencies in an ageing athletic population (40, 91, 105).

This section will address four main issues with respect to nutrition for this population. Firstly, the importance of energy intake equalling daily energy expenditure will be discussed with a focus on the mix of macronutrients (carbohydrate, fat and protein) appropriate for optimal athletic performance. Secondly, the role of micronutrients for athletic performance and any specific issues relevant to the older athlete will be discussed. Thirdly, methodological difficulties associated with dietary assessment will be considered. Finally, the estimation/calculation of daily energy expenditure as a means of validating diet records will be discussed.

## Energy Intake

With increasing physical activity there is an associated rise in the demand for energy. One of the primary aims for the ageing athlete should be to ensure adequate energy intake to meet energy demand. However, dietary surveys have consistently documented a decline in food intake with increasing age (318). Such a trend would have a negative impact on the athletic performance of the older individual who continues to maintain an intense physical activity regime. Restrained eating in athletes can cause significant detrimental outcomes to body function (79). Many athletes are over-focused on reducing body mass and body fat below levels that are consistent with long-term health and performance (79) and this trend may also be evident amongst the ranks of master and veteran athletes. As such, with a reduced caloric intake, the nutritional quality of the diet becomes increasingly more important (369).

To date, there is no clear evidence that older athletes do not meet energy requirements adequately. The available studies investigating the diet of older groups of athletes have reported significantly higher energy intakes in athletes than in age-matched controls or compared with the RDA/RDI values (40, 91, 105, 190).

Butterworth et al (91) compared the dietary intake of highly conditioned elderly women and sedentary females using seven-day diet records. The researchers found that the highly conditioned women consumed significantly more energy, protein and carbohydrate than the sedentary group. In a recent study using female athletes, Beshgetoor and colleagues (40) used four-day diet records to compare the dietary intakes of master cyclists and runners that took nutritional supplements with those that did not ( $50.4 \pm 2.2$  years). The researchers reported caloric intakes of both the supplementing athletes ( $2079 \text{ kcal.day}^{-1}$ ) and non-supplementing athletes ( $2001 \text{ kcal.day}^{-1}$ ) to be greater than the 1632 kcal per day reported by the U. S. Department of Agriculture for non-athletic women of a similar age.

For older male athletes the trend for larger average energy intakes is also evident (105, 190). Using seven-day diet records Hallfrisch et al (190) reported energy and protein intakes in senior athletes (58-75 years) to be higher per kg of body mass than in body mass index (BMI)-matched healthy controls. Similarly, elderly sportsmen have been reported as consuming energy intakes 24% higher than French RDA values when assessed using seven-day diet records (105).

Taken together, these findings suggest that the energy intakes of ageing athletes are correspondingly higher than the general population in response to the increased energy requirements created by the physical training demands. However, whether the higher reported intakes were enough to meet the energy demands of the athletes remains uncertain. Of the above studies, only Chatard et al (105) attempted to quantify daily energy expenditure to ascertain if energy intake matched energy expenditure. These researchers used a questionnaire to evaluate each subject's habitual physical activity over a seven-day period and to estimate daily energy expenditure (DEE). Nine out of

the 18 sportsmen surveyed were estimated as having total DEE greater than their calculated energy intake, with deficits ranging from 580 to over 3000 kJ per day. Assuming that these athletes were experiencing no changes in body mass, then it is possible that these subjects were either having DEE overestimated or, more likely, energy intake under-estimated/underreported (209). However, there is also the argument that during the study by Chatard et al (105) the 'energy deficient' sportsmen identified were not actually meeting their energy requirements adequately, an outcome that would have serious implications for exercise performance. The most accurate method of determining the accuracy of dietary assessment surveys in a population is to verify DEE using the doubly labelled water technique (466). However, to date there has been no study to assess and validate dietary intake in an elderly athletic population using such methods.

## Macronutrients

Energy rich nutrients in the form of carbohydrate, fat, and protein provide the necessary fuel to maintain body functions both at rest and during various forms of physical activity. These nutrients, called macronutrients, play an important part in maintaining the structural and functional integrity of the organism (297).

For individuals who regularly expend high amounts of energy on a daily basis, adequate energy supply is a primary concern. In addition to total energy intake meeting energy expenditure, the proportion of kilojoules derived from carbohydrate, fat and protein can also contribute to athletic performance (98). However, use of proportions in making dietary recommendations may actually be misleading in terms of providing optimum nutrition and can prove unnecessary and unfeasible for some athletes (85). Specific recommendations for individual energy components may be more useful when

they are based on body size, weight and body composition goals, the sport being performed, and sex of the athlete (98).

## **Carbohydrate**

The weight of evidence suggests that athletes should consume the majority of their energy intake in the form of carbohydrate (CHO). Official position statements prepared by sports nutrition expert groups and some research studies have advised athletes to consume diets providing energy from carbohydrate sources ranging from 55% to greater than 70% of total energy intake (85). However, Burke et al. (85) suggest that it is preferable to provide recommendation for routine CHO intake in grams relative to the body mass of the athlete. The researchers provide guidelines for recommended CHO intake per kilogram for long term or routine dietary behaviour in recreational athletes (5-7 g.kg<sup>-1</sup>.day<sup>-1</sup>; moderate exercise of < 1 hour per day), endurance athletes (7-10 g.kg<sup>-1</sup>.day<sup>-1</sup>; 1-3 hours per day moderate to high intensity exercise) and those undertaking extreme exercise programs (10-12+ g.kg<sup>-1</sup>.day<sup>-1</sup>; >4-5 hours of moderate to high intensity exercise).

From the available literature concerning dietary intakes of veteran athletes it is unclear as to whether, as a group, these athletes are meeting CHO intakes for optimal performance (40, 105, 190). Chatard et al. (105) reported an average daily CHO intake of 338 grams which when divided by the mean body weight of the 18 elderly sportsmen investigated in the study equates to 4.8 g.kg<sup>-1</sup>.day<sup>-1</sup>. In an earlier study involving sixteen endurance trained older athletes the mean CHO intake was 4.4 g.kg<sup>-1</sup>.day<sup>-1</sup> (190). More recently, for older female endurance athletes, Beshgetoor et al (40) reported an average CHO intake of 269-277 grams per day with no body mass of the subjects provided. The relative contributions of the macronutrients to total energy

intake (EI) in the study of Beshgetoor et al. (40) were cited as 17-20% protein, 28% fat and 52-55% carbohydrate.

Burke et al. (85) suggest that 'endurance trained' athletes (1-3 hours of moderate to high intensity exercise per day) should be consuming CHO in the range of 7-10 grams per kg body mass per day. This value is much higher than the values reported above for ageing athletes. Lower than desirable daily CHO intake can be detrimental to glycogen replenishment after exercise, which can in turn limit subsequent athletic performance (223). However, in a review article by Hawley et al. (206) the researchers concluded there was little scientific support that chronically increasing daily CHO intake will lead to an improved training capacity, although acute supplementation may be essential when rapid recovery is required. Consequently, further research is warranted to identify if older athletes are consuming sufficient CHO for optimal athletic performance.

## **Fat**

The World Health Organisation (WHO) provides recommended guidelines for fat intake based on the general health benefits that can be derived from a reduction in overall fat consumption, particularly the consumption of saturated fats ([http://www.who.int/dietphysicalactivity/publications/trs916/en/gsfao\\_overall.pdf](http://www.who.int/dietphysicalactivity/publications/trs916/en/gsfao_overall.pdf) Retrieved 21 August. 05). There has been some recent attention paid to the potential for performance enhancement through manipulating lipid metabolism via high fat diets (203, 205, 258). However, for health purposes, the general recommendations are that athletic diets should provide moderate amounts of energy from fat (20% to 25% of energy) with no benefit in consuming diets with less than 20% of the energy derived from fats (98).



From the available literature on nutritional status of groups of older athletes, it is apparent that these cohorts of athletes consume fat as a proportion of total energy intake greater than the guidelines indicated above with values ranging from 28% (40) to 36% (105). As an absolute value, high fat intakes in these groups (63-107 g.day<sup>-1</sup>) reflect the larger overall nutrient intake in many athletes. However, a high relative contribution of energy from fat is discouraged for health purposes. Taken in conjunction with the lower than optimal CHO intakes for older athletes described above, this may suggest a possible variable that could limit optimal sporting performance. At present it is unknown if an exchange of energy intake from dietary fat sources with that from dietary CHO would benefit the ageing athlete in training and recovery, once again highlighting the need for further research in this area.

## **Protein**

Protein is continually being degraded and synthesised by the body and accounts for approximately 15% of body weight (383). The role of amino acids in forming structural proteins such as in muscle tissue, and functional proteins in the form of enzymes and antibodies, as well as providing a potential source of energy, highlight the importance of protein to be continually provided by the diet. There is some debate as to the relative amount of protein required in an exercising population (265, 309). In a joint position statement by the American College of Sports Medicine, American Dietetic Association and the Dietitians of Canada (8), an increased need for daily protein requirements was recommended for both endurance and resistance-strength trained athletes (1.2-1.4 g.kg<sup>-1</sup> body weight and 1.6-1.7 g.kg<sup>-1</sup> body weight respectively). However, it is considered a varied diet that meets energy needs will generally provide protein in excess of requirements (IOC Consensus Statement, [http://multimedia.olympic.org/pdf/en\\_report\\_723.pdf](http://multimedia.olympic.org/pdf/en_report_723.pdf); Retrieved 21 August 2005).

Ageing results in a decrease in muscle mass and function often referred to as sarcopenia (138), leading some researcher to argue for higher protein requirements for older individuals due to an altered muscle protein metabolism (96, 460, 461). However, age-related alterations in muscle protein metabolism can be also influenced by participation in an exercise program (403). The combination of increased amino acids and exercise are additive in optimising protein synthesis although this is dependent on the timing of intake (140). While the RDA for protein in older men and women could be inadequate (96), there remains no clear guidelines for the protein requirements of the highly physically active elderly. Assuming that the requirements of this older population of athletes is similar to that of younger athletes then ageing athletes participating in regular endurance exercise should be consuming between 1.2 and 1.4 g.kg<sup>-1</sup>.day<sup>-1</sup>.

From the limited studies into nutrient intake in elderly athletes it appears that protein consumption is greater than the above recommendations (40, 105, 190). Investigations of nutrient intakes using male athletes reported an average protein intake of 1.5 g.kg<sup>-1</sup>.day<sup>-1</sup> in both studies (105, 190). The over 35 year old female athletes in the studies of Beshgetoor et al (40, 41) would appear to have an average daily protein intake of 1.5 to 1.9 g.kg<sup>-1</sup>.day<sup>-1</sup>. It is likely that the higher overall dietary intake of these athletic individuals helps in contributing to them successfully meeting minimum dietary protein requirements. This finding is repeated in many other studies into the dietary intake of both athletes and the general population (359), suggesting that it is unlikely that older athletes need to consciously increase the protein content of their diet. More important for the intensely training athlete, is the timing of protein ingestion, with recent studies demonstrating potentially beneficial effects upon protein metabolism as a result of manipulating the composition and timing of nutrient delivery (268, 423, 456).

It has been argued that post-exercise glycogen synthesis can be enhanced with the addition of protein and certain amino acids to CHO (225, 455), and that the combination of CHO and protein has an added benefit of stimulating amino acid transport, protein synthesis and muscle tissue repair (223).

Based on the few available studies in ageing athletes it seems that while the overall quantity of protein intake is adequate for exercise performance, there is no research addressing the importance of the timing of protein intake for this specific athletic population. Due to the possible additive effect of ageing and exercise on protein requirements, it is possible that the well-trained older athlete may benefit substantially from well structured nutritional practices with respect to protein intake. Whether there are any greater benefits to controlling the timing of protein intake in an older athletic population compared with young athletes has not been investigated.

## Micronutrients

Vitamins and minerals are required for the effective regulation of all metabolic processes. Small quantities of vitamins and minerals play highly specific roles in facilitating energy transfer in biological systems (323). Deficiencies in these micronutrients may cause decreased performance (158, 160). The requirements for many vitamins and minerals may increase with age and exercise (98, 113, 281, 459). Exercise stresses many of the metabolic pathways in which these micronutrients are required, may increase turnover and loss from the body, and also increases micronutrient demand due to increased needs for repair and maintenance (281). These increased demands emphasise the importance of adequate nutritional practices in order for athletes to avoid micronutrient deficiencies.

With increasing energy intake there is generally an increase in the intake of the micronutrients (98). Provided that an adequately varied diet is chosen the RDI/RDA for the micronutrients should be satisfactorily achieved (362, 383). It is generally acknowledged that if energy intake is adequate for the maintenance of body mass and is consumed from a variety of foods, vitamin and mineral supplements are not needed. A combined position statement acknowledged that micronutrient supplementation may be required by some athletes with special circumstances (98). However, the ageing athlete was not identified in this report as a group with special needs.

While young athletes that adequately increase their nutrient intake to meet energy expenditure should be able to avoid the risk of micronutrient deficiencies, there are several reasons suggested that this may not be the case in an ageing athletic population (243). Gastrointestinal function is generally well preserved with ageing regarding the digestion and absorption of macronutrients, but the ageing gastrointestinal tract becomes less efficient in absorbing some micronutrients such as vitamin B12, vitamin D, and calcium (381, 382). While several reviews have indicated ageing athletes may have a need for higher than RDI intakes for specific micronutrients (362, 383) to date, few research studies have examined micronutrient intake in older athletes (105).

In measuring the nutritional status and physical fitness of 23 elderly French sportsmen (mean age  $63 \pm 4.5$  years), Chatard et al. (105) concluded that this active elderly population had a higher nutritional status than RDA or non-active elderly, nearing the nutrient intake of young athletes. However, despite greater intakes of nutrients there were still some subjects that were determined to have deficiencies for specific vitamin and mineral intakes (magnesium, vitamin D and calcium). Several

other studies have also identified lower than RDA intakes for several of the micronutrients in ageing athletes (40, 91). Reaburn and Le Bon (364), cited in Reaburn (362) reported lower than RDA intakes for calcium and iron in female runners and for zinc and magnesium in both male and female runners. Less than RDA calcium intakes have also been found in female cyclists and runners (40) and in female endurance athletes (91). Beshgetoor and Nichols (40) also reported vitamin E to be only 87% of RDA. In many cases these findings were only in several individuals rather than the study group as a whole. However, it should be noted that athletes (including older athletes) may already have higher micronutrient needs than the average population (111, 113). Consequently, RDA/RDI information may not be adequate for those engaged in heavy training.

A factor that may further compound any micronutrient deficiencies in ageing athletes is the potential for increased needs caused by age-related changes in metabolism or decreased total energy intake (141, 287). While the few studies of nutrient intake in elderly athletes have indicated that the total energy intake of this group is higher than the RDA or age-matched sedentary controls (91, 105, 364), they have not indicated if energy intake was sufficient to balance daily energy expenditure. Therefore, it is not clear if all ageing athletes are successful in meeting their daily energy needs and overall nutritional requirements, which could affect sporting performance, training and recovery. At present there is a growing need for well-controlled research into the role of micronutrient supplementation in the highly-trained older athlete.

## Measurement of Dietary Intake

The importance of nutrition for athletic performance has been the topic of sports science research since Berry and colleagues studied the diets of elite sportspersons competing in the 1948 Olympic games (206), and the importance of diet on athletic performance has been repeatedly demonstrated (151, 360). Over the past few decades, a variety of methods have been developed to obtain dietary information (132). However, there is criticism from researchers, from the public, and from the media, that dietary assessment in general is too inaccurate (254). For research purposes, valid and reliable measures of food consumption are essential for estimating or measuring nutrient intakes for individual athletes or groups of athletes (132).

The methodology used for diet analysis can significantly influence the validity of describing nutritional status of individuals or populations (35, 387). There is also substantial evidence that self-reported energy intakes underestimate energy needs (42, 181, 253, 387). Additionally, interpretations of micronutrient data should be made cautiously as it is difficult to estimate correctly the influence of storage, cooking or rewarming on vitamin concentrations in food, and accurate assessment of micronutrients can require as long as 41 days (33).

At present there are two main techniques for measuring food consumption—recording of current dietary intakes (i.e. food record), and retrospective methods such as 24-hour dietary recall and food frequency questionnaires. The latter techniques rely on the memory of the individual to accurately document the foods they have eaten during a preceding period of time ranging from days to the whole year. Self-reported diet records require the participant to weigh or estimate using household measures all foods and beverages consumed over a defined time period. The weighed diet record has been

suggested as the ‘gold’ standard against which other or new methods for measuring dietary intake are compared or validated (43, 132). However, the limitations of this and other techniques is openly acknowledged (122, 254). While a short-term dietary record can provide a reasonable estimate of the general quality of the diet (417) it is crucial that the limitations of any method utilised are considered when interpreting the information obtained (35). Most of the published studies of dietary intakes of athletes have utilised food records using household measures (85).

There are many potential sources of error in collecting food intake data (35). For prospective data collection using diet records/diaries, factors such as gender, body weight, smoking, the literacy level of the participants, their motivation to maintain the food record, the quality of participant training by the researcher, and the added burden of maintaining diet records causing modification of diet behaviour, have all been shown to influence results (209). Although dietary records are appropriate and considered accurate if the respondents are adequately trained, under-reporting of actual intake is still high (132). Similar difficulties are also associated with recall methods. Factors such as subject motivation, memory, and communication ability along with the ability to estimate food portion sizes make it difficult to quantify diet intake. Furthermore, regardless of the method of data collection, the conversion of diet information obtained from the participant into nutrient information using food composition data presents additional sources of error in dietary assessment (63, 263).

The prevalence of under-reporting of food intake is a major issue in dietary assessment research (65, 232, 272). To address this concern the comparison of energy intake (EI), and energy expenditure or basal metabolic rate (either predicted or measured) provides a means of identifying under-estimates of energy intakes from food

records for both individuals and groups (132). By assessing energy expenditure to determine the extent of under-reporting of actual dietary intakes, factors such as age, body mass and BMI, gender, smoking status, and physical activity levels have all been associated with under-reporting (31, 65, 232). Methods of measuring or estimating DEE and basal metabolic rate (BMR) are discussed in the next section.

In an effort to address the issue of under-reporting and to validate energy intakes, Goldberg and colleagues (181) developed a range of cut-off values based on the ratio between EI and estimated or measured BMR (EI:BMR). The EI:BMR ratio determines whether reported energy intakes are realistic with regard to the energy required for a person to live a normal lifestyle and are adjusted for sample size and measurement duration of dietary intake.

One of the easiest methods of applying Goldberg's cut-off values is to calculate BMR from the equations of Schofield et al (392) or the Harris-Benedict equation (164). Although this ratio is crude and dependent on estimating BMR the Goldberg's cut-offs are a useful method of checking under-reporting of dietary intakes in individuals (132).

A recent evaluation of the effectiveness of using Goldberg cut-off ratios for identifying diet reports of poor validity, classified their sample group as under- (34%), acceptable- (62%) and over- (4%) reporters for energy intake (46). This high proportion (34%) of under-responders was attributed to the use of a single cut-off value. By taking into account the contribution of physical activity of the subjects when establishing cut-off values better sensitivity without loss of specificity was achieved. The researchers concluded that to identify diet reports of poor validity using the Goldberg cut-off for EI:BMR, information is needed on each subject's activity level (46). The above study suggests that when estimating DEE from equations of BMR in order to validate dietary



assessment by identifying under-reporting individuals, some form of physical activity level measurement should be performed concurrently. In the present study, the participants were all well-trained athletes participating in substantial weekly exercise activities. Consequently, any difficulties in estimating or measuring DEE in individuals should be considered.

## Measuring Energy Expenditure

Accurate assessments of dietary intake are essential for assessing the relationships between diet and health (209). However, the quantification of errors in dietary data can be difficult to detect in the absence of techniques to verify dietary survey methodology (271). One approach is to measure or estimate the DEE of the individuals being investigated to verify that energy intake is sufficient to meet energy expenditure.

Total DEE or its components (BMR, physical activity energy expenditure) can be measured using laboratory techniques such as calorimetry (466), or alternatively, estimated using prediction equations, physical activity records, pedometers or heart rate monitors (121). Laboratory-based methods that rate high with respect to validity and reliability do not lend themselves to large group dietary surveys because they are restrictive with respect to monitoring daily exercise and diet behaviours. Investigators have therefore developed alternative survey methods, physiological markers, and mechanical or electrical monitors for use in the field (391).

A common method of deciding if energy intake is adequate for energy expenditure is to use formulas based on height, body mass and other factors with the most common example being the Harris-Benedict equation (164). The Schofield equation (393) is an alternative method of estimating basal metabolic rate and energy

expenditure that is used by the National Health and Medical Research Council of Australia when analysing dietary intake. One limitation of the Schofield equations is the large age ranges used. However, most healthy individuals under 60 years have actual measured BMR's within 10 per cent of the value predicted from the Schofield equation (<http://www.nhmrc.gov.au/publications/diet/n6p1.htm> Retrieved 17 Feb. 05).

Exercise increases total daily expenditure beyond these estimates (466). Methods that have been employed to account for individual differences in energy expenditure are grouped into seven major categories- calorimetry, job classification, survey procedures, physiological markers, behavioral observation, mechanical and electronic monitors, and dietary measures (259). Unfortunately, there is no single instrument that fulfills the criteria of being valid, reliable, and practical while not affecting behavior.

Methods that are very precise such as direct and indirect calorimetry are impractical on a population basis. Instruments designed to measure and record movement or metabolic demand such as heart rate monitors and accelerometers (153, 366), as well as biochemical measures of metabolic turnover (293) provide a practical alternative but are not without their limitations. Numerous surveys have also been designed and used to estimate energy expenditure from general living and the cumulative effects of exercise (343).

The above research confirms that including some form of measurement or estimation of energy expenditure can only strengthen research that aims to assess dietary intake in athletes. Methods using biochemical indices are well suited to research studies. However, the technique of comparing the ratio of EI and predictions of BMR and DEE is effective for describing or identifying underestimates of energy intakes from

food records (132). In trying to evaluate the importance of habitual dietary intake for performance and recovery in the well-trained older athlete, typical DEE must also be assessed in order to validate dietary data.

### ***Overall Summary***

The growth in the relative population of elderly and the concomitant increases in older participants in sporting activities in western societies (439) highlights the need for further research on this unique sporting sub-group. The importance of recovery to the physical training process has been presented with reference to the potential mechanisms by which ageing may influence these recovery and repair processes. The main hypothesis presented suggests that ageing skeletal muscle experiences greater exercise-induced fatigue/damage and has a slower rate of repair/recovery from this fatigue/damage. This leads to a prolonged duration for complete functional recovery.

This review of the literature has identified deficiencies with respect to the research literature relating to recovery from hard physical training and competition in ageing athletes. One of the main limitations of the existing literature to investigate the effects of ageing on muscle damage and muscle recovery has been the confounding influence of decreased activity levels that often occur in conjunction with increasing age (274). Training older individuals acutely or throughout the lifespan results in significant functional benefit and potential protection from exercise-induced muscle damage (114). Therefore, the need to account for participant training status when investigating exercise-induced muscle damage and repair is essential. Furthermore, many of the existing studies that have compared muscle recovery in young and ageing humans or animals have used highly damaging protocols of lengthening contractions

that may not be representative of typical physical training and competition induced fatigue or damage in athletes.

Some of the difficulties in successfully monitoring training and recovery in athletes have been identified from the literature relating to overtraining (176, 277, 450). The overwhelming evidence in the literature confirms that sporting performance remains a suitable measure to use when investigating recovery mechanisms (193, 450) and is therefore the logical choice of measurement in this investigation. To date there has been no research to investigate recovery or overtraining in an older athletic population. Theoretically, an impaired recovery may increase the susceptibility of the older athlete to overtraining induced symptoms (252).

The importance of optimal nutrition for exercise has been presented, highlighting the importance of adequate nutrient intake and the timing of nutrient intake for satisfactory recovery from physical training or competition (76, 77). The distinct lack of literature describing the dietary intakes of ageing athletes demonstrates the need for further research in this area. As such the difficulties in validly measuring dietary intake (under-reporting) and methods of overcoming these difficulties (comparison with daily energy expenditure) have been presented.

While the popular opinion amongst athletes, coaches and scientists is that ageing affects recovery from physical training and competition (252, 326, 363), there is no conclusive research evidence to confirm this assumption. The present study will address this limitation by providing the first investigation to compare recovery from intense endurance exercise in well-trained performance-matched young and ageing endurance athletes.

## **CHAPTER III:**

### **METHODS**

#### ***Outline***

This PhD project investigated the effect of ageing on physical and psychological recovery from intense exercise. The project was broken into four related investigations. The first gathered the opinions from a number of athletes pertaining to ageing and recovery via a questionnaire that was distributed to assist with subject recruitment for the studies that followed. The second follow-up study measured the dietary intake of young and ageing runners, cyclists and triathletes. The third study assessed physiological recovery in young and veteran athletes from intense training. The final study examined the perception of fatigue and recovery in response to intense exercise in performance-matched young and veteran athletes.

The protocols used in this PhD project were approved by the Griffith University Human Research Ethics Committee, approval number HSC/06/02/hec.

#### ***Participants***

There were over 100 athletes that participated in this PhD project. The first investigation in the project surveyed 100 athletes ranging in age from 18 to 60 years. This survey was designed to assist with the recruitment of subjects for the subsequent investigations. These investigations required the recruitment of training and fitness matched young and ageing athletes in order to investigate any differences in the dietary intake and physical recovery from exercise as a consequence of ageing. The athletes also had to be considered as well-trained not just physically active as per the American College of Sports Medicine Guidelines of 30 minutes of moderate physical activity on most days of the week (24). Therefore, training thresholds were set at a minimum of

200km per week cycling and/or a minimum of 40km per week running and had to be actively competing before inclusion into the investigations. The training criteria ensured that the average training volume for the participants in studies 2-4 was greater than 10 hours week and included vigorous exercise.

To assist with matching the performance criteria in young and ageing athletes the upper age for the ageing participants was set at 55 years (although a very enthusiastic 56 year old was also included in studies 3 and 4). This age limit was selected due to the recent research by Pimentel et al. (351) that reported a negligible decline in maximal aerobic power and ten kilometre race time in endurance-trained runners up to 50 years of age. Thus, young and ageing athletes were successfully matched for performance and maximal oxygen uptake.

### ***Apparatus and Protocols***

Recovery can be indirectly assessed by monitoring the return of performance capability after the recovery process (413). As such a number of performance measures were selected that were considered to possess a reasonable degree of similarity to the competition demands of the trained cyclists that participated in this investigation. Performance at the thirty-minute time trial (TT30) was considered to be the best measure of physiological recovery.

There were also a number of assessment protocols based on functional performance such as the ten-second test (10ST), and indirect tests of muscle function such as the countermovement jump (CMJ), and the maximal voluntary isometric quadriceps force (MVIF). In addition to these indirect functional measures, other non functional variables were used in this study such as assessment of muscle soreness (SOR), ratings of motivation, fatigue and recovery, and changes in blood biochemistry

variables (creatine kinase activity). Both the functional and non-functional measures used in the current investigation are commonly used assessment tools in monitoring overtraining and assessing the effects of exercise induced muscle damage (215, 463).

Due to the relatively brief methodology provided in the following four chapters, a more detailed description and justification of the tests employed during the current investigation are described below.

### Exercise Recovery Questionnaire

The exercise recovery questionnaire (Appendix A) was designed specifically for this investigation as a recruitment tool to assist with the enlistment of suitable athletes for the series of studies to be performed. This questionnaire required athletes to provide information pertaining to demographics (age and exercise experience), training volumes (hours and sessions per week), and a variety of questions relating to recovery. The final part of the questionnaire invited athletes to provide their contact details if they met the minimum training criteria for inclusion in the subsequent studies and were willing to volunteer as research participants. A more detailed description of the questionnaire and the administration of the questionnaire is provided in chapter IV.

### Nutritional Assessment

The diet of the participants was assessed in two ways. The first was a food frequency questionnaire that identified the foods usually eaten and how often. This questionnaire was developed by the Queensland Institute of Medical Research and has been previously used to quantify dietary intakes of athletes from this laboratory (11). The second required the athletes to maintain a food diary over three days while participating in the study. This required participants to keep a record of all the foods

they consumed over several 24-hour periods to enable an estimation of 'habitual' diet (Appendix B).

It should be noted that there is substantial controversy over the accuracy and validity of different methods of dietary analysis (35, 42, 271). Food Frequency Questionnaires (FFQ), 24-hour dietary recall, diet history and food records are amongst the most commonly used techniques. The first three methods described are retrospective relying on the memory of the participants, while food records are prospective as they are ideally recorded as the subject prepares and eats the food. However, each of these methods has its inherent limitations as to the accuracy of the data gleaned as a representation of 'normal' nutrient intake. It has become common to validate the accuracy of these analysis methods through the measurement of Doubly Labelled Water (DLW) as an indication of energy expenditure (32, 247, 348). This enables the total reported energy intake to be compared with the total energy expenditure over the same time period (assuming there is no net gain or loss of mass) to assess whether there is over or under reporting of intake. Both dietary records and recorded intake have been validated against DLW as an indication of group and individual nutrient intake (48).

One of the objectives of this investigation was to analyse the dietary intakes of ageing athletes with respect to adequacy for sport and general health as there are some concerns over the nutrient needs of the ageing population (141). The other purpose of performing dietary assessment was based on the importance of adequate nutritional status for exercise and recovery (76, 84, 85, 267). This second function was to check that there were no major differences in dietary intake between the different age groups



investigated, such as total energy and/or carbohydrate intake over the three days, which could have contributed to impaired performance and recovery.

Subjects were given written and verbal instructions on how to maintain their dietary diaries. Diet diaries were collected and discussed with the participants to check for accidental omissions or limited detail. Dietary diaries were analysed with a commercial dietary analysis software programme (FoodWorks<sup>TM</sup> Nutrition Software) in conjunction with a trained dietitian employed by the University.

### Physical Activity Questionnaire and Energy Expenditure

Normal physical activity was assessed using the Baecke Questionnaire for the Assessment of Physical Activity (23). This self-administered physical activity questionnaire has been rigorously validated against other methods of physical activity assessment including a variety of physical activity questionnaires and accelerometers (227, 311), and doubly labelled water, considered to be the gold standard for physical activity determination (348, 356). Consequently, this questionnaire has even been used when validating new methods of physical activity assessment (347). For the sport activity component of this questionnaire, cycling and running, the main sports participated in by the population used in this study, were classified into the middle (1.26 mJ.hour<sup>-1</sup>) level of physical activity as suggested by Baecke (23). However, it should be noted that most of the athletes investigated in this study were undertaking weekly exercise many hours above the highest time selection provided by this questionnaire. The questionnaire was mailed to the participants to complete at home before their initial visit to the laboratory.

Luhrman and Neuhaeuser Berthold (276) investigated the validity of various equations for predicting resting metabolic rate in elderly subjects. These researchers

found that, at the group level, these equations provide a valid estimate of resting metabolic rate, but on an individual basis, estimation errors can be high. Although the participants in the study of Luhrman and Neuhaeuser Berthold (276) are much older (>60 years) than the veteran athletes in the present study, similar conclusions have been reported for 18-59 year old Italian males and females (131), supporting the idea that prediction equations may need to be reviewed for specific populations groups. Although the Schofield equation is the recommended method of estimating DEE by the Australian National Health and Medical Research Council, the validity of this equation in young Australian males and females has been challenged (350, 453). However, in the present study DEE calculated from both the Schofield and Harris-Benedict equations was shown to be significantly correlated with EI in young athletes (Chapter V), providing some support for the use of these equations in this investigation (Appendix C).

## Height, Mass and Body Composition

Height was measured to the nearest 0.1cm using a wall mounted stadiometer according to the guidelines specified by Norton and Olds (329). Mass (to the nearest 0.1kg) and percentage body fat were measured using a bioelectrical impedance analyser (BIA) and scales (PE56, Tanita, Tokyo, Japan).

Measurement of body composition with BIA is limited in that when assessed, individuals must be in a similar state of hydration for valid results (39, 430). In addition, the values provided by BIA cannot be validly compared with results from other analysis techniques (468). However, the technique has been reported to be suitable for determining body composition in athletes (162), and for the purpose of body composition analysis in this study BIA was considered a suitable method.

## Progressive Maximal Test (GXT)

The GXT enables the determination of power output, heart rate, cadence, and  $\dot{V}O_2$  at peak effort (highest workload achieved), and at the modified D-max anaerobic threshold (D-max<sub>mod</sub>). The GXT was conducted in accordance with the protocols outlined by Craig et al., (129). After a self-determined warm-up, the participants performed a continuous, progressive incremental test to exhaustion on the electromagnetically braked, Lode® Excalibur Cycle Ergometer fitted with a racing saddle, drop handlebars and each athlete's own pedals. The ergometer dimensions were set by each cyclist to replicate the dimensions of their own bicycle (recorded for future reference) and the test was performed with the ergometer in 'hyperbolic' mode, so that power output is constant regardless of pedal cadence (rpm).

The test began at 100 W, with the power output increasing by 50 W every five minutes until volitional exhaustion, or the participant could no longer maintain a pedal cadence above 70 rpm. For smaller (<80 kg) participants the power output was increased by 25W every five minutes after the 250 W level had been completed. Throughout this test during the final two to three minutes of each five minute sub-maximal workload, heart rate was recorded and expired gas collected using MedGraphics CPX metabolic cart and a Lohmeier M607 three lead ECG. Data collection was continuous toward the end of the test after the subject reported a RPE of greater than fifteen. Expired gas analysis enabled the determination of oxygen consumption ( $\dot{V}O_2$ ), carbon dioxide production ( $\dot{V}CO_2$ ), minute ventilation ( $V_E$ ), and the respiratory exchange ration (RER). Peak  $\dot{V}O_2$  ( $\dot{V}O_{2\text{ peak}}$ ) was determined as the average of the highest two consecutive 15 s  $\dot{V}O_2$  readings. Maximal power output ( $\dot{W}_{\text{max}}$ ) was determined as the power output of the highest completed stage. If a full

five minutes was not completed then  $\dot{W}_{\max}$  was calculated based on the proportion of the final stage undertaken (see formula 1 & 2). In this formula  $\dot{W}_{\text{com}}$  is the power output for the last completed stage,  $t$  is the time in seconds that the cyclist maintained the power output during the final 300 second stage, and 25 or 50 is the workload increment of the stage in watts.

$$(1) \quad \dot{W}_{\max} = \dot{W}_{\text{com}} + (t/300*50) \quad \text{or} \quad (2) \quad \dot{W}_{\max} = \dot{W}_{\text{com}} + (t/300*25)$$

At the end of each workload, a sample of capillary blood was collected from a fingertip and assayed for lactate. Subjects also provided a rating of perceived exertion (RPE) at the end of each workload (55). Blood lactate and power output values were plotted to enable calculation of the lactate transition threshold using the *Automated Data Analysis for Progressive Tests* (ADAPT version 1.2, AIS software, Canberra, Australia). The lactate transition threshold was calculated using a modification of the D-max (D-max<sub>mod</sub>) method developed by Cheng et al (106), and is the point on the polynomial regression curve that is the greatest perpendicular distance from a straight line connecting the workload preceding a 0.4 mmol.L<sup>-1</sup> rise in blood lactate to the final workload completed (62)(Appendix D).

Cyclists were vigorously encouraged to complete a final full-minute workload as they approach volitional maximum. Respiratory variables were determined as the average of the last 60 seconds of each 5-minute workload. All tests took between 25 and 40 minutes. The variables measured during the GXT have a technical error of measurement ranging from 1.0-4.2%.

### Laboratory 30-Minute Time Trial (TT30)

The key to measuring recovery for the athlete is their performance, 'Performance is the gold standard parameter for the training and overtraining reaction and can be practically determined as maximum peak power, speed, or time for a race distance or underdistance, or time to exhaustion for a given speed or power' (413). As such the TT30 in the laboratory was considered to be the most appropriate measurement of recovery in the well-trained cyclists participating in this investigation.

The TT30 is referred to as the 'race of truth' (129) due to the absence of tactics, drafting and environmental conditions (heat, wind, cars). Laboratory assessment of time trial fitness can be used as an important dependent variable for monitoring the effects of training, diet, psychological preparation, and ergogenic aids (45).

This test was a maximal intensity 30-minute self-paced time trial where individuals attempted to achieve the highest average power output over the 30 minutes on the electromagnetically braked bicycle ergometer. Heart rate, lactate, perceived exertion and oxygen consumption were measured throughout this test. The ergometer was set in 'linear' mode for the TT30, whereby power output increases in proportion to pedal cadence (rpm) and is represented by the formula:

$$(3) \quad \dot{W} = LF * (\text{rpm})^2.$$

In the above formula, LF is the linear factor to be set on the ergometer and rpm is the cycling cadence in revolutions per minute. Thus the formula is rearranged so that

the appropriate LF can be set according to the power output ( $\dot{W}$ ) required as per the following formula:

$$(4) \quad LF = \dot{W} / (\text{rpm})^2$$

Prior to the TT30 subjects had performed the progressive maximal test (GXT) to determine peak exercise parameters and  $D\text{-max}_{\text{mod}}$ . The power output corresponding to  $D\text{-max}_{\text{mod}}$  was used to initially select a LF on the electromagnetically braked cycle ergometer. Thus power varied with cadence, and the cadence used in formula 4 above was based on the mean cadence self-selected by the individual at the power output closest to  $D\text{-max}_{\text{mod}}$  whilst they were completing the GXT.

After completing a warm up before the TT30 the cyclist was familiarised with the desired power output and cadence by doing two 20s efforts at the target power output. During this period athletes were allowed to make adjustments to the LF if desired to make the workload harder or easier. The within-subject variability for the TT30 as represented by TEM and %TEM for the cohort participating in this study was 5.8 W and 2.2% respectively

Accumulated work, heart rate and cadence were recorded every minute during this test. Average power output sustained for the TT30 was then calculated from the total accumulated work. Capillary blood samples and RPE were collected from the fingertip during the final minute of each five-minute stage.

## Blood Sampling and Analysis

Venous blood samples (14 ml) were taken from the antecubital region using serum separator (SS) and lithium heparin evacuated tubes. After collection and appropriate clotting time for SS tubes, blood samples were centrifuged for 5 minutes at 4000 rpm, at a temperature of 4°C. The separated plasma and serum was then stored in small aliquots and immediately frozen at -80°C until being thawed for analyses. Analysis for creatine kinase (CK) activity was performed as an indirect marker of exercise induced muscle damage. Samples were assayed using dry slide chemistry by the Pathology department of the Mater Hospital, Brisbane Australia (Vitros, Ortho-Clinical Diagnostics, Neckargemünd, Germany). The coefficient of variability for this analyser for CK was 3.2% at 104 IU and 4% at 407 IU.

Creatine kinase is regularly used as a marker of muscle damage induced by exercise (337, 436), and although it is generally thought to be highest after eccentric contractions, recent studies have reported significantly elevated serum CK activity after aerobic endurance exercise (123, 428). It has also been reported to be elevated in athletes compared with sedentary subjects when at rest (236). Hence, there appears to be fluctuation in CK activity in response to intense daily training load that may reveal differences between groups of subjects for damage and recovery of muscle tissue. However, it should be noted that CK activity is highly variable (330), and there is argument that CK levels are not a good indicator of muscle damage (280, 283). Although acknowledging complications with finding statistical differences due to subject variability, Hartmann and Mester (199) considered that diagnostics based on the determination of CK appear a sensible and useful means of evaluating any increase in muscle stress or individual tolerance to muscular exertion. However, overemphasis of

blood levels of myofibre proteins such as CK has been discouraged in favour of more functional measurements such as force/torque producing capability (463).

The choice of CK over other muscle enzymes commonly measured, such as myoglobin and lactate dehydrogenase, is due to the previously reported time course of these enzymes in the blood. Subjects had blood drawn at each exercise session (24 hours apart), some of the other markers often peak within 24 hours and may even have returned to rest before sampling the next day (283, 428).

### Capillary Blood Tests

During the testing sessions capillary blood samples were drawn from the fingertip at rest and during the GXT and TT30 tests. A single drop of blood was assayed for lactate levels using the *Accutrend* lactate analyser (Roche Diagnostics, Basel, Switzerland). Throughout the investigation this analyser was calibrated and maintained in accordance with manufacturer's instructions. The coefficient of variability of this analyser during the investigation was 6.7% at 1.72 mmol/L and 3.4% at a lactate concentration of 6.46 mmol/L.

The Accusport Lactate Analyser® (ACC) uses reflectance photometry to measure molybdenum blue. This substance is a direct product from the conversion of lactate via a lactate oxidase-mediator reaction. Automated analysers such as the ACC are limited if large numbers of assays are being performed at once. However, they are advantageous in convenience and ease of operation, and provide immediate feedback to athletes (44).

The ACC has previously been validated for accuracy against the Kodak Ektachem® (154). This analyser has been reported to have a coefficient of variation of 7% and 4.6% at 1.7 and 14.4 mmol/L respectively and is linear up to 18mmol/L (154).



Recent studies have also evaluated the ACC as an analysis instrument and while the general consensus is that the analyser is reliable, there is concern over the validity when compared to other analysers (305, 352). However, a recent study by Bishop (44) confirmed the validity of this analyser for assessing athletes and monitoring lactate-workload relationships such as the GXT used in the present investigation.

### Perceived Soreness (SOR)

Participants were asked to subjectively rate their perceived soreness at various stages during Study Three. This was assessed using a 100mm verbally anchored visual analogue scale (Figure 3.1). The visual analogue scale has been shown to be an appropriate repeated measure of pain following delayed onset muscle soreness (229, 291). Measurement of soreness using the visual analogue scale is commonly performed in studies of both clinical and experimental pain (30, 426). The scale ranges from ‘no pain whatsoever’ to ‘the greatest level of pain one could ever have’. Participants place a vertical mark on the scale according to their rating of perceived soreness and the measured distance (mm) of the vertical mark from the left anchor is the soreness score.



**Figure 3.1: Visual analogue pain scale**

### Countermovement Jump (CMJ)

To assess explosive lower-body or leg power, a standing single countermovement jump was used. After the prescribed warm-up the subjects stood on a

contact mat with hands on their hips. Using a countermovement or 'dip' action the subjects jumped for maximum height aiming to land in an upright, extended position on the balls of the feet before bending the knees to absorb the impact of landing. The hands were kept on the hips throughout. After a familiarisation period, three trials were performed with 30-60 seconds between trials. The single best jump taken as the score and the three jumps were also averaged. The result was recorded as metres jumped, watts and watts per kilogram.

The CMJ is a vertical jump without arm swing. Sargent (386) devised the first vertical jump test (VJ). Since that time the VJ has been extensively utilised in the evaluation of athletes and several alternative methods and devices have been developed and assessed (124, 257, 396). The VJ in this study was a countermovement jump performed using a timing platform (60) designed to calculate the change in height of the body's centre of gravity derived from the flight time (458). This apparatus consists of a digital timer connected by a cable to a resistive mat (Kinematic Measurement Systems, Lismore, Australia). The timer onset is triggered by the unloading of the subjects' feet from the mat and is stopped at the moment of touchdown. This test assumes that the position of the jumper on the platform is the same in take-off and in landing. The height of the jump (H) during the flight time (Tf) is calculated using the acceleration of gravity (g) as follows:

$$(5) \quad H = g * T_f^2 / 8$$

When compared with film analysis, the error of measurement has been reported to be in the order of  $\pm 2\%$  (249). This test has also been shown to be a reliable test in

males over fifteen years old (coefficient of variation < 7%) and to correlate well with other traditional field tests (458). By removing the arm swing the CMJ focuses the effort on the leg extensor muscles (146). Therefore, the CMJ is the preferred test as a measure of leg power over the VJ with arm swing (474).

Performance at the countermovement jump after exercise was intended to identify any impaired functional recovery in the older cyclists. Vertical jump using this technique has been shown to significantly decline after endurance exercise (266). Furthermore, Klein and colleagues (246) found after one hour of recovery from fatiguing contractions of the triceps surae muscles maximal vertical jump was significantly lower than baseline value for an elderly (-9%; 66 years) but not a young group (-3%; 25 years). However, in a recent investigation into the effects of exercise-induced muscle damage on the recovery of dynamic knee extensor strength, Byrne and Eston (92) found that impairment of muscle function was less when the stretch-shortening cycle was used in vertical jumping performance. For the present investigation it was considered that the use of a countermovement more closely reflected the specific functional demands of sport and exercise than a squat jump (no countermovement).

The technical error of measurement (TEM) for height jumped during the CMJ was calculated according to the methods described by Pederson and Gore (341). For the cohort of subjects used in the present investigation the within-run TEM was 0.013 metres and %TEM was 3.8%.

## Leg Strength (MVIF)

Assessment of leg strength was performed by measuring the maximal voluntary force produced during an isometric contraction (no movement) of the quadriceps muscle

group with the knee fixed at a 90-degree angle. Subjects were required to sit upright on a bench with their dominant leg flexed 90° at the knee joint (measured using a goniometer: lateral malleolus, lateral epicondyle of the tibia and greater trochanter), and with their arms crossed. This angle reflects a common angle used for isometric force measurement and is the approximate angle of the knee at the top of the cycling action (438). A material collar attached to a metal chain and connected to a 2.5 kN load cell (XTRAN® 2.5 kN, Applied Measurement, VIC, Australia) was then attached to their ankle, and they were instructed to contract their quadriceps muscle group as rapidly and as forcefully as possible for a three second period. At the end of the contraction subjects relaxed the muscle as quickly as possible. Upon initiation of the contraction a threshold voltage (0.5 mV) triggered the collection of data followed by a three-second verbal count down provided by the investigator. Subjects performed three trials with a one-minute recovery between efforts.

The peak force (MVIF) was measured by means of the load cell (XTRAN 2.5 kN, Applied Measurement, VIC, Australia) and was collected, interpreted and analysed using a personal computer and data acquisition software (AcqKnowledge, Biopac Systems, Santa Barbara, USA). The linearity of the load cell used in this investigation has been determined over the entire range of forces likely to be encountered (10-1000 N). Known weights were suspended from the equipment and the voltage produced recorded and compared by Pearson product-moment correlation coefficient ( $r = 0.999$ ). The load cell was calibrated at regular intervals by suspending metal plates of known weight (calibration at 200, 400 and 600 Newtons) in order to calculate the coefficient of variability for within-run and between-run measurements. The XTRAN® load cell used in this study has a within-run and between-run coefficient of variation of less than one percent. The within-subject variability for this test as represented by TEM and

%TEM for the cohort participating in this study was 31 N and 5.5% respectively. Recent research that has described the reliability of maximal voluntary isometric force in healthy young subjects suggests that a change of  $\pm 76\text{N}$  has a 95% likelihood of being a real change (320).

Maximal voluntary isometric force has been commonly used as an indicator of exercise induced muscle damage. Previous research has demonstrated that isometric strength is reduced immediately after exercise and recovers over the following hours to days after the exercise (92). Decline in maximal force/torque is the preferred method for reporting functional changes due to exercise-induced muscle damage (463). Isometric force of the quadriceps was chosen due to the significant use of the quadriceps muscle group during bicycle exercise.

It has been suggested that isometric force has limitations when used for the assessment of athletic performance (470). Furthermore, MVIF has been reported to be unchanged in overtrained subjects (167). However, there are a number of recent studies that have reported reductions in isometric strength after exhaustive endurance exercise (266, 283, 427-429), as well as after resistance exercise (92). Consequently, this easy to administer and reliable measure was included in the current investigation as an indirect indicator of muscle damage and altered muscle function.

### Ten Second Bicycle Test (10ST)

The 10ST involves an 'all out' or greatest possible effort on the bicycle ergometer over 10-seconds according to the protocol of Telford, Minikin and Hahn (425). The predominant energy pathway for this test is the alactic anaerobic energy system and this test is considered to be relevant to road cycling events requiring a sprint to the finish line (129). This test uses the Repco® front access wind braked

bicycle ergometer (Exertech EX-10, Repco, Huntingdale, Australia) and has a reported test-retest correlation coefficient of 0.97 (425). The test is popular as a measure to assess the requirement in team sports to perform maximal or near-maximal sprints of short duration (146). A similar test is also utilised to assess anaerobic power and alactic ‘capacity’ in track and road cyclists (129). The within-subject variability for this test as represented by TEM and %TEM for the cohort participating in this study was 0.44 W.kg<sup>-1</sup> and 3.2% respectively

After the designated warm up, which included two practice acceleration efforts up to top speed in 2-3 second with a 60 second recovery between efforts, subjects began this test in the standing position with the pedals stationary at  $\pm 45^\circ$  to the horizontal position, preferred foot forward. They were then given the command ‘start pedalling when ready’ to initiate the test and data collection. The monitor attached to the bicycle ergometer recorded peak power, time of peak power, and work done in absolute and relative (per kg) terms. Power was also sampled every second during the test. Due to the possible contribution of glycolytic energy pathways to this type of test (119) the participants performed a ten-minute active recovery before participating in any other tests.

### Rating of Perceived Exertion (RPE)

The rating of perceived exertion (55, 56) integrates a variety of strain signals into a general ‘whole body’ sensation. Signals coming from the cardio-vascular, respiratory, muscular and nervous systems provide the performer with a perception of the intensity of exertion.

Originally, the RPE category scale was set to range from the lowest degree of exertion, 6, to the highest degree, 20 and was based on a linear relationship between

RPE and heart rate. A newer category-ratio scale (CR-10) was devised and has been shown to have a high correlation with lactate (56). In the original scale odd numbers are given anchor descriptions such as very, very light for 7, and very, very hard for 19. The original scale was used in this investigation.

In general, RPE provides a physiologically valid method of regulating and monitoring exercise intensity (142, 284). Many studies compare RPE, heart rate, lactate, and workload ratios in the monitoring of athletes in training and recovery (277, 285, 410). Changes in these parameters may reveal signs of fatigue and inadequate recovery in the cyclists during the study. Furthermore, recent research has demonstrated a difference between young ( $25 \pm 1$  years) and ageing ( $85 \pm 1$  years) males for RPE during an isometric contraction muscular fatigue task.

## Ergometers

The ergometers used in this experiment were the Excalibur Electromagnetically Braked Bicycle Ergometer (Lode Excalibur, Groningen, The Netherlands) and the Exerstress Air Braked Front Access Bicycle Ergometer (Exertech EX-10, Repco, Huntingdale, Australia). Both of these ergometers are commonly used in the testing of athletes for research and athlete monitoring purposes. As with all testing methods there is an inherent variability that contributes to the error of measurement. In a study of five research-grade Repco ergometers, the average reading at a true power of 275W was low by less than 0.5%. At a power of 1140W the average reading was high by 1.5% (295). Similarly, in a recent review of cycling tests Paton and Hopkins (340) reported on the systematic errors in electromagnetically braked ergometers and cited variability between 0.5 and an incredible 50%. These authors suggested that anyone using an electromagnetically braked ergometer should ensure that the ergometer works

reproducibly in constant-power mode. Consequently, the Lode® ergometer used in this experiment was baseline calibrated with a dynamic calibration rig at the Queensland Academy of Sport, Brisbane, Australia. In addition, regular ‘biological’ calibrations were also performed with the same subject exercising at a constant workload (100W) while having heart rate and respiratory gases monitored.

## Expired Gas Analyser

Respiratory gases were collected and analysed using the MedGraphics CPX metabolic cart. This is a computer linked diagnostic device for pulmonary exercise tests and indirect calorimetry measurements. All tests were performed using breath by breath analysis with 15 second averaging. The pneumotachometer was calibrated for volumes using a Hans Rudolph Three Litre Syringe®. Gas analysers were calibrated using two known mixtures of high and low concentration. The gas analysers and pneumotachometer were calibrated before and after every test using high and low concentration mixtures of  $\alpha$  grade calibration gases and a Three-Litre Hans Rudolph® Syringe.

Although respiratory gas analysis is the most common laboratory method of assessing aerobic capacity, certain limitations still exist. Measured volumes reported by different laboratories can be inconsistent, especially if there is a difference in altitude between laboratories (183). In the present investigation statistical comparisons were only made between values obtained in the laboratory located at Griffith University.

## Statistics

In the four studies undertaken in the present PhD investigation a large amount of data was obtained and several statistical procedures applied. For all data the



Kolmogorov-Smirnov test (Appendix E), normality plots, and box plots were performed in order to;

1. Evaluate whether the data was normally distributed to determine the most appropriate statistical test to use.
2. Test for outliers that should be removed prior to further statistical analyses

Individual values that were greater than two standard deviations from the mean were excluded from further statistical tests. If the Kolmogorov-Smirnov test indicated that the data was normally distributed, parametric statistical tests were performed. These included two-way analysis of variance with repeated measures (group x time), Pearson-product moment correlation analysis and student *t*-tests. Within-subject factors and between-subject factors were transformed for comparison using a 'simple contrast' with Bonferroni adjustments. When data was not normally distributed the Friedman test was used for variables performed over repeated measurements, Mann-Whitney U tests were used for comparison between age-groups, and Spearman's rho for correlation analyses.

Bland (49) suggests that for small samples rank tests cannot produce any significance at the usual 5% level and for statistical analysis of small samples, normal methods are required. Consequently, when the data was not normally distributed both non-parametric and parametric tests were performed. The specific statistical tests applied are identified in the methods section of each study in the following chapters.

Two of the main variables for comparison of recovery between young and veteran athletes in the present study were endurance performance (TT30) and perceived muscle soreness (SOR). Consequently, a power analysis was performed for differences in exercise performance at the TT30 and perceived muscle soreness. Based on the number of subjects in Study Three (Chapter VI) and the TEM of the TT30 (2.2%), at an alpha

level of 0.05, there was 77% power to detect a 5% decline in cycling performance across the three days. For the measurement of perceived soreness in Study Four (Chapter VII), the TEM for the visual analogue scale was 9.5 mm or 41% (arbitrary units of soreness). Therefore, a change of at least 10 mm (100%) was set as the minimum detectable change. For the subject numbers in this study there was better than 99% power of identifying a 10mm change in perceived soreness over the three days.

Data was collated and graphs produced using Excel for Windows computer software. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Inc., v. 11.5, Chicago, IL, USA). Statistical significance was set at  $<0.05$ . Data is presented as mean  $\pm$  standard deviation (SD) or as frequencies when appropriate.

## CHAPTER IV:

### STUDY ONE

#### *Opinions on ageing and recovery in an athletic population*

##### Introduction

The widely accepted view that recovery is impaired with age in the older athlete is clearly emphasised in the following statements taken from popular running websites.

'As we get older, recovery from hard training sessions takes longer, while the cumulative effects of normal 'wear and tear' and previous injuries are increasingly evident. As time goes by, joints tend to become less flexible, full-range movement more difficult and pain and stiffness ever more apparent.'

<http://www.sports-coach.net/prewp/schome-masters.html>

'You may discover that you require a longer recovery time after hard efforts as you age. Be sure to recover from one hard workout or race before attempting the next one.'

<http://www.running.net/features/fidlerfeb.html>

'Recovery time increases with age hampering the ability to train at the same levels as when you were younger. This may account for much of the loss in performance.'

<http://www.teamoregon.com/publications/vo2max.html>

The above statements clearly suggest that ageing prolongs the time required for recovery from exercise, increases the athlete's susceptibility to injury, and leads to unavoidable performance declines. Similar views are often presented in the popular

coaching literature (363), although very little research evidence is usually provided regarding the effects of ageing on recovery. The above views are also supported amongst researchers as Noakes (326) describes his own personal experience with ageing and training in an early edition of *'Lore of Running'*;

‘When I first penned these pages I was enjoying the peak of physical age of the early 30s. I could not conceive that with the passage of just a few short years, much of what I took for granted would need to be modified.

Now that I am over 40, I know there are concessions one has to make to ag[e]ing. One simply can no longer train with the same intensity.’

(326)

Noakes also makes reference to several notable runners that have been able to maintain outstanding competitive performances later in life, attributing their continued high performance levels with a reduction in training frequency and volume to assist with promoting recovery.

Optimising recovery from training and competition is emphasised by coaches and scientists as an essential element for sporting success. However, there is far more published research on optimal physical preparation for sport than on how best to recover from exercise (177). As described above the widely accepted view is that the duration taken to recover from training or competition is longer for the older athlete (363). Bompa (51) states that ‘Athletes older than 25 require longer recovery periods after training than younger athletes’ and yet in the very next paragraph suggests that athletes with more *experience* will recuperate faster because they have a superior physiological adaptation. Consequently it seems reasonable to suggest that the impact of ageing on

recovery from exercise remains equivocal and these two contrasting views exemplify the need for research into this previously unaddressed area.

The purpose of this study was to describe the opinions of well-trained athletes with respect to fatigue and recovery as a result of training and competition, how athletes perceived the effects of these variables on subsequent performance levels, and common strategies used to promote recovery. It was hypothesised that older athletes would report a longer period of time for complete recovery after training or competition.

## Materials and Methods

### Subjects

One hundred athletes from the South-East Queensland, Australia region provided information pertaining to training and recovery via a one-page questionnaire. The mean age of the participants was  $35 \pm 10$  years (range 18-60). The mean time spent training each week was  $13.2 \pm 6.9$  hours spread over  $8 \pm 3$  training sessions. All participants were competing in organised sporting events at the time of completing the survey.

### Questionnaire

The *Exercise Recovery Questionnaire* (Appendix A) was developed to assist in the recruitment of subjects for the various studies to be undertaken as part of a major study into the effects of age on recovery. This questionnaire was intermittently distributed between March 2003 and January 2005 to coaches, masseurs, bicycle stores, and individual athletes within the region. Follow-up of responses involved visiting the relevant parties to collect any completed questionnaires. Approximately 160 questionnaires were distributed in order to obtain 100 completed responses. This represents a response rate of approximately 60%.

In brief, the questionnaire requested the volunteers to provide information regarding;

- age, sex, and training history,
- current training sessions (frequency) and hours (volume) per week,
- verbal descriptors of feelings experienced after hard training or competition,
- personal opinion as to whether these feelings would affect performance,
- estimation of how long the feelings persisted,
- personal opinion as to whether the period that these feelings lasted was longer after 30 years of age, and
- if and what strategies were used to assist recovery.

For the question relating to what strategies were used to assist recovery, the responses were classified into seven broad categories. These included massage, sleep, diet, supplements, stretching, easy training and aquatic/hydrotherapies.

### **Statistical Analysis**

Data from the questionnaire were tabulated and divided into groups based on age. Due to the question ‘If you are over 30 years of age, does full recovery take longer than when you were in your teens or twenties?’ responses were divided into 18-29 years (<30) and 30-60 (30+) years subsets. Additionally, in order to identify if age related changes were gradual a further division of responses categorised participants into ‘under 30’ (18-29 years [<30]), ‘thirties’ (30 to 39 years [30’s]) and ‘forty plus’ (40 to 60 years [40+]) groups.

The Kolmogorov-Smirnov Z test for normality was applied to the data. Where data from the groups was parametric, either a one-way analysis of variance (ANOVA)

or independent group *t*-test was used to test for between-group differences. For variables that were identified as non-parametric, either the Mann-Whitney U or Kruskal-Wallis H tests were also applied as a test for between-group differences. Spearman ( $\rho$ ) and/or Pearson-product moment ( $r$ ) correlation analyses were also performed to examine relationships between variables of interest.

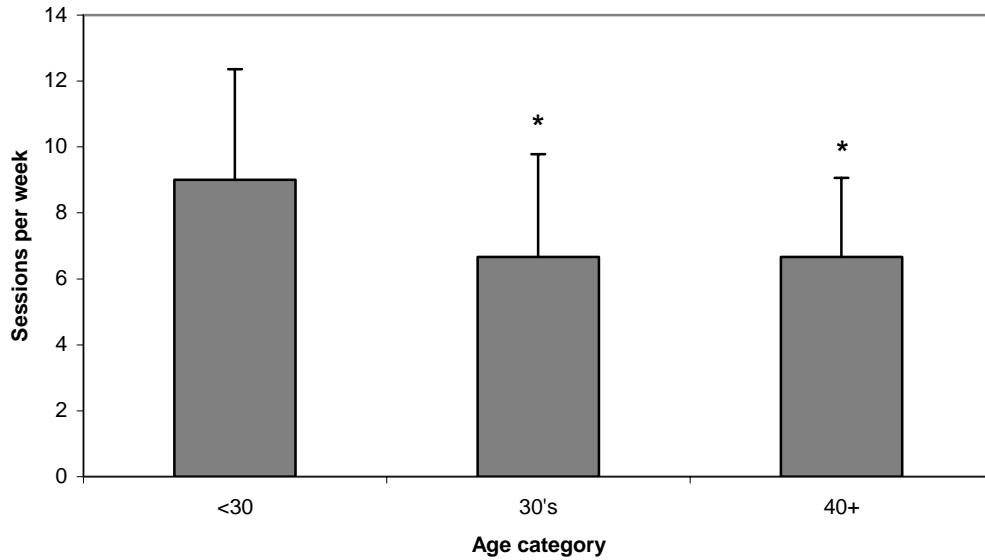
For nominal data relating to post-exercise symptoms and recovery strategies frequency tables were generated to compare groups. A chi-square test was used to identify age-group differences for frequencies of 'yes' (positive) responses to the questions. In the results, *p* denotes the alpha value where only parametric statistics have been used, and *P* when non-parametric methods have also been applied.

## Results

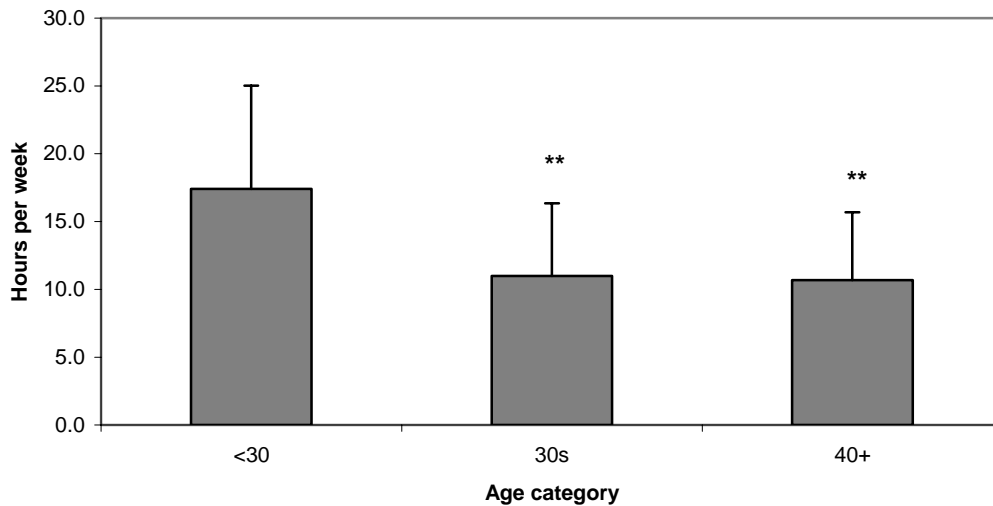
Of the 100 athletes that completed the questionnaire, there were 36 aged between 18 and 29 ( $24 \pm 3$  yrs), 30 aged from 30 to 39 ( $35 \pm 3$  yrs) and 34 aged 40 and above ( $47 \pm 5$  yrs). In total 32% were females with the highest number of females in the 18-29 age category (42%) and the lowest number in the 40+ category (24%). There were no significant differences between males and females for the weekly training variables of frequency or duration, nor for the estimated time taken for full recovery. Consequently, males and females were not separated for subsequent analyses.

There was a significant difference between groups for the number of training sessions per week with the under 30 years age-group (<30) averaging  $9 \pm 3$  sessions per week compared with  $7 \pm 3$  and  $7 \pm 2$  sessions for the respondents in their thirties (30's) and over 40 years (40+) respectively (Figure 4.1). Similarly, total training volume was significantly greater for the younger group with an average reported training time of  $17.4 \pm 7.8$  hours compared with  $10.5 \pm 4.6$  and  $11.3 \pm 5.0$  hours in the 30's and 40+ age

groups (Figure 4.2). The 40+ group had significantly more prior years of training and competition than both the 30's and <30 groups ( $22.5 \pm 14.8$ ,  $14.3 \pm 10.4$ , and  $12.2 \pm 5.7$  years, respectively).



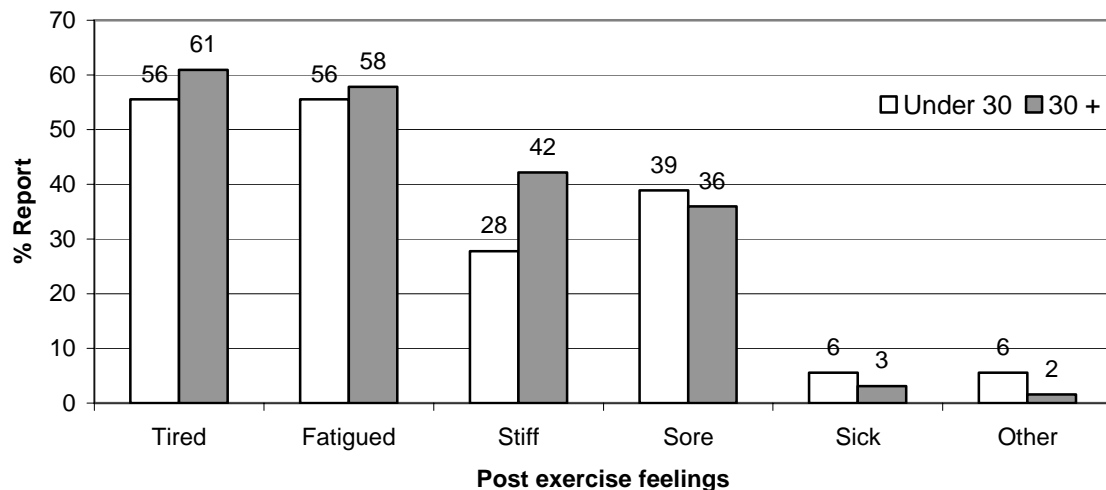
**Figure 4.1: Weekly training frequency of three age groups of surveyed athletes (n=100), \*=significantly different ( $p<0.05$ ) from athletes under 30 years of age (<30).**



**Figure 4.2: Weekly training volume for three age groups of athletes in hours per week (n=100), \*\*=significantly different ( $p<0.001$ ) to athletes under 30 years of age (<30).**

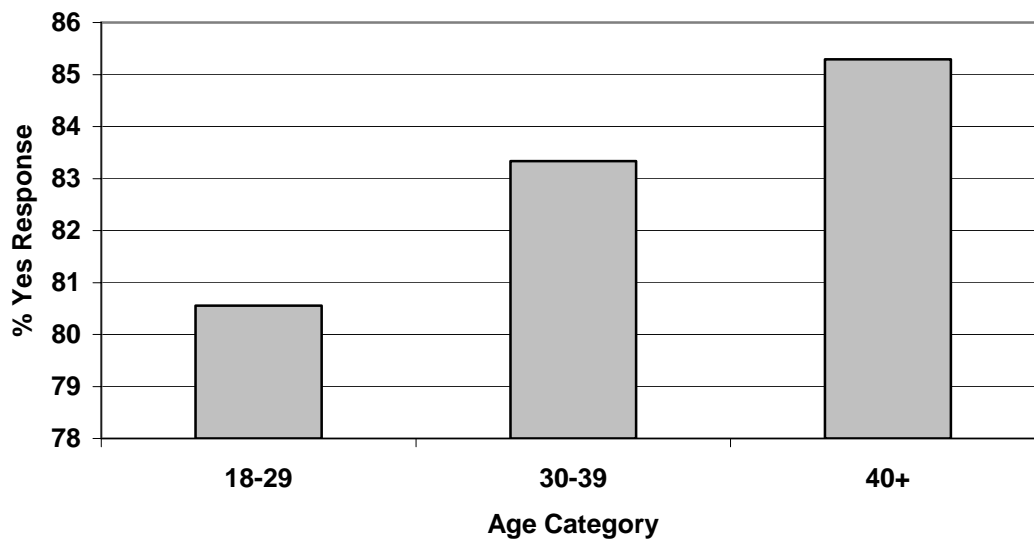


Figure 4.3 shows the percentage of athletes from each age category that acknowledged that they experienced a specific post-exercise sensation as represented by the verbal descriptors, tired, fatigued, stiff, sore, sick and other. The majority of athletes from each age group identified with feeling ‘tired’ or ‘fatigued’ post-exercise. Almost one-half of the 30+ age group (42%) also reported feeling ‘stiff’ post-exercise compared with only 28% of the <30 group. ‘Soreness’ was similar for both the <30 and 30+ age categories at 39% and 36%, respectively. Less than 10% of both age groups of athletes reported feeling ‘sick’ or ‘other’ sensations after training or competition.



**Figure 4.3: Post-training and competition feelings for athletes under 30 (n=36) and 30 plus (n=64) years. Bars represent percentage of athletes in each age category that reported experiencing each feeling after training or competition.**

In response to the question ‘*While these feelings persist do you think they would affect your performance if you were required to race/train hard again?*’ more than 80% of athletes from all age groups responded ‘yes’. This percentage appeared to increase slightly with age when the data is presented across the three age groups (Figure 4.4)



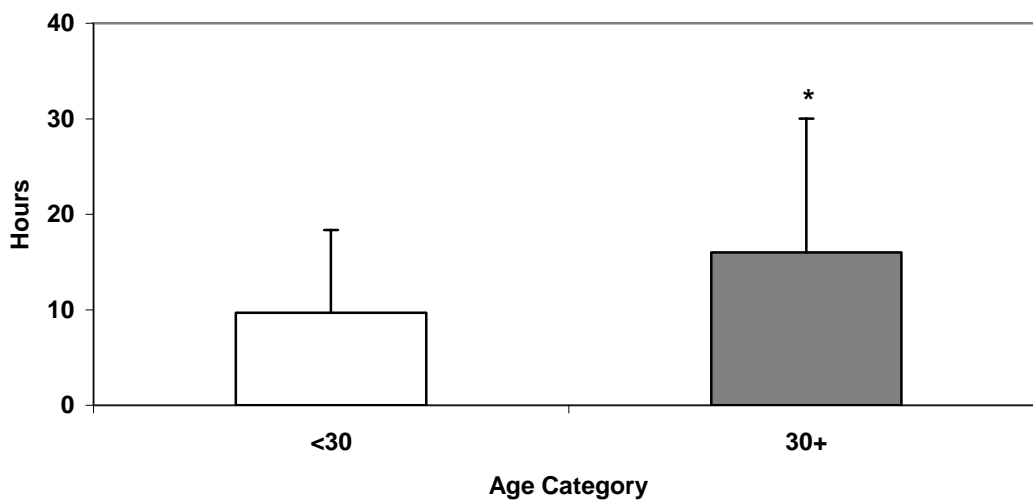
**Figure 4.4: Percentage ‘yes’ responses for three different age categories to the question; ‘While these feelings persist do you think they would affect your performance if you were required to race/train hard again?’**

The next question asked the respondents to estimate how long the post-exercise feelings would last for, from ‘up to an hour’ to ‘48 hours or more’. The mean duration reported was  $13.7 \pm 12.6$  hours with ‘24 hours’ as the most frequent response (26.5%) (Table 4.1).

**Table 4.1: Table of frequencies for the question, ‘In total, how long do these feelings last for?’ (<30 = respondents aged 18-29 years, 30+ = respondents 30 years and older).**

|     | Hours | 1  | 3 | 6  | 9 | 12 | 18 | 24 | 36 | 48+ |
|-----|-------|----|---|----|---|----|----|----|----|-----|
| <30 | %     | 28 | 6 | 22 | 3 | 19 | 0  | 22 | 0  | 0   |
| 30+ | %     | 19 | 2 | 19 | 0 | 18 | 2  | 29 | 2  | 10  |

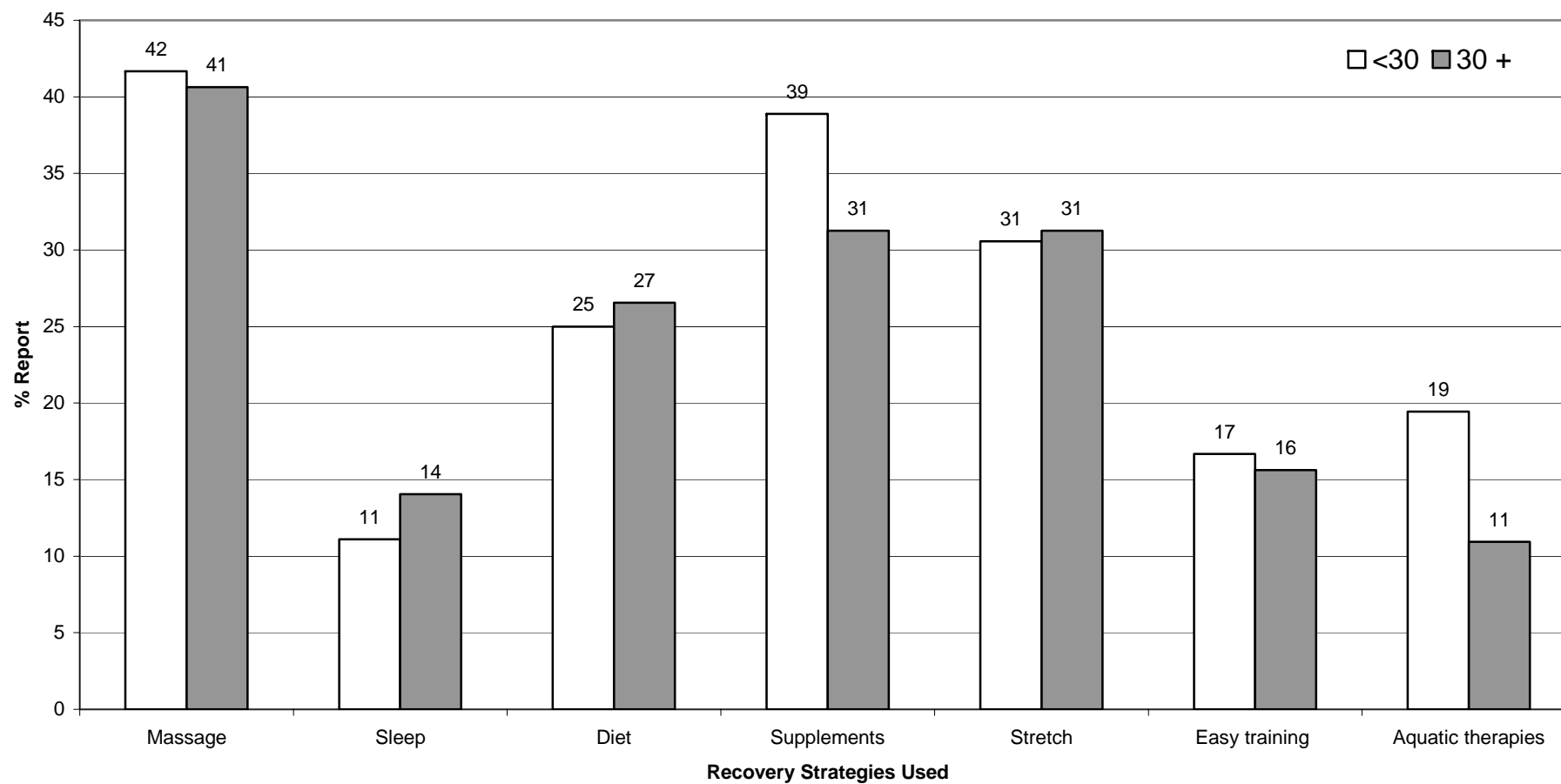
Comparison of the mean estimated recovery time for the <30 and 30+ groups revealed a significant difference between the age groups (Figure 4.5,  $P < 0.05$ ). More than 40% of the athletes from the 30+ group estimated that full recovery duration took 24 hours or more compared with only 22% in the <30 group (Table 4.1).



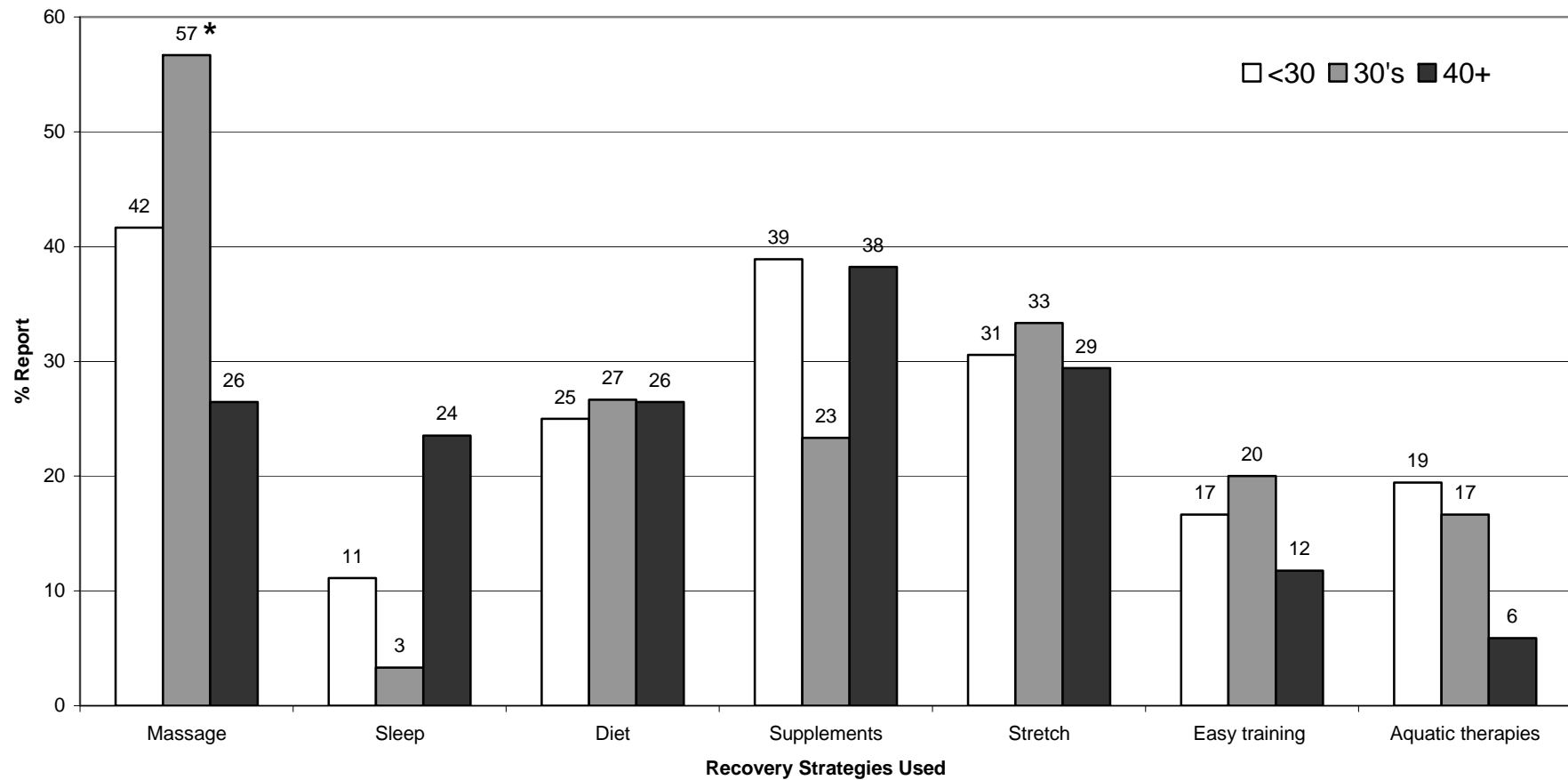
**Figure 4.5: In total, how long do these feelings last for? Reported time taken to recover from training or competition in under-30 (<30) and 30-plus (30+) years of age of athletes (n=100), \*=significantly different ( $P<0.05$ ) from athletes under 30 years of age (<30).**

For the 64 respondents aged 30 years and older the question ‘*If you are over 30 years of age, does full recovery take longer than when you were in your teens or twenties?*’ revealed that 55% agreed, 36% were unsure and 9% disagreed. When the 30+ group was divided into 30’s and 40+ age groups, slightly more of the 40+ group (59%) agreed with the statement while more in their 30’s were ‘unsure’ (40%).

Similar numbers from each age category claimed to use specific recovery strategies in order to reduce the duration of recovery from intense exercise (76%). Specific strategies used by <30 and 30+ age groups were similar in frequency except for the use of supplements and aquatic/hydrotherapies (Figure 4.6). When the data is presented for three different age categories, a significant difference between the age groups was observed in the frequency of massage use (Chi-Square,  $P=0.049$ ). The different report of sleep as a recovery intervention between age groups also approached significance (Chi-Square,  $P=0.052$ ) (Figure 4.7).



**Figure 4.6: Recovery strategies used by athletes. Bars represent the percentage of athletes within each age group (<30 = 18-29, 30+ = 30-60 years) that reportedly use each specific strategy to help promote recovery.**



**Figure 4.7: Recovery strategies used by athletes.** Bars represent the percentage of athletes within each age group (<30 = 18-29, 30's = 30-39 and 40+ = 40 to 60 years) that reportedly use each specific strategy to help promote recovery, \* = significantly different to other two groups  $P<0.05$ .

Spearman and Pearson correlation analyses identified weak but significant associations between several variables (Table 4.2). Most notably there was a significant association between training years and recovery duration ( $\rho=0.28$ ,  $P=0.006$ ). There were also significant correlations between age and training years ( $r=0.48$ ,  $p<0.0005$ ), age and training frequency ( $r=-0.29$ ,  $p=0.004$ ) and age and training hours per week ( $r=-0.38$ ,  $p<0.0005$ ).

**Table 4.2: Pearson product moment (r) and Spearman's rank correlation ( $\rho$ ) coefficients for responses relating to training and recovery from the exercise recovery questionnaire.**

|                    | Test          | Age | Years Training   | Training Frequency | Training Hours     | Recovery Duration |
|--------------------|---------------|-----|------------------|--------------------|--------------------|-------------------|
| Age                | $\rho$<br>$r$ | 1   | 0.36**<br>0.48** | -0.27**<br>-0.29** | -0.36**<br>-0.38** | 0.18<br>0.15      |
| Years Training     | $\rho$<br>$r$ |     | 1                | -0.01<br>-0.06     | -0.08<br>-0.09     | 0.28**<br>0.28**  |
| Training Frequency | $\rho$<br>$r$ |     |                  | 1                  | 0.74**<br>0.74**   | -0.09<br>-0.10    |
| Training Hours     | $\rho$<br>$r$ |     |                  |                    | 1                  | -0.18<br>-0.22*   |
| Recovery Duration  | $\rho$<br>$r$ |     |                  |                    |                    | 1                 |

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\*. Correlation is significant at the 0.01 level (2-tailed).

## Discussion

This study documented the opinions of well-trained athletes in regard to fatigue and recovery from training and competition, and identified strategies commonly used by athletes to promote recovery. The main finding from the study is confirmation that amongst endurance athletes aged 18 to 60 years there is a belief that recovery from exercise is delayed as a consequence of ageing. This opinion is supported by the significantly longer estimated time for complete recovery after training and competition reported by athletes aged 30 years and above compared with those aged under 30. However, the question that remains unanswered by this study is whether this perception of impaired recovery translates to an actual physiological impairment that would impact upon training and competition performance?

The significantly longer training history in the 40+ group is not surprising given their age. However, the differences in weekly training frequency and volume of the three groups highlight some potential issues for the investigation of ageing on recovery. A decline in the frequency and volume of training with age has previously been reported in the literature (201, 239, 355, 442). However, in a recent paper describing the rate of decline in endurance-trained compared with sedentary men, training volume was found to decrease with age but this was not evident until after 50 years of age (351). In fact, the 30-39 age group in the study of Pimentel et al. had the largest training volume of all the groups (~11 hours) followed by the 40-49 age category (~9 hours) and then the 20-29 group (~8.5 hours). In contrast, the group with the highest weekly training volume in the present study was the 18-29 age category (17 hours), while the mean weekly training hours of the 30-39 and 40+ groups in the present investigation were similar to the corresponding figures reported by Pimentel et al. (351).

The reasons for these differences can only be speculated. It is possible that the 18-29 age group respondents in the present study were simply participating in abnormally large training volumes or may have been competing at a higher competitive level. However, the endurance-trained men in the study by Pimentel and colleagues (351) were highly competitive runners having finished in the top ten for their age group in a major 10km foot race. As there was no identification of competitive level provided by the survey used in this study no such comparison can be made. Alternatively, it has been suggested that time constraints play a major part in the training of ageing athletes with family and work commitments limiting training time (363). It is possible that the subjects in the present study represent this shift in training priority with age. Furthermore, the Gold Coast, Australia, has a climate that is conducive to outdoor physical training and may have contributed to the larger training volumes of the younger athletes in the current study.

The 20-29 age group in the investigation of Pimental and colleagues (351) had a marginally lower relative  $\dot{V}O_2\text{max}$  than the 30-39 year old participants (68.5 vs. 69.2 ml.kg<sup>-1</sup>.min<sup>-1</sup>) which may have been a result of the slightly lower training volume for this group as indicated above. The importance of maintaining training volume and intensity, particularly with ageing, cannot be underestimated. An overall age-related decline, and faster declines in physiological parameters such as  $\dot{V}O_2\text{max}$ , have been reported for ageing athletes compared with sedentary subjects (201, 419). However, there is evidence that these declines may not be entirely due to the ageing process *per se* but may be partially attributed to a lower training volume (351). When training volume is maintained, smaller age related reductions in  $\dot{V}O_2\text{max}$  have been observed (239).



Another major finding of the present study is the large proportion (42%) of 30+ athletes reporting the symptom 'stiff' compared with only 28% of those under 30. Buckwalter (74) comments in a review on ageing and mobility that 'weakness, stiffness, and musculoskeletal pain that limit mobility are among the most frequent complaints of middle-aged and older people' and continues on to suggest that weakness, pain and restriction of motion due to changes in the soft tissues are the greatest cause of impairment for older people. Similarly, in an investigation into the effect of age and reduced muscle use on several muscle stiffness parameters, Brown et al. (73) begin with the statement; 'It is not uncommon to hear older adults complain about muscle stiffness; yet, stiffness as a fundamental aspect of age-associated change is not well understood'. Several studies have investigated the degree of musculotendinous stiffness for a variety of joints and muscles in athletes (186), ageing sedentary individuals (333) and older active individuals (172). It appears that with ageing there is an increase in mechanical measures of stiffness (173, 333), but whether these measurements are associated with increases in perceived stiffness requires further research.

Any association between measured mechanical stiffness and the self-reported perception of stiffness in this study may have serious consequences for the ageing athlete with respect to exercise-induced muscle damage. McHugh et al. (301) measured hamstring stiffness in 20 young volunteers (28.5 years) after dividing them into 'stiff', 'normal' and 'compliant' groups and observed that lengthening muscle contractions induced significantly greater strength loss, pain, muscle tenderness, and creatine kinase activity in the 'stiff' compared with the 'compliant' groups. Further research is required to determine if similar patterns exist in older versus younger athletes, particularly given that age-related changes in the measurement of mechanical stiffness are suggested to be prevented or reversed by regular exercise training (251, 332).

Anecdotal reports suggest that the older athlete cannot train as hard or as often as their younger counterparts (327). Reaburn (363) argues that ‘both research and anecdotal evidence strongly suggest that ageing athletes need longer to recover.’ The finding in the present study of a significant difference for the reported time for full recovery after exercise between the <30 and 30+ groups provides statistical evidence for these arguments. Reaburn (363) also suggests that ‘too many ageing athletes train hard but ignore recovery strategies, except when they become sick or are injured’. The evidence from the present study suggests that the ageing athlete agrees with Reaburn with respect to the longer time required for recovery. However, in contrast to the suggestion that recovery is neglected by this group, the number of athletes in the 30+ age category that reported the use of specific strategies to promote recovery (75%) indicates that the majority of older athletes are not ignoring the importance of recovery strategies.

The recovery strategies utilised by the participants in the current study is diverse and reflects an awareness of the importance of recovery to performance. However, while over 80% of the surveyed subjects felt that their performance would be detrimentally affected by prior exercise, only 75% of the participants used recovery strategies between training sessions. Furthermore, there was no direct association between those that did not consider their performance to be affected by prior exercise and the non-use of recovery strategies. Upon further analysis, 20 athletes, or 24%, of those that believed that subsequent performance would be affected did not use any form of recovery strategy, independent of age group.

For those athletes that did use specific recovery strategies, massage (41%), supplements (34%), stretching (31%), and diet (26%) were the most popular, in

descending order of frequency. The high frequency of massage and low frequency of sleep as selected recovery interventions for the 30-39 age group compared with the other age groups is an interesting finding that warrants further research. Changes in lifestyle with age, such as increasing work demands and the specific demands of a young family, may contribute to group differences by precluding sleep as a practical recovery option for athletes in the 30-39 category. However, while it is tempting to make such speculations there is insufficient data to confirm or refute any suggested reason for age-differences in selection of recovery strategies.

Only 26% of the athletes surveyed reported the use of diet as a method of recovery. Of the four recovery strategies most frequently utilised by the athletes in this study, appropriate nutrition has the most scientific support for effectiveness in promoting recovery (76, 80, 206). The research support for massage, supplements and stretching to aid recovery is more controversial (98, 191, 404, 433). The questionnaire did not require participants to identify specific supplements used, thus there may be confusion between the appropriate category for accepted nutritional supplements such as glucose powder used to make up a sports drink and other forms of supplement that are more equivocal in their effectiveness for recovery such as antioxidants (325) or L-carnitine (118).

The present study observed significant correlations between recovery duration and the variables of training history and training volume. Furthermore, the significant correlations between age and both training frequency and volume emphasise the need for further research on the interaction between these variables. The majority of previous research suggests that there is clearly a trend for training volume to decrease with age (148, 282, 421) and the present study supports these findings. However, the significant

negative association between training volume and perceived recovery time lends support to the argument that delayed recovery, like many other physiological parameters such as  $\dot{V}O_2$  max, may not be entirely a product of ageing *per se*. The detraining effect due to reductions in training volume may be a significant contributor to physiological decline even in an athletic population. Hawkins et al. (202) suggested that training reductions, which appear to be an inevitable aspect of ageing, lead to an age-related decline in  $\dot{V}O_2$  max that is similar for both athletic and sedentary individuals. Unfortunately, it is impossible to elucidate from the findings in the current study as to whether the reported increase in the duration of recovery with age is a product of age-related reductions in training volume or whether an age-induced slower recovery prevents the maintenance of higher training volumes.

It is important to identify that the questionnaire was designed to recruit subjects for the subsequent studies on nutrition and physical recovery and to gather information on the general perceptions on recovery in athletes across a spectrum of ages. As such the questionnaire was unvalidated and therefore the findings of the questionnaire should be treated with caution with respect to whether these findings can be generalized to the wider athletic community. A more unbiased approach would be to include questions with equal weightings of positive and negative responses to each question.

In conclusion, the current study has shown that amongst one hundred athletes aged from 18 to 60 years of age there is an age-related decline in self-reported training frequency and volume, and in the time taken to recover from training and competition. More than 80% of athletes indicated that post-exercise symptoms would affect subsequent performance. Young and ageing athletes report similar patterns of use with regard to recovery interventions and massage is the most prevalent choice of recovery

intervention. Older athletes estimate a longer average time for recovery from intense exercise or competition, and the reported recovery duration is significantly associated with both training volume and training history.

# **CHAPTER V:**

## **STUDY TWO**

### ***Dietary intake and ageing in cyclists, runners and multi-sport athletes.***

#### **Introduction**

Chapter IV highlighted the relatively poor use of nutrition as a recovery strategy in both young and older athletes. Nutrition is widely acknowledged as an essential ingredient for successful sporting performance. Before, during and post race/training nutrient intake can significantly impact on an individual sporting performance (77). For the well-trained athlete, normal dietary intake plays a major role in the effectiveness of any physical training program and as such often receives significant attention in the field of sports science. While many studies have examined dietary intakes in young elite athletes (81, 86, 87, 454), there are only a few published investigations describing the nutrient intake of the older athlete (40, 91, 105, 190).

The purpose of this study was to describe the dietary intake of a cohort of veteran athletes and to compare the dietary intakes of this older group with a training- and performance-matched younger group of athletes and also against the current recommended daily intakes for these populations.

It has been reported that there is a 19 to 33% decrease in energy intake between the ages of 24 and 80 years of age, and an associated decrease in vitamin and mineral intakes (91). Furthermore, there is evidence that ageing can increase the average daily requirements of certain micronutrients (381). Consequently, if the trend of a decreasing nutrient intake is occurring in an ageing athletic population, then such behaviour may have major implications for exercise performance in this group. Regular intense exercise increases the average daily requirement for certain micronutrients (159).

Therefore, the potential for increased energy and micronutrient demands as a result of regular exercise, combined with an age-related decrease in nutrient intake, highlights the importance of investigating dietary intake in the ageing athletic population.

## **Materials and Methods**

### **Subjects**

Sixteen veteran ( $43.8 \pm 5.0$  years) and thirteen young ( $24.0 \pm 4.8$  years) athletes provided information regarding their normal dietary intake. Subjects were screened for injury or illness, training volume and training history. All participants were actively participating in cycling and/or running training and competition. Those who only cycled were completing a minimum of 200 km per week, while the runners were undertaking a minimum of 40 km per week. Multi-sport athletes were meeting the minimum criteria for at least one of the sports. There were initially twelve cyclists, nine multi-sport athletes and eight runners involved in the study. All subjects agreed to participate in the study voluntarily and provided written informed consent according to the requirements of the Institutional Human Research Ethics Committee.

### **Methods**

Upon volunteering for the study, as a general indicator of activity level participants provided written information regarding number of training sessions per week and total weekly training hours. To provide an additional indication of the physical activity levels of the subjects, daily physical activity was also assessed in a subgroup of nineteen participants by using the self-administered Baecke Physical Activity Questionnaire (23). This questionnaire provides a rating of total daily activity comprised of work activity, sport activity and leisure activity. Basal energy expenditure

(BEE) and estimated daily energy expenditure (DEE) were calculated using the equations of Schofield (392) and Harris-Benedict (164) (Appendix C).

Based on the inclusion criteria for participation in the study identified above, the self-reported training volumes, and the Baecke questionnaire measure of physical activity index, the participants were homogeneously estimated to have a daily energy expenditure (DEE) 80% above their estimated basal metabolic rate (BMR). Body mass and percent body fat were measured using electronic scales with inbuilt bioelectrical impedance analysis (PE56, Tanita, Tokyo, Japan). Height was measured to the nearest 0.001m using a portable wall-mounted stadiometer.

### **Dietary Assessment**

Two methods of dietary assessment were administered. The first, a semi-quantitative food frequency questionnaire developed by the Queensland Institute for Medical Research, was mailed to the participants with their information package (data not shown). The second method of assessment was via a three-day diet record (Appendix B).

After initial telephone recruitment, participants attended an orientation and familiarisation session and were taught how to record their food, beverage and supplement intakes. Each participant received a food record that contained instructions for recording of normal dietary intake (Appendix B). Participants were asked to record their intake during preparation or immediately after meals or snacks and were requested to measure or practice estimating food portions in cups, spoons or from weight or volume labels. They were also encouraged to clip labels from foods to their record and to provide recipes for any unusual products they consumed.



For nineteen of the subjects the record was completed for three successive days as they participated in the later subsequent recovery study (Chapter VI). Daily review of records was performed when volunteers returned to the laboratory each day for exercise testing as a part of Study Three. During this review, the investigator verbally checked vague or illegible entries for food type or portion and where possible these were amended. The records for the other ten subjects were included in a training diary with the recording days spread over a four-week period (two week days and one weekend day). For these ten participants, diet records were only reviewed at the end of the four-week training period.

Goldberg et al. (181) defined minimum cut-off limits for energy intake below which a person of a given sex, age and body weight could not live a normal life-style. 'CUT-OFF 1' tests whether reported energy intake measurements can be representative of long-term habitual intake of a group or individual. 'CUT-OFF 2' tests whether reported energy intakes are a plausible measure of the food consumed during the actual measurement period. Based on the limits derived by Goldberg et al. (181), a recorded energy intake (EI) of below  $1.35 \times \text{BMR}$  in individuals was considered as unlikely to represent habitual intake and to exclude potential under-reporters of EI. Calculations of the CUT-OFF 2 limits were then derived for both groups to confirm the validity of the mean EI as an accurate measure of the food eaten by the young and veteran groups during the study period prior to statistical comparisons. The EI/BMR ratio (BMR calculated from the Schofield equations) must be greater than the CUT-OFF 2 limit to be considered a valid indication of food eaten by the athletes in each group during the study.

Analysis of nutrient composition was conducted using the dietary analysis software *Foodworks*® (Xyris Software, Highgate Hill, Australia). A qualified dietitian entered food record data and generated an average daily intake of macro- and micronutrients for each participant.

### **Statistical Analyses**

All data is presented as mean  $\pm$  standard deviation. Prior to statistical comparisons, individual and group data was assessed for validity using minimum cut-off limits of Goldberg et al (181) as described above. The Kolmogorov-Smirnov test was performed on the data from both groups to check for normality. Where data were normally distributed, an independent Student's *t* test was used to determine statistical differences in nutrient intakes between young and veteran athletes. Non-parametric data were compared using a Mann-Whitney U test. Association between variables were analysed using Pearson product-moment and Spearman rank correlation analyses.

### **Results**

Using the Goldberg CUT-OFF 1 to test whether reported energy intakes were a plausible measure of the habitual intake, three participants from the young group and two from the veteran group were identified as likely under-responders and not included in the data analyses. Descriptive characteristics for all the remaining participants are presented in Table 5.1. Of the 24 included participants there were five runners, ten cyclists and nine multi-sport athletes. There were no significant differences between the two age groups for physical characteristics such as height and weight or for any of the physical activity and training measurements.

**Table 5.1: Physical and training characteristics of young and veteran runners, cyclists and multi-sport athletes.**

|                         | Age<br>(years) | Height<br>(metres) | Mass<br>(kg)   | Body<br>Fat<br>(%) | Baecke<br>Total<br>Activity<br>Index | Baecke<br>Sport<br>Activity<br>Index | Training<br>Volume<br>(h/wk) |
|-------------------------|----------------|--------------------|----------------|--------------------|--------------------------------------|--------------------------------------|------------------------------|
| <b>Young<br/>n=10</b>   | 24 ± 5         | 1.75 ±<br>0.06     | 70.2 ±<br>7.7  | 12.4 ±<br>5.8      | 12.1 ± 1.8<br>n=8                    | 5.3 ± 0.6<br>n=8                     | 15.4 ± 4.1                   |
| <b>Veteran<br/>n=14</b> | 44 ± 5         | 1.75 ±<br>0.08     | 73.2 ±<br>10.6 | 11.6 ±<br>3.8      | 11.4 ± 1.2<br>n=9                    | 5.0 ± 0.5<br>n=9                     | 11.7 ± 4.1                   |

For the remaining athletes in each group, the CUT-OFF 2 values derived for the young group and veteran group were 1.35 and 1.41, respectively. These CUT-OFF values are well below the mean EI/BMR for each group presented in Table 5.2. The mean energy intake of both the young and veteran groups was comparable to the mean DEE calculated by the Schofield and Harris-Benedict equations (Table 5.2). Both the Schofield and Harris-Benedict equations were significantly correlated with EI for the young group ( $r=0.69-76$ ,  $p<0.05$ ) but not the veteran group ( $r=0.19-0.24$ ,  $p>0.05$ ). Neither the Baecke total activity index or sport index were significantly associated with energy intake ( $p>0.05$ ).

**Table 5.2: Estimated daily energy expenditure and recorded energy intake in young and veteran athletes (DEE: daily energy expenditure, EI: energy intake, BMR: basal metabolic rate).**

|                     | <b>DEE (kJ)<br/>Schofield<br/>Equation</b> | <b>DEE (kJ)<br/>Harris-<br/>Benedict<br/>Equation</b> | <b>EI<br/>(kJ)</b> | <b>EI/BMR</b> |
|---------------------|--|---|--------------------|---------------|
| <b>Young n=10</b>   | 12681 ± 1529                               | 12748 ± 1490  | 12979 ± 3270       | 1.83 ± 0.35   |
| <b>Veteran n=14</b> | 12672 ± 1389                               | 12320 ± 1436  | 14234 ± 4485       | 2.03 ± 0.61   |

Statistical comparison of the mean daily energy intake of the macronutrients fat, carbohydrate and protein indicated that there was a significant difference between the young and veteran groups for percentage fat intake as a proportion of total energy intake (Table 5.3). Mean daily protein intake in both groups was more than double the Australian RDI of 0.75 g.kg<sup>-1</sup> body mass. Average daily carbohydrate intake was not statistically different between groups. However, there were eight veteran athletes and three young athletes consuming daily intakes of less than five grams per kilogram body mass (Appendix F).

There were no significant between-group differences in mean daily intake for any of the micronutrients. Both groups were found to have a mean daily micronutrient intake well above the upper range of RDI for all variables except potassium (RDI: 1950-5460mg, young: 4456 ± 1347mg, Veterans: 5171 ± 1151mg). A small number of athletes from each group did not have daily intakes above the RDI for vitamin A (five veteran, 2 young), vitamin C (one young), sodium (two veteran, one young), magnesium (two young), calcium (one veteran), and zinc (two veteran, two young).

**Table 5.3: Daily nutritional intakes of fat, protein and carbohydrate intake in young and veteran athletes. T total intake, S saturated, P polyunsaturated, M monounsaturated, SC simple carbohydrates, CC complex carbohydrates, g.kg<sup>-1</sup> grams per kilogram body mass, % percentage contribution to total energy intake.**

|                         | Fat      |          |          |          |       | Carbohydrate |           |           |                    |      | Protein  |                    |      |
|-------------------------|----------|----------|----------|----------|-------|--------------|-----------|-----------|--------------------|------|----------|--------------------|------|
|                         | T<br>(g) | S<br>(g) | P<br>(g) | M<br>(g) | %     | T<br>(g)     | SC<br>(g) | CC<br>(g) | g.kg <sup>-1</sup> | %    | T<br>(g) | g.kg <sup>-1</sup> | %    |
| <b>Young<br/>n=10</b>   | 97±35    | 35±18    | 17±7     | 36±14    | 29±6* | 405±130      | 201±68    | 198±73    | 5.7±1.5            | 52±9 | 122±43   | 1.7±0.6            | 16±3 |
| <b>Veteran<br/>n=14</b> | 129±47   | 52±31    | 17±6     | 47±12    | 35±5  | 389±136      | 180±65    | 204±76    | 5.4±2.0            | 46±7 | 145±50   | 2.0±0.7            | 17±4 |

\* significantly difference to veteran group (p<0.05)

## Discussion

The purpose of this investigation was to describe the dietary intake for a cohort of well-trained veteran athletes and to compare this dietary intake with a similar group of young athletes and the Australian RDI to identify if veteran athletes are at risk for sub-optimal dietary intakes. With respect to overall energy intake, the present data suggests that veteran athletes consume at least as many kilojoules per day as young athletes. Due to this high energy intake, it is likely that they are obtaining adequate micronutrients when compared with RDI, a further finding of this current study. However, there is a difference in the proportion of energy obtained from fat sources in the veteran group that may have implications for longer term health and athletic performance.

The mean proportion of fat intake in the veteran group of 35% is similar, but slightly higher than, Australian adults of similar ages (32.1-33%, 19-64 year old) described in the 1995 National Nutrition Survey (302). Furthermore, the relatively high saturated fat intake in this group of veteran athletes (52 grams.day<sup>-1</sup>) is in the 90<sup>th</sup> percentile of the population distribution. The higher proportion of energy intake from fat in the older group may also have been at the expense of carbohydrate intake with a small but non-significant difference ( $p=0.09$ ) between groups for relative energy intake from carbohydrate sources ( $52 \pm 9\%$  Young;  $46 \pm 7\%$  Veteran). There was very little difference in absolute or relative amounts of protein intake between the two groups with protein intake in g.kg<sup>-1</sup>.day<sup>-1</sup> well above the recommended guidelines (1.2-1.4 g.kg<sup>-1</sup> body weight per day) for endurance athletes (98).

The high fat intake could suggest potentially negative health implications for this older group. The *Dietary Guidelines for Australians* published in 1992

recommended that individuals should eat a diet low in fat and, in particular, low in saturated fat, due to the potential health risks (type 2 diabetes, coronary heart disease) associated with a diet high in fat (322). In the more recent publication *Dietary Guidelines for Older Australians* Truswell (444) revisited the earlier guidelines and concluded that the main priority should be a reduction in amount of saturated fat in the diet. However, the average intake of saturated fat intake by the veteran athletes in the present study would suggest that these guidelines are either not known or being ignored by the majority of older athletes in the present study.

In a recent review of nutrition and the ageing athlete, Reaburn (362) reported that older athletes appear to consume more fat relative to total energy than the recommended population targets or than health sedentary age-matched controls. He suggested that this might be due to older athletes consuming a greater daily energy intake, but also indicated that the RDA/RDI are not specific enough for older age groups and indicated it was more likely that an older population may not be as informed about the benefits of a low-fat diet as a younger population. Whether this suggestion applies to the older group in this investigation is unknown. However, for health purposes, the older group of athletes surveyed in the present investigation may benefit by modifying their diet in line with the above recommendations.

Of greater importance to the highly active and competitive athletes studied in this investigation, is the quantity of carbohydrate (CHO) consumed each day. The importance of high CHO intake before, during and after exercise has been widely emphasised (85, 126, 224). For athletes requiring rapid recovery between training sessions, a high CHO diet has been demonstrated to assist recovery and performance (151). Consequently, the recommended daily CHO intake for endurance athletes

engaging in daily exercise of 1-3 hours duration at moderate to high intensity has been identified as between 7 and 10 grams per kilogram of body mass per day (85). Assuming that the training volumes in excess of ten hours per week reported by the participants in the current investigation place them into the above category described by Burke et al. (85), then we can also assume that both the young and the veteran subjects could benefit by increasing daily CHO intake. More than 50% of the veteran athletes in this investigation had a daily CHO intake of less than five  $\text{g.kg}^{-1}.\text{day}^{-1}$ .

A possible explanation for this sub-optimal intake of carbohydrate in the large number of veteran athletes surveyed could be a cohort effect whereby prior experiences and age influence food choices. Although there is increasing information available to athletes with respect to nutrition for performance it cannot be assumed that the veteran athletes in this investigation are aware or willing to adopt these practices. Burke et al. (85) examined CHO intake in relation to the year of publication from surveys of male and female endurance athletes. They observed that athletes appear to have been increasing the proportion of CHO in their diets over the past decades. The older athletes in the present investigation may be representative of the cohort of younger athletes that were surveyed in the 1970's and 1980's and have not modified eating patterns in response to changes in availability and quality of nutritional information.

Other researchers that have surveyed the nutritional intake of older athletes reported similar CHO intakes relative to body mass ranging from 4.4-5.2  $\text{g.kg}^{-1}.\text{day}^{-1}$  (40, 91, 105, 190). These figures are also below the 7-10  $\text{g.kg}^{-1}.\text{day}^{-1}$  recommended for athletes (85, 98). Together with the results of the present investigation, these findings suggest that improving CHO intake relative to training patterns for older athletes might be an area for future research.



Underreporting of dietary intake is a common problem with many forms of dietary assessment in both free-living individuals and athletes (42, 47, 181). Goldberg et al (181) identified four main reasons for low records of energy intake. These include a failure to record everything eaten, conscious or sub-conscious under-reporting, modification of eating patterns during the survey period, and statistical uncertainty arising from the high level of day-to-day variability. To counter problems with underreporting, Goldeberg et al. defined minimum cut-off limits to evaluate energy intake data which were applied in this investigation. In the present study, dietary data from five participants were excluded based on the minimum cut-off limit provided by Goldberg et al. where energy intake was at least 1.35 times the estimated BMR. This suggests good compliance by the subjects under investigation with respect to dietary records. The group means for energy intake were well above the calculated cut-off values (1.35 and 1.41 for young and veteran groups, respectively) and can therefore be considered a valid representation of the actual dietary intake for each group during the period of investigation.

Only one other published investigation into the dietary intake of the older athlete has also attempted to compare EI with DEE (105). Chatard et al. used a seven-day questionnaire to quantify DEE and sport activity. Although the mean reported energy intake was higher than the mean DEE (EI = 11549 kJ; DEE = 11429 kJ), 50% of these athletes still had a dietary EI below their corresponding DEE. Similarly, in the present investigation, even after exclusion of data from participants deemed as under-reporters, seven of the fourteen veteran athletes and six of the ten young athletes had EI below DEE as predicted by the Schofield equation.

In addition to the possible sources of error in the measurement of EI identified above, there are also problems associated with the calculation of DEE (391, 395). The present study used a combination of self-reported training activity and the Baecke Physical Activity Questionnaire to assist with the calculation of DEE from standard equations for BMR. However, the simplistic approach of identifying a common physical activity level of  $1.8 \times \text{BMR}$  for all subjects may have limited the sensitivity of the DEE calculations for comparison with EI (46). For example, although the Baecke total activity index has been reported to have a high correlation with physical activity level (348), the poor correlations between the Baecke ‘total activity’ and ‘sport activity’ indices, with EI in the present study suggests that this questionnaire is not sensitive enough to discriminate between activity levels in these well-trained individuals. This may be due to the high individual variability that has been reported for questionnaires of physical activity (53). Furthermore, the poor correlation coefficients between EI and the calculations of DEE for the veteran group in the present study suggest that these commonly utilised equations may not be as accurate for highly active ageing athletes.

It is only possible to speculate as to whether the combination of ageing and intense training substantially increase the micronutrient requirements for the elderly athlete in excess of the commonly prescribed RDA/RDI guidelines. Several recent reviews have provided arguments for increased intake above the RDA/RDI guidelines for specific vitamins (Folate, Riboflavin, B6, B12, D and E) and minerals (Fe and Ca) in older competitive athletes (95, 362, 369, 383). The average daily intake by the athletes in the present study was well above the Australian RDI for all the micronutrients except potassium with very few individuals below the recommended guidelines. Considering the inherent difficulties in accurately describing habitual intake of some of the micronutrients from commonly-used short term dietary surveys (33), it is difficult to

ascertain from the current findings whether the veteran athletes in the present study were ingesting sub-optimal quantities of any of the micronutrients.

Beshgetoor et al. (40) found that the mean vitamin E intake in non-supplementing older female athletes was only 87% of Dietary Reference Intake (DRI) and only 79% of DRI for calcium. Previous studies have also identified individual athletes that were below their respective regional RDI guidelines for several of the micronutrients (91, 105). However, the mean daily intake of all the micronutrients by the older athletes in these studies was well above the respective country's dietary guidelines, similar to the findings of the current investigation.

In conclusion, this study has found that the percentage of energy derived from fat sources was higher in the veteran group than in a group of similarly-trained younger athletes. The veteran athletes surveyed successfully met the minimum micronutrient requirements for training and competition demands. However, the present results suggest that veteran athletes have lower than recommended intakes of carbohydrate for optimal training and performance, highlighting the need for further research and improved nutritional education in this population.

## **CHAPTER VI:**

### **STUDY THREE**

#### ***Physiological recovery during three days of intense laboratory time-trial exercise in young and veteran cyclists***

##### **Introduction**

It is commonly accepted amongst athletes and coaches that a progressive decline in the rate or speed of recovery from training and competition occurs with advancing age (303, 363). The age-related declines in physiological function and athletic performance consistently observed in older individuals (139, 421) may, in part, be due to impaired rate of recovery. Although there is some evidence of an age-related difference in exercise-induced muscle damage and adaptive potential (296), much of this research has been undertaken on animal (72) or non-athletic human populations (375), and has used fatigue/damage protocols such as maximal eccentric muscle contractions that are unrealistic to the training and competition undertaken by most athletes.

Finding the most appropriate measures of performance, fatigue and recovery in an athletic population appears problematic (244). Numerous investigations into overreaching and overtraining have attempted to establish suitable markers that can be used to diagnose overreached athletes suffering from prolonged training-induced fatigue (163, 168, 176, 450) but there is limited availability of valid diagnostic tools (450). At present, actual physical performance is considered to be the 'gold standard' measure for training and overtraining reactions (413). The most appropriate measure to use as an indicator of undesirable training fatigue is a decrement in athletic performance occurring in conjunction with continued training (277).

In a recent study McLester et al. (303) investigated muscular endurance recovery from an acute bout of resistance exercise. A significant difference was observed in endurance recovery between young (18-30 yrs) and old (50-65 yrs) resistance trained subjects at 72 hours post exercise. However, to date there has been no published study that has examined the effects of high-intensity endurance exercise experienced through 'typical' training or competition on fatigue and recovery in young and ageing athletes. Such intense exercise may theoretically elicit a period of reduced performance until the bodily systems are replenished and repaired. While it has been suggested that performance decline and recovery time is greater for the well-trained older athlete, (432) this suggestion has yet to be confirmed. Therefore, the aim of this investigation was to compare the responses of young and veteran cyclists to repeated days of high-intensity endurance cycling performance similar to that experienced during typical competition or training. We hypothesised that younger athletes would tolerate the repeated days of high intensity exercise with little or no affect on performance but that, due to impaired recovery, the veteran athletes would demonstrate a decrease in cycling performance over the duration of the study.

## **Materials and Methods**

### **Subjects**

Ten young (18-31 years) and ten veteran (39-56 years) cyclists were recruited via a questionnaire, newsletter invitation and word-of-mouth to participate in the study. For each age group nine males and one female volunteered to participate. All subjects were completing a minimum of 200km of cycling training per week, for at least six months and were actively competing in regular club level cycling competitions at the time of testing. Medical history, diet and training status were obtained via

questionnaire. Recovery data is presented for only nine subjects from each group due to the withdrawal of one young and one veteran subject (both males) prior to completion of the study. The characteristics of each group are described in Table 6.1.

## **Procedures**

Participants were required to attend the exercise-testing laboratory on four separate occasions. The first visit served as a familiarisation and information session. Subjects received dietary diary training, were familiarised with the testing protocols to be performed during their subsequent visits, and undertook a graded incremental test to volitional exhaustion (GXT) on a cycle ergometer. This test enabled the determination of peak values for respiratory parameters and the calculation of the modified D-max lactate anaerobic threshold (62).

The subjects returned to the laboratory after a minimum of 48 hours (2-7 days) for a further three consecutive testing sessions (T1, T2, T3) during which they undertook 30-minutes of intense time-trial exercise. Prior to all testing sessions subjects were instructed to have abstained from intense exercise for at least 24 hours and were requested to have avoided food and caffeine for a minimum of two hours. Following each test session a standard breakfast was provided to assist post-exercise glycogen replacement. During the three days of testing participants maintained a dietary record for the 24-hour period prior to each test session. Participants also completed a food frequency questionnaire to identify foods most commonly consumed as a qualitative dietary evaluation. The food records and food frequency questionnaires were then analysed by a qualified dietician using dietary analysis software (Foodworks, Xyris Software, Highgate Hill, Australia).

**Table 6.1: Descriptive characteristics of veteran (n=9) and young (n=9) cyclists (mean  $\pm$  SD).**

| Group   | Age<br>(years) | Height<br>(m)   | Mass<br>(kg)   | Body fat<br>(%) | Weekly<br>training<br>volume<br>(km) | Peak power<br>(watts) | <i>Peak <math>\dot{V}O_2</math></i><br>( <i>ml.kg.min<sup>-1</sup></i> ) |
|---------|----------------|-----------------|----------------|-----------------|--------------------------------------|-----------------------|--|
| Veteran | *45 $\pm$ 6    | 1.79 $\pm$ 0.06 | 76.9 $\pm$ 9.7 | 11.6 $\pm$ 3.2  | 301 $\pm$ 59                         | 320 $\pm$ 41          | 57.3 $\pm$ 4.3   |
| Young   | 24 $\pm$ 5     | 1.80 $\pm$ 0.07 | 74.2 $\pm$ 8.5 | 11.2 $\pm$ 4.5  | 311 $\pm$ 96                         | 322 $\pm$ 49          | 58.7 $\pm$ 5.0   |

\* significant difference between groups,  $p < 0.05$ .

On days T1-T3, subjects presented at the laboratory and sat quietly whilst completing a standard pre-test questionnaire pertaining to recent diet, training, health status, injury and travel. Food records for the preceding 24 hours were collected and reviewed. Body mass and percent body fat were recorded using bioelectrical impedance scales (PE56, Tanita, Tokyo, Japan) and a venous blood sample taken from the antecubital region and analysed for CK activity using dry slide chemistry (Vitros, Ortho-Clinical Diagnostics, Neckargemünd, Germany).

A standardised warm up (five minutes cycling at a ~100W) was then performed prior to testing. Participants then performed the following non-specific performance tests in the following order; the countermovement jump (CMJ), a maximal isometric contraction of the right quadriceps muscle group (MVIF) and a ten-second sprint test on a wind-braked bicycle ergometer (10ST). Recovery time between tests was standardised prior to, and after undertaking the thirty-minute time trial (TT30) each day. Within fifteen minutes of completing the TT30 all the non-specific performance tests were repeated. Each test session (T1-T3) was separated by exactly 24 hours to account for diurnal variation. The time trial on T1 and the pre TT30 non-specific performance tests served as the baseline scores for subsequent comparison.

### ***The graded progressive incremental test (GXT)***

The GXT is a progressive incremental test to volitional fatigue for elite cyclists (129), and was performed on an electromagnetically-braked cycle ergometer (Lode Excalibur, Groningen, The Netherlands). During the last minute of each five-minute workload increment, ratings of perceived exertion (RPE) (57), blood lactate (Accutrend, Roche Diagnostics, Basel, Switzerland), heart rate (Lohmeier M607, B.Braun Medical



Electronics, Spangenburg, Germany), and oxygen consumption were recorded (CPX, MedGraphics, St. Paul, Minnesota). Peak power ( $W_{\max}$ ) was calculated from the proportion of the final workload completed (192). Anaerobic threshold (AnT) was predicted from the relationship between blood lactate and power output (62) and was calculated using the Automated Data Analysis for Progressive Tests (ADAPT version 1.2, AIS software, Canberra, Australia).

### ***30-minute laboratory time-trial (TT30)***

On days 1-3 the cyclist completed a maximal intensity 30-minute self-paced time trial on the Lode Excalibur cycle ergometer. The ergometer was set in the 'linear' mode during the trial where power output increases in proportion to pedal cadence. The ergometer was set for each individual based on the average self-selected cadence during the GXT while they were cycling at the power output closest to their calculated AnT.

Mean power output, HR and lactate for each TT30 were calculated during the TT30. Power output and HR were recorded every minute throughout the TT30. Finger-prick blood lactate samples were measured in the final minute of each five-minute stage (minutes 5, 10, 15, 20, 25 and 30).

### ***Non-specific performance tests***

Several non-specific performance tests (CMJ, 10ST, MVIF) were performed before and after the TT30 each day following a standardised cycle ergometer warm up and then ten minutes after completing the TT30. The CMJ and 10ST were used to measure the dynamic performance of the leg extensor muscles. Participants performed the CMJ using a timing mat (Kinematic Measurement Systems, Lismore, Australia) according to the previously described methods (146). The 10ST (425) was completed on a front access wind-braked cycle ergometer (Exertech EX-10, Repco, Huntingdale,

Australia). Due to the possible contribution of glycolytic energy pathways to this type of test (120) the participants performed a ten-minute active recovery before participating in any other tests.

MVIF was performed as a measure of strength and was determined with subjects sitting in a specially modified chair with back support firmly strapped in place at the waist. A velcro cuff was attached immediately superior to the medial malleolus of the ankle joint and the cuff was connected via a steel chain to a load cell (XTran 2 KN, Applied Measurement, VIC, Australia) that was securely anchored behind the chair. A goniometer was used to set the knee joint between 90° and 100° (fully extended being 180°). Force-time data was collected via the load cell and processed using a data acquisition software package (AcqKnowledge, Biopac Systems, Santa Barbara, USA). Contraction began at the end of a verbal countdown and maintained for three to four seconds. During the MVIF subjects placed each hand on the opposite shoulder in a 'crossed-arms' position. A thirty-second rest was provided between contractions.

### **Statistical analysis**

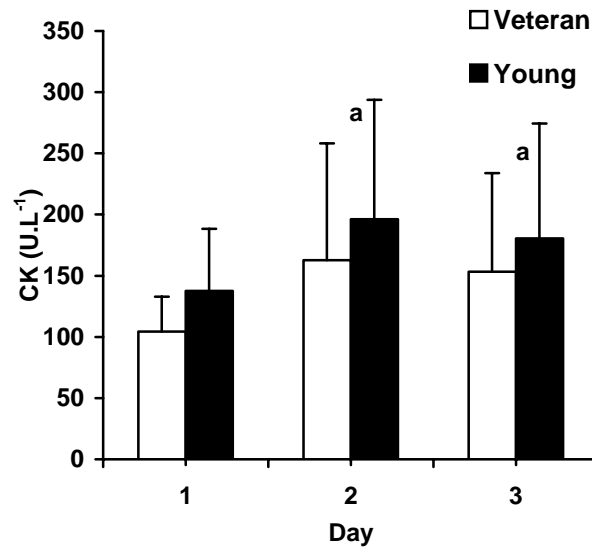
Values for all data are presented in the text and figures as the mean  $\pm$  standard deviation (SD). Independent Student t-tests were used to compare general descriptive characteristics between the two groups. Statistical comparisons between the young and veteran groups for variables measured during the TT30 (power, HR, lactate), and CK were made via a two-way (group\*day) repeated-measures analysis of variance (ANOVA). Data were examined for normal distribution by the Kolmogorov-Smirnov test. Due to a non-normal distribution for CK, this data was log transformed prior to statistical analysis but these data are presented graphically as raw values. A three-way (group\*pre-post\*day) repeated-measures ANOVA was used to analyse the non-specific

tests performed before and after the TT30 each day. Pearson correlation coefficients were calculated to investigate relationships between changes in variables over the three days. The level of significance was set at  $<0.05$ .

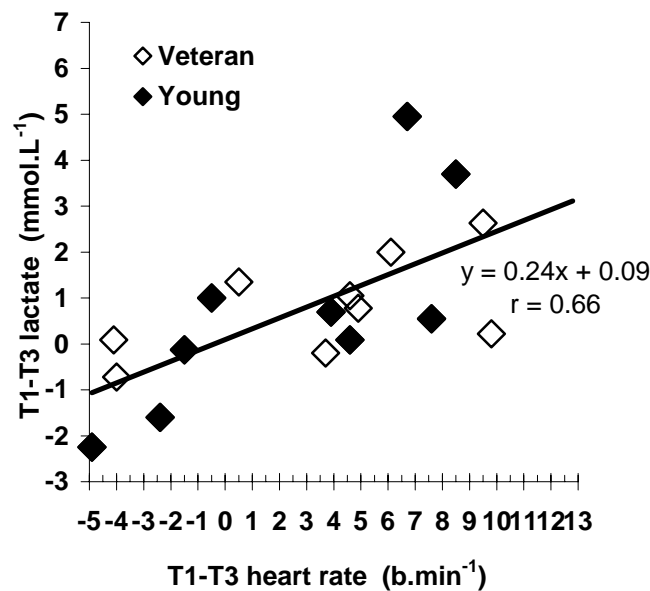
## Results

There was a significant difference between the groups for age but there were no other differences for height, body mass, percent fat or training volume at the beginning of the study (Table 6.1). Total nutrient intake for each group, as determined from the diet records, was not significantly different between groups (Young:  $12.72 \pm 3.55 \text{ MJ} \cdot \text{day}^{-1}$ , Veteran:  $12.95 \pm 1.91 \text{ MJ} \cdot \text{day}^{-1}$ ). Aerobic peak power, peak oxygen consumption, AnT (Young:  $75 \pm 11\%$  & Veteran:  $79 \pm 8\%$ ), CMJ, 10ST and absolute MVIF were similar for both groups throughout the investigation (Table 6.1).

During the three consecutive days of cycling time trials, there was no time effect or group\*time interactions for mean power output during the TT30 in either group (T1 -  $3.58 \pm 0.48$  &  $3.44 \pm 0.29$ ; T2 -  $3.65 \pm 0.43$  &  $3.41 \pm 0.24$ ; and T3 -  $3.66 \pm 0.42$  &  $3.43 \pm 0.26 \text{ W} \cdot \text{kg}^{-1}$  for Young and Veteran respectively). In both young and veteran cyclists the mean heart rate during the time trials significantly decreased from T1 to T3 by approximately three beats per minute ( $\text{b} \cdot \text{min}^{-1}$ ) with no difference between groups. Serum CK activity was elevated from baseline at days two ( $p=0.004$ ) and three ( $p=0.024$ ) for both groups with no between groups effect for either raw (Figure 6.1) or log-transformed data. Mean blood lactate concentration during the TT30 tended to decrease from T1 ( $6.6 \pm 2.3 \text{ mmol} \cdot \text{L}^{-1}$ ) to T3 ( $5.8 \pm 1.6 \text{ mmol} \cdot \text{L}^{-1}$ ) with the individual change in mean lactate from T1-T3 significantly correlated with the change in mean TT30 heart rate from T1-T3 ( $r=0.66$ ,  $p=0.003$ , Figure 6.2).



**Figure 6.1:** Serum creatine kinase activity (CK) over three days of repeated thirty-minute cycling time trials (pre time trial blood sample). *a*, denotes significant time effect on log transformed data (significantly different from day 1 for groups combined  $p < 0.05$ ).



**Figure 6.2:** Scatter plot of change from day one to day three (T1-T3) for average lactate (mmol.L<sup>-1</sup>) and heart rate (b.min<sup>-1</sup>) during the 30 minute cycling time trials,  $r = 0.66$ ,  $p = 0.003$ .

There were no significant group\*time interactions for any of the non-specific performance tests. Therefore, the peak values over the three days for both groups combined are presented (Table 6.2). A significant pre\*post interaction for MVIF was evident whereby post TT30 MVIF was on average 4% lower than pre TT30 values. By the next day MVIF had always recovered to be not significantly different from baseline MVIF. For the CMJ there was a small but significant time effect evident as a decline in the average (but not the peak) height jumped at T3 ( $0.331 \pm 0.043$  m) compared with T1 ( $0.340 \pm 0.045$  m,  $p=0.008$ ) and T2 ( $0.337 \pm 0.043$  m,  $p=0.011$ ).

**Table 6.2: Non-specific performance tests (peak values) in veteran and young cyclists (mean  $\pm$  SD) before and after a 30-min time trial performed on three consecutive days.**

| Day | CMJ<br>(m)         |                   | MVIF<br>(N.kg <sup>-1</sup> ) |                | 10ST<br>(kJ)  |               |
|-----|--------------------|-------------------|-------------------------------|----------------|---------------|---------------|
|     | PreTT30            | PostTT30          | PreTT30                       | PostTT30       | PreTT30       | PostTT30      |
| 1   | 0.353 $\pm$ 0.047  | 0.353 $\pm$ 0.043 | 7.6 $\pm$ 1.3                 | 7.2 $\pm$ 1.3* | 9.3 $\pm$ 1.3 | 9.2 $\pm$ 1.3 |
| 2   | 0.351 $\pm$ 0.042  | 0.354 $\pm$ 0.046 | 7.6 $\pm$ 1.4                 | 7.2 $\pm$ 1.5* | 9.2 $\pm$ 1.3 | 9.1 $\pm$ 1.3 |
| 3   | 0.343 $\pm$ 0.043# | 0.346 $\pm$ 0.043 | 7.4 $\pm$ 1.6                 | 7.2 $\pm$ 1.3* | 9.2 $\pm$ 1.4 | 9.2 $\pm$ 1.4 |

CMJ; countermovement jump, MVIF; maximal isometric force, 10ST; 10-sec cycle

ergometer test. \* significant difference between pre and post,  $p < 0.05$ ; # significant

difference between T1 and T3 for mean jump height,  $p < 0.05$ .

## Discussion

This study identified that three days of repeated high-intensity endurance exercise did not affect cycling time trial performance for either the younger or veteran cyclists and that no effect of age was observed in the rates of recovery between bouts. The maintenance of mean power output during the time trial on each day suggests a complete aerobic endurance recovery between tests. Similarly, the non-specific performance measures did not change significantly over the three days of simulated time trials.

The significant changes in CK activity, together with the decrease in average HR during the simulated time trials and the decline in CMJ height at T3, are suggestive of physiological or neurological changes that may be associated with exercise-induced muscle damage and residual fatigue. A change in serum CK activity is often measured as an indication of exercise induced muscle damage (199, 427). Although reduced function has been suggested as the preferred measurement for defining exercise induced muscle damage (463), Noakes (328) has identified CK activity to increase in proportion to the intensity and duration of the endurance activity. In a recent study, better performing cyclists during a multi-day road race have been found to have higher CK activities than other competitors (286). Hence, although there was no performance decrement over the three days for the well-trained group of athletes (young and veteran) in the present study, the CK changes confirm that the cyclists in this study did experience a degree of muscle damage as a consequence of the daily testing and performance protocols.

The absence of a significant decline in time-trial performance in either group may be due to the requirement for participants to refrain from any other exercise during

the period of the study. In support of this suggestion, a reduction in training volume, while maintaining training frequency and intensity, has been proposed as the most effective tapering strategy for performance improvement (321). In the well-trained cyclists used in the present study, thirty minutes of intense endurance cycling exercise per day may have successfully provided this taper effect as training intensity was high but there was a reduction in normal daily volume for the duration of the three-day study. As such it is plausible that the taper effect may have potentially masked any fatiguing aspects of the daily TT30 rides and even contributed to the young group producing their highest TT30 average power at T3.

Age related differences in perceptions of pain and soreness (179), as well as perceptions of fatigue and recovery, may contribute to the common belief that recovery is delayed in an ageing athletic population and provide unique challenges to investigating this hypothesis. To investigate the fatigue effect of the repeated 30-minute time trials it may be necessary to monitor and permit the continuation of training during the experiment, or to control the training volume undertaken in addition to the laboratory time trials, rather than, as was attempted in this study, eliminate extra activity altogether.

The significant decrease in CMJ height from T1-T3 also suggests a degree of residual fatigue due to the repeated days of time-trial exercise. However, there was no decrease in MVIF or 10ST performance by either group across the three days. The complete recovery of performance each day by both groups for MVIF and the 10ST is consistent with previous research that has used similar cycling exercise, to elicit fatigue, and non-specific performance measures, to monitor recovery of strength and power in young athletes (37, 38, 269). Leveritt et al. (269) measured isometric and isokinetic



quadriceps strength in young resistance trained subjects at 8 and 32 hours after fifty minutes of cycling at 70-110% of critical power and found strength to be fully recovered eight hours after the endurance exercise bout. Similarly, Bentley et al. found peak torque at  $60^{\circ} \cdot s^{-1}$  (38) and isometric force (37) reduced at six but not 24 hours after 30 minutes of cycle exercise. These authors also investigated recovery of leg power after the 30-minutes of endurance cycling by using a concentric squat jump and a six-second cycle sprint and found the 30-minute cycling time trial had no effect on subsequent peak power during the six-second sprint but vertical jump was significantly reduced at six hours after the endurance cycling exercise (38). In the present study the mean vertical jump was significantly lower by the third day of testing, suggesting residual muscle fatigue due to the cumulative effect of repeated days of high-intensity endurance cycling time trials. However, the decrease in CMJ height from T1 to T3 was less than one centimetre and as such may not be clinically significant to the predominantly endurance cyclists involved in this study, particularly because the fatigue that may have contributed to a decline in CMJ appeared to have no detrimental effect on endurance cycling performance.

Mean heart rate during the TT30 declined significantly across the three test days for both groups. Because heart rate is often monitored in training and testing as an indicator of positive training adaptations or maladaptation associated with overreaching (3), the above findings suggest that interpretation of changes in maximal and average heart rate should be treated with caution during intensified training periods in both young and veteran athletes. Richardson et al. (367) reported a decrease in maximal heart rate (3 bpm) and sub-maximal heart rate response (5 bpm) in cross country runners after two days of high intensity training, and in a subsequent study found that plasma volume, cardiac output and stroke volume were positively effected by two consecutive

days of intense running exercise in trained runners (368). While not measured in the present study, the findings of these earlier studies would suggest that three days of intense exercise in the present study may have lead to an acute exercise-induced plasma volume expansion and a concomitant increase in stroke volume, which contributed to the decline in mean time trial heart rate over the three days.

The repeated days of TT30 exercise was selected as an appropriate method for simulating a period of intensified training and, based on common perceptions amongst athletes and coaches, eliciting residual fatigue in a group of veteran athletes. However, any perceived residual fatigue did not have any detrimental effect on cycling performance for either group. When attempting to quantify fatigue and recovery there are inherent difficulties associated with the accurate measurement of performance (218). The appropriateness and sensitivity to detect change with a self-paced time trial performance test, such as the one used in this study, compared with a constant load to exhaustion test has previously been debated (220, 230). Although it may lack sensitivity due to the effect of pacing strategies, the TT30 was selected for this study as it was considered to be representative of the typical competition or training experienced by these athletes. Other alternatives could have been to utilise a longer time trial (e.g. 60 minutes) or to increase the duration of the study to greater than three days. An ‘overreaching’ study whereby training volume is increased over a two-week period (192) may reveal differences in recovery of performance between young and veteran athletes. However, the purpose of the present study was to monitor recovery from a short period of intense training, typical of normal weekly training activities, not in response to overreaching.

In conclusion this study investigated a commonly accepted but as yet unproven hypothesis that the time course of recovery from high-intensity endurance exercise is longer in ageing versus younger athletes. The present results suggest no differences between young and veteran cyclists for cycling performance or non-specific performance tests over three days of high-intensity endurance cycling exercise. However, there was evidence of exercise-induced responses to the time-trials with both groups demonstrating increases in serum CK activity, indicative of muscle damage, and a decrease in exercising heart rate over the three days. There was also a small but significant decline in mean jumping power by day three for both groups. The absence of any difference between the two age groups in performance per se may suggest a need to investigate the impact of ageing on differences in perception of fatigue and recovery in response to intense training or competition. The present data suggest that three days of consecutive high-intensity endurance cycling time-trials does not induce performance-limiting fatigue in either young or veteran competitive cyclists.

*This study has been accepted as it is presented above for publication in the Journal of Sports Medicine and Physical Fitness.*

## **CHAPTER VII:**

### **STUDY FOUR**

#### ***Differences in perception and report of muscle pain in young and veteran athletes***

##### **Introduction**

Physical training involves the processes of inducing fatigue and subsequent recovery. Integral elements to the monitoring of the training response are the measurement of physiological (heart rate) or psychological (perceived exertion) parameters (207, 449). It is widely accepted by athletes and coaches that age can affect the recovery processes, delaying or impairing the desired response to training (363). For the competitive older athlete an impaired recovery may have serious implications for training and performance.

A common side effect of intense training and competition is the experience of delayed onset muscle soreness (DOMS) (15). The pain associated with intense and/or unaccustomed exercise generally peaks at around 24-48 hours after the exercise session (108). The degree of soreness, along with ratings of fatigue have been widely used as indicators of training-recovery status in the monitoring of overtraining in athletes (216, 240).

There is some evidence that perception of pain, effort and fatigue during exercise may be altered with the ageing process in a non-athletic population (5, 405). In a recent review of age differences in neurophysiology of nociception and perceptual experience of pain, various examples of age-related increases in pain perception were reported (178). Hence it is feasible that there is a disproportional increase in perception

and report of fatigue and soreness in the ageing athlete compared with actual physiological fatigue and recovery rate.

The monitoring of fatigue and recovery often uses psychometric measurement instruments such as the Profile of Moods States (214), Recovery-Stress Questionnaire for Athletes (242), and subjective ratings of well being (216). An altered perception of soreness, fatigue, exertion and recovery in older athletes may affect the manner in which coaches and athletes interpret this information.

There is a paucity of empirical research that has investigated physiological or psychological recovery in ageing athletes. To date, only three studies have investigated age-related differences in functional recovery and muscle soreness (112, 133, 303). Unfortunately, one study did not compare soreness changes between the two age groups (303), while the other two studies found no significant difference between age groups in soreness rating following lengthening contractions of the elbow flexors (112, 133). All of the previous studies used high-intensity resistance exercise to elicit fatigue and DOMS. No study has investigated physiological or psychological recovery from high-intensity endurance exercise in well-trained veteran athletes.

The purpose of this investigation was to compare the physiological and psychological responses of young and veteran (>35 years) cyclists to three days of intense cycling exercise. Performance is considered the 'gold standard' parameter for training and overtraining reactions (413). As such, this study sought to investigate the effect of age on physical performance, perceptions of soreness, fatigue and recovery over three days of intense exercise. It was hypothesised that intense endurance exercise performed on three consecutive days would elicit declines in physical performance as

well as altered perception and report of fatigue and muscle soreness in an older group of well-trained cyclists compared to performance younger cyclists.

## **Materials and Methods**

### **Subjects**

Ten young (18-31 years) and ten veteran (39-56 years) cyclists were recruited to participate in the study. All subjects were cycling at least 200km per week for a minimum of six months prior to participating in this study and were actively competing at club level at the time of testing. Data is presented for only nine subjects from each group due to one young and one veteran subject withdrawing before completing the study. Participants were initially screened for suitability to participate in the study before completing more detailed medical history, diet and training status questionnaires.

### **Familiarisation**

Participants were required to attend the exercise-testing laboratory on four separate occasions. The first visit served as a familiarisation and information session. Subjects received dietary diary training, were familiarised with the testing protocols to be performed during their subsequent visits and undertook a graded incremental test to volitional exhaustion (GXT) on a cycle ergometer. This test enabled the determination of peak values and the calculation of the modified D-max lactate anaerobic threshold (62) necessary for performing the time trials during the subsequent test sessions.

### **The progressive incremental test (GXT)**

Protocols for the GXT are described in Chapter III.

### **Anaerobic threshold (AT)**

Protocols for the determination of AT are described in Chapter III.

## **Time trials**

The structure of the three days of time trial exercise is described in Chapter III.

## **Perception measures**

On days T1-T3 participants began each test session by quietly completing a standard pre-test questionnaire pertaining to recent dietary intake, training, health status (illness and injury), and travel. Subjective ratings of motivation (1 'poor', 2 'OK', 3 'good', 4 'excellent'), muscle soreness (100mm visual analogue scale verbally anchored by 'no pain whatsoever' and 'the greatest level of pain one could ever have'), fatigue (0 'no fatigue' – 5 'extremely fatigued'), and total quality of recovery (TQR) (244) were also recorded at this time. Following the TT30, subjective ratings of muscle soreness were recorded again and the non-specific performance tests were repeated prior to subjects warming down.

## **The 30-minute laboratory time-trial (TT30)**

Protocols for the TT30 are described in Chapter III.

## **Statistical analysis**

Descriptive characteristics for each group (anthropometry, peak power, anaerobic threshold,  $\dot{V}O_2$  peak) were compared between the young and veteran cyclists using unpaired t-tests. Outliers that were more than two standard deviations outside the mean were removed prior to performing statistical tests. All variables were checked for normal distribution using the Kolmogorov-Smirnov test of normality. Normally distributed variables measured over the three testing days were compared within (time) and between (age) groups using a two-way repeated measures analysis of variance. Non-parametric variables (fatigue, motivation, and TQR) were analysed using the Friedman's test. Where applicable (eg. soreness) data was log<sub>10</sub> transformed to enable parametric analyses. The level of significance was set at <0.05.

## Results

There were no differences between the veteran and young cyclists for any of the descriptive variables except age ( $45 \pm 6$  and  $24 \pm 5$  years). Height, mass, training status, total energy intake (Table 7.1) and fitness (peak power, peak  $\dot{V}O_2$  and anaerobic threshold, [Table 7.2]) were matched between groups. Both groups displayed similar physiological responses to the three days of time trial efforts with no change in performance (average power output) or difference between age groups during the TT30 (Table 7.3). There were significant decreases in mean heart rate ( $p < 0.05$ ) for both groups across the three test days.

**Table 7.1: Anthropometric, training and dietary characteristics of veteran and young cyclists (mean  $\pm$  SD).**

| Group   | Age<br>(years) | Height<br>(m)   | Mass<br>(kg)   | Body fat<br>(%) | Weekly<br>cycle<br>training<br>(km) | Energy<br>intake<br>(kJ.day <sup>-1</sup> ) |
|---------|----------------|-----------------|----------------|-----------------|-------------------------------------|---|
| Veteran | $45 \pm 6^*$   | $1.79 \pm 0.06$ | $76.9 \pm 9.7$ | $11.6 \pm 3.2$  | $301 \pm 59$                        | $12953 \pm 1908$                            |
| Young   | $24 \pm 5$     | $1.80 \pm 0.07$ | $74.2 \pm 8.5$ | $11.2 \pm 4.5$  | $311 \pm 96$                        | $12723 \pm 3548$                            |

\* significant difference between groups,  $P < 0.05$  (Independent  $t$ -test).

**Table 7.2: Physiological fitness variables in young and veteran cyclists (mean  $\pm$  SD).**

| Group   | Peak Aerobic<br>Power<br>(watts) | Peak $\dot{V}O_2$<br>(ml.kg <sup>-1</sup> .min <sup>-1</sup> ) | Anaerobic Threshold<br>(% of $\dot{V}O_2$ peak) |
|---------|----------------------------------|--|---|
| Veteran | $320 \pm 41$                     | $57.3 \pm 4.3$   | $79 \pm 6$                                      |
| Young   | $322 \pm 49$                     | $58.7 \pm 5.0$   | $75 \pm 12$                                     |



**Table 7.3: Physiological responses and performance during three consecutive days (T1, T2, T3) of maximal cycling time trials in young (Y) and veteran (V) cyclists (mean  $\pm$  SD).**

|    | Average Power<br>(W.kg <sup>-1</sup> ) |                 | Average Heart Rate<br>(b.min <sup>-1</sup> ) |               | Average Blood<br>Lactate Concentration<br>(mmol.L <sup>-1</sup> ) |               |
|----|--|-----------------|--|---------------|---|---------------|
|    | V                                      | Y               | V  | Y             | V   | Y             |
| T1 | 3.44 $\pm$ 0.29                        | 3.58 $\pm$ 0.48 | 157 $\pm$ 14                                 | 161 $\pm$ 15  | 6.8 $\pm$ 1.8   | 6.4 $\pm$ 2.7 |
| T2 | 3.41 $\pm$ 0.24                        | 3.65 $\pm$ 0.43 | 154 $\pm$ 12                                 | 160 $\pm$ 13  | 5.8 $\pm$ 1.4   | 6.2 $\pm$ 2.0 |
| T3 | 3.43 $\pm$ 0.26                        | 3.65 $\pm$ 0.42 | 154 $\pm$ 12#                                | 158 $\pm$ 13# | 6.0 $\pm$ 1.8   | 5.6 $\pm$ 1.5 |

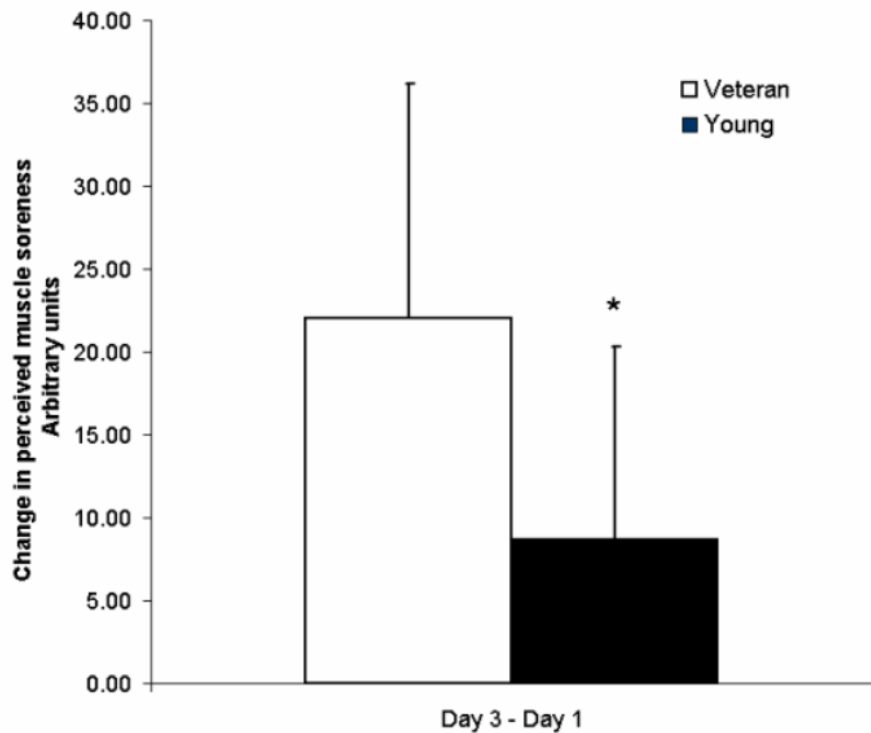
# significant within group change T1-T3,  $p < 0.05$  (repeated measures ANOVA).

For the measures for perceived fatigue and recovery there were changes in the mean value across the three days for both the young and veteran groups. These changes were statistically significant only for the veteran group (Table 7.4). The change in muscle soreness from T1 to T3 was significantly greater in the veteran than in the young group (Figure 7.1).

**Table 7.4: Motivation, perceptions of fatigue, and perceived quality of recovery (TQR) in veteran and young cyclists over three 30-minute laboratory time trials performed on consecutive days (T1, T2, T3). Values are in arbitrary units (mean  $\pm$  SD). Values in parenthesis are the scale for each parameter.**

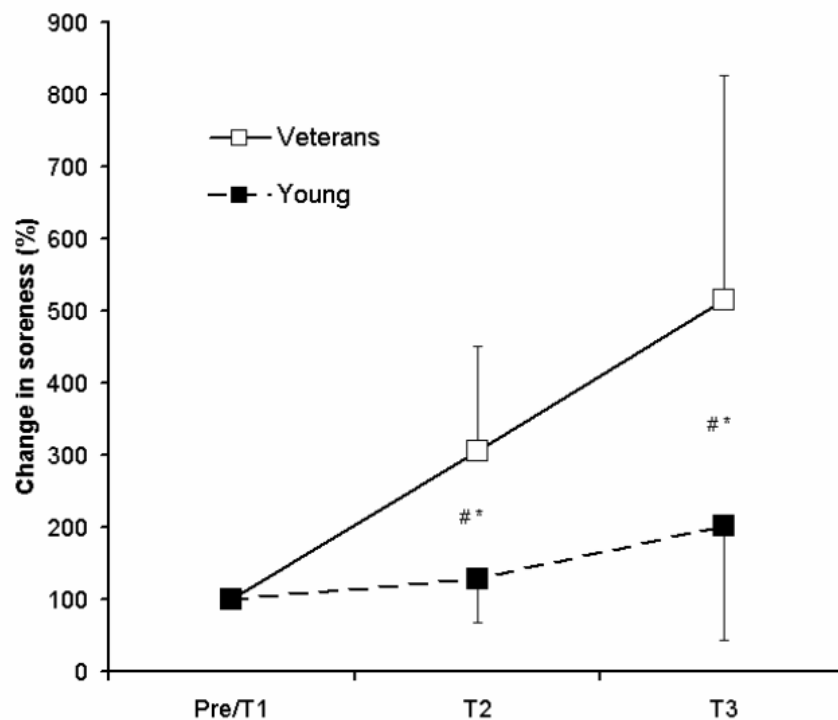
|    | Motivation<br>(1-4) |               | Fatigue<br>(0-5) |               | TQR<br>(6-20)   |                | Soreness<br>(1-100) |                 |
|----|---------------------|---------------|------------------|---------------|-----------------|----------------|---------------------|-----------------|
|    | V                   | Y             | V                | Y             | V               | Y              | V                   | Y               |
| T1 | 2.9 $\pm$ 0.6       | 3.0 $\pm$ 0.5 | 1.7 $\pm$ 1.2    | 1.7 $\pm$ 1.1 | 15.8 $\pm$ 2.5  | 16.3 $\pm$ 2.6 | 6.2 $\pm$ 5.2       | 15.4 $\pm$ 15.5 |
| T2 | 2.9 $\pm$ 0.6       | 3.0 $\pm$ 0.7 | 1.9 $\pm$ 0.8    | 1.8 $\pm$ 1.0 | 14.7 $\pm$ 1.7  | 15.4 $\pm$ 2.5 | 16.7 $\pm$ 12.4     | 19.9 $\pm$ 14.9 |
| T3 | 2.4 $\pm$ 0.9       | 2.9 $\pm$ 0.8 | 2.6 $\pm$ 0.9*   | 2.2 $\pm$ 0.9 | 13.8 $\pm$ 2.1* | 15.1 $\pm$ 2.9 | 28.2 $\pm$ 14.1*    | 24.2 $\pm$ 17.1 |

\* = significant change over T1-3,  $P < 0.05$  (Friedman's test).



**Figure 7.1: Change in pre time-trial perceived soreness (arbitrary units) of the legs from day one to day three in young and veteran cyclists. *a*, denotes significant difference between groups;  $p < 0.05$ , *t*-test).**

When soreness data was converted to represent a relative change from the baseline value reported on the first day (100%) there was a significant ( $p < 0.05$ ) time effect at day two and three as well as a group by time interaction with a significant difference between groups at each subsequent time point (Figure 7.2). The veteran group reported a 305 ( $\pm 146$ ) and 515 ( $\pm 311$ ) % increase in soreness at T2 and T3 respectively, while the change in soreness in the young group was 128 ( $\pm 61$ ) and 202 ( $\pm 158$ ) % at T2 and T3.



**Figure 7.2: Relative change in perceived soreness of the legs over three consecutive days of cycling time trial exercise in young and veteran cyclists; # denotes significantly within group change from baseline, \* denotes significant between group difference (Two-way ANOVA).**

## Discussion

The purpose of this study was to investigate the changes in physiological performance and the perception of soreness, fatigue and recovery in young and veteran cyclists over three consecutive days of intense endurance cycling time trial exercise. The main finding of this study is that although veteran athletes demonstrated a significant change in report of fatigue, soreness and quality of recovery, this was not accompanied by any decrement in physical performance. In contrast, the changes in these same perception measurements across the three days were not significant for the younger group. To our knowledge no previous study has reported a difference between

young and veteran well-trained subjects for the perception of soreness following a period of either acute or repeated days of intense endurance exercise.

The increase in reported ratings of fatigue and muscular soreness, together with the decrease in perceptions of recovery in the veteran group could be considered as indications of greater muscular damage or impaired recovery in the older group of athletes. This altered perception of recovery in the older athlete is in agreement with the view commonly expressed within the literature (363), supporting the suggestion of a need for alternative and more aggressive recovery strategies to be adopted by the ageing athlete. However, the alterations in perceived fatigue, muscle soreness and recovery were not accompanied by substantial evidence of physiological fatigue with cycling performance unaffected over the three days. Thus, it is speculated that for the age group and training status of subjects in this study, physiological recovery is not delayed in the veteran cyclists and the effect of age on recovery is merely a perceived impairment. This may be due to the fact that peak  $\dot{V}O_2$  and training volumes were matched in the subjects in the present study therefore physiological recovery is similar but neural fatigue/recovery may still be slower leading to the perceptual differences between age groups.

There is a possibility that differences in reported ratings of fatigue, muscular recovery and soreness in the older cohort in the present study are due to a self-fulfilling prophecy or 'Pygmalion' effect (145). The lack of apparent physiological fatigue as indicated by the maintained TT30 performance support this view. This would suggest that for these two groups matched for aerobic fitness levels, muscle damage and recovery was in fact not affected by age, but due to the commonly held belief that it

should be impaired. Alternatively, the potential for age-related physiological or neurological changes to influence perception and report of pain cannot be discounted.

Current knowledge of age-related differences and similarities in pain perception and pain mechanisms is extremely limited (179). Studies that have investigated differences in pain perception and report in different age groups have included clinical studies and laboratory based investigations. Although there is a paucity of high quality empirical investigations available, a recent review of the literature tentatively suggests that pain sensitivity may differ in adults of advanced age (178).

The limited and equivocal research on age differences in musculoskeletal pain make it difficult to explain the age-related differences in the present study (338, 467, 476). Supporting the findings of the present study, Wilkieson et al (467) found a significant increase in the reported severity of visual analogue scale rated pain in adults over 45 years of age suffering from rheumatoid arthritis when compared with younger adults. In contrast, Parker et al (338) reported the opposite relationship with a significant negative association between advancing age and self-reported pain intensity in rheumatoid arthritis sufferers. More recent studies have investigated age differences in the report of musculoskeletal pain in the neck, hip, back, and in fibromyalgia sufferers with disparate findings indicating the need for further investigation (179).

Complicating the findings of the present study, there is evidence that older adults have higher levels of pain tolerance (179). In studies of clinical pain perception, a reduction in intensity of post-operative pain per decade of advancing age has been suggested in those individuals over 60 years of age (426). In support of the argument for age-related alterations in pain threshold, laboratory studies using noxious stimuli such as temperature or mechanical stimulation to investigate pain threshold have also

found increased thresholds in older subjects with the weight of evidence supporting an age-related decline in pain sensitivity (178). However, age-related changes in pain threshold, often only measured at the cutaneous level, may not be transferable to deep tissue pain such as the ratings of muscle soreness reported in the present study (261). It appears that older individuals may have an increased response to higher intensity stimuli and a reduced tolerance of strong pain and post-injury pain and tenderness may resolve more slowly in older persons (179).

A possible cause for the reduced tolerance of strong pain and slower pain resolution in the elderly may be a result of impaired pain inhibitory systems. Washington et al. (464) examined differences in the magnitude of endogenous analgesic responses in young ( $n=15$ ; 22-27 years) and older ( $n=15$ ; 67-87 years) subjects and found the magnitude of analgesic response to be significantly less in persons of advanced age when compared with younger adults. A reduction in the efficiency of endogenous analgesic systems would make it more difficult for older adults to cope with severe or persistent pain states and may account for the different ratings of muscle soreness in the veteran cyclists over the three days of cycling time trials in the present study. An endogenous analgesic effect would theoretically occur in response to the DOMS experienced by subjects in this study and thus a blunted response as a consequence of age could impact upon report of perceived soreness by the veteran cyclists.

Previous work by Zheng et al. (482) also provide support for the findings of increases in pain ratings for the older group in the present study. These researchers found a slower resolution of capsaicin-induced hyperalgesia in an older ( $79.0 \pm 5.7$  years) group of volunteers compared with a younger group ( $25 \pm 4.6$  years), suggesting

that the slower resolution of mechanical hyperalgesia may reflect a reduced capacity of the ageing central nervous system to reverse the sensitisation process once it has been initiated. However, it should be noted that the average age of the veteran subjects in the present study ( $45 \pm 6$  years) is well below the age of the older subjects in the studies by Washington et al. (464) and Zheng et al. (482). Thus, it can only be speculated as to whether the impaired endogenous analgesic response or slower hyperalgesia resolution are applicable to this particular group of veteran cyclists and further research is warranted.

The above arguments for an altered perception and report of pain may be associated with differences in perceived exertion reported by young and ageing volunteers. In a recent fatigue study by Allman and Rice (5), older participants were found to rate their exertion higher than the young group during the early stages of an intermittent isometric contraction time-to-fatigue task even though final exertion and total time to fatigue were not different between groups. Such a finding supports the suggestion that while fatigue and effort may be similar between young and ageing subjects, the transmission and interpretation of the associated stimuli may in fact change with age. As a consequence, many of the measures of the perceived effects of the three days of time trial exercise changed significantly in the veteran cyclists but not the younger cycling group in the present study.

It should be noted that a limitation of these findings is the cross sectional nature of this investigation. It is difficult to suggest that the different response to the high-intensity endurance exercise of the older group in this study is a product of ageing per se or represents some other underlying difference between the two cohorts that is not a



direct result of ageing. A well-controlled longitudinal study would be the only method by which these findings could be confirmed.

In conclusion, the current data strongly suggest that for perception of pain and fatigue associated with high-intensity endurance exercise, ageing athletes demonstrate a greater perception of fatigue, muscle soreness and impaired recovery than younger similarly-trained cyclists. Moreover, the present data suggest that, despite maintenance of physical performance, older cyclists appear to subjectively recover more slowly than performance-matched younger cyclists following repeated days of high-intensity endurance exercise.

*This study has been submitted for review to The Journal of Pain.*

# **CHAPTER VIII:**

## **GENERAL**

### **DISCUSSION AND**

### **CONCLUSIONS**

This thesis has provided the first quantitative investigation into the effect of age on the rate of recovery from exercise representative of training and competition demands in the well-trained, ageing, endurance athlete. The widely held belief amongst athletes and coaches that ageing has a deleterious effect on the rate at which an athlete can recover from intense training and competition has been explored via survey, nutritional analyses, recovery of performance capacity, and the perception of recovery after repeated days of intense endurance exercise.

Commonly held perceptions amongst the athletic population regarding the effects of ageing on recovery have been presented with respect to post exercise symptoms, duration required to recover, effect of age on recovery, and strategies used to facilitate recovery. The dietary intake of a group of older athletes has been surveyed and, when compared with a similar population of young athletes, nutritional differences have been identified. The recovery of physical performance in response to three days of high-intensity endurance cycling exercise in two groups of training and performance-matched young and veteran athletes has been compared with no notable differences identified. Finally, this investigation has found that well-trained ageing athletes demonstrate differences in the perception and report of fatigue, muscle soreness and recovery when compared with performance-matched well-trained younger athletes.

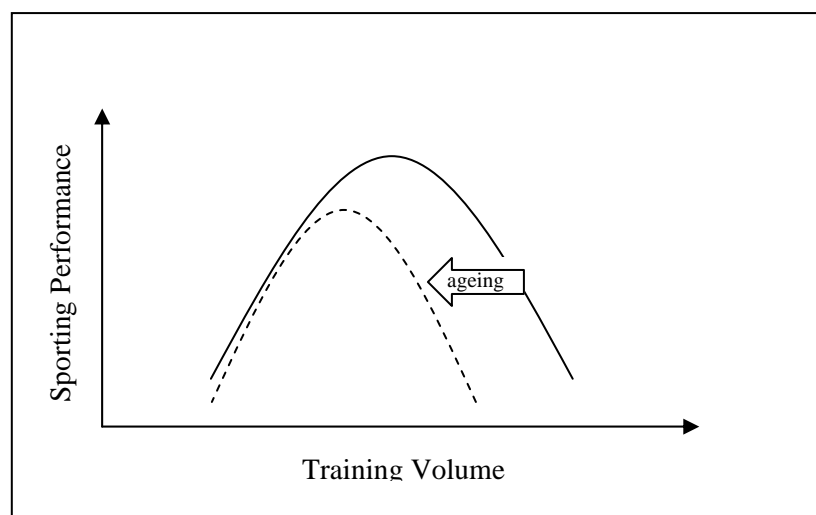
### ***Exercise Recovery Survey Findings***

The time reported for recovery after intense training or competition by the surveyed athletes that were aged 30 years and older supports the notion that recovery does take longer as a result of ageing. The mean recovery time reported by the young athletes of less than ten hours in comparison with the mean of sixteen hours reported by the 30+ athletes has implications for when multiple training sessions are completed in the one day (approximately 12 hours apart). In such a scenario, younger athletes could potentially fully recover between sessions while if older athletes have not recovered between training bouts they will begin the next exercise session while still experiencing residual fatigue. This difference in recovery duration may have two possible implications for training in the older athlete. The average frequency of training that can be undertaken by older athletes may be limited to a single training session each day. Alternatively, if a high frequency of training is still pursued by the older athlete, then the quality of training may be affected as training intensity is impaired due to an accumulation of fatigue.

The implications for decreasing the period of recovery between training sessions can be demonstrated by the work of Busso et al. (89, 90). These researchers used mathematical modelling of performance in response to variations in training input and found that the time needed to recover performance after a single training session increased from  $0.9 \pm 2.1$  days during low-frequency training, to  $3.6 \pm 2.0$  days when engaged in high-frequency training. Furthermore, the progressive gains in performance that could be achieved for a given training load decreased during high-frequency training. Previously untrained participants were found to require almost 24 hours between training sessions to realize optimal performance gains. This recovery time is substantially longer than the mean recovery period suggested by the athletes in the

present study (12-16 hours). However, the well-trained group of athletes in the present study should have substantially better exercise tolerance than the previously untrained group described in the initial study by Busso et al. (89). The argument that an increase in training frequency impacts upon recovery and performance, highlights the potential consequences that reduced recovery may have for the older athlete. Frequency of training may have to be substantially reduced to avoid excessive fatigue.

Busso et al. (89) demonstrated an inverted-U-shape relationship between daily amounts of training and performance (dose-response: see Figure 2.7) using mathematical modeling of actual training in six untrained males ( $32.7 \pm 5$  years). If delayed recovery as a result of ageing altered the dose-response curve then relationship between optimal amount of training and optimal performance gains would be reduced. Effectively, the curve would shift to the left and the reduced frequency of training for optimal results may lead to a decrease in amplitude of the curve (Figure 8.1). Such a scenario may present as a decline in both performance and in training volume, both of which have been identified within the ageing athlete (200, 351).



**Figure 8.1: Simplified ‘inverted-U’ dose-response curve of training and performance demonstrating the effect of impaired recovery as a result of ageing (broken line)**

In the present study there was a significant decline in training volume and frequency with age. The findings also indicated that with ageing there was a longer perceived duration required for complete recovery from training and competition. Noakes (327) argues that changes in training volume are due to the inability to recover as rapidly after each training session. However, from this study it is not possible to identify a cause-effect relationship for these two variables, training volume and recovery. Similarly, with respect to  $\dot{V}O_2$  max and age, other researchers have identified the same conundrum, indicating an inability to elucidate whether the decrease in training volume and intensity with age causes  $\dot{V}O_2$  max to be reduced or, alternatively, with the age-related reduction in  $\dot{V}O_2$  max, perception of exercise difficulty is increased and training volume and intensity are consequently decreased (351). The role that recovery from exercise plays in the age-related decreases in performance and training still remains unclear. Physiological recovery processes are essential for adaptation from physical training (241) and to enable continued training. An age-related impairment of recovery may be a substantial contributor to the age-associated reductions in training and volume described above.

The survey conducted in this investigation found a significant difference in the estimated time taken to recover from training and competition between young and ageing athletes. However, an awareness or perception of a slower recovery from exercise in the ageing athlete still fails to quantify the extent to which recovery is actually affected by age. An overall awareness of the importance of recovery to athletic performance amongst the surveyed athletes is the likely reason that more than 75% reported the use of some form of strategy to help enhance recovery. Considering the limited amount of quality research to confirm the efficacy of many of the recovery

strategies reported (191), the finding that only 25% of the sampled athletes reported the use of dietary practices as a method of enhancing recovery from training or competition raises questions as to dissemination of nutritional information to athletes. Adequate energy intake and the timing of energy intake post exercise have been demonstrated as fundamental to optimising recovery from exercise (76, 98, 267). Therefore, if recovery is impaired as a result of ageing it would seem imperative that the competitive ageing athlete optimise nutritional intake for enhanced recovery. The low percentage of athletes in the present study that reported the use of dietary practices to promote recovery suggests that this is not the case, highlighting the need for the investigation of dietary intake in a group of well-trained ageing athletes.

### ***Dietary Analysis***

The purpose of the dietary analysis was to provide general information as to the dietary intake of well-trained veteran athletes, and to compare this dietary intake with similarly-trained younger athletes. Differences between these groups in their dietary intake may identify possible causes of the age-related slower recovery from training and competition described in Chapter IV. Furthermore, comparison of the dietary intake of the veteran athletes in the current study with the RDI/RDA, and also with widely accepted guidelines for dietary intake in athletes, was intended to reveal or dispel possible causes for the age-related increase in recovery duration.

The two main findings from the dietary analysis were the significantly higher dietary fat intake in the veteran athletes compared with the young group, and the lower than recommended carbohydrate intake for both age groups. The first of these findings may have implications for overall health in the older group. The second finding has implication for achievement of optimal athletic performance in both age groups.

The dietary analysis revealed a higher percentage of energy intake provided by fat and the high mean intake of saturated fat in the veteran athletes compared with the young athletes in the present investigation. Whether this high proportion of dietary fat intake would have any influence on performance and recovery in these athletes requires further research. Overall dietary fat intake may have no effects on performance as long as adequate carbohydrate is being consumed with respect to the specific needs of the athlete (85). However, the health implication of this high fat dietary behaviour warrants discussion.

A high proportion of dietary fat in the form of saturated fat has been linked with greater risk of death from coronary heart disease (CHD), cancer and stroke (245). As such, the significantly higher proportion of dietary fat in the veteran athletes compared with the young athletes in the current study may lead to health complications later in life. The veteran athletes also had a mean intake of saturated fat in the 90<sup>th</sup> percentile for their age. However, the association between dietary saturated fat and CHD for males has recently been questioned as a result of a 16 year study of CHD mortality in Great Britain (52). Furthermore, whether this higher intake of saturated fat is likely to be as much of a health problem for the highly active subjects in the present study is also equivocal given that swimming exercise in rats has been shown to ameliorate many of the deleterious effects of a diet high in saturated fat (342). The high physical activity volume and intensity undertaken by the veteran athletes in the current study may provide a substantial protective effect from age-associated disease such as CHD (398). In contrast, recent research has provided a strong argument for the role of genes rather than an individual's physical activity level to dietary induced effects on plasma levels of low-density lipoprotein cholesterol (469). An alternative viewpoint may be that the high saturated fat intake in this well-trained group of athletes compared with the

population norms may simply be a reflection of a high overall energy intake due to the energy demands of training (362).

Difficulties in accurately estimating habitual dietary intake in free-living humans cannot be discounted as a potential cause of the significant difference between the two age groups in the present study (132). Age-related differences in the description of certain food types and in cooking methods may have contributed to the different percentage of fat intake between the young and veteran athletes. Alternatively, this difference may represent a cohort effect whereby dietary practices of young athletes have changed over time (85). The diet of the veteran athletes in the current study may be representative of the typical diet of young athletes 20 or 30 years ago. It is only possible to speculate at present as to the cause of the difference in fat intake between the groups in the present study.

The second major dietary finding from the present study was the low level of carbohydrate per kilogram of body mass consumed by the athletes in the present study. It is widely accepted that recovery and athletic performance are both dependent upon appropriate nutritional practices (98). Both the young and veteran groups investigated in the present study had mean CHO intakes below the recommended quantity for endurance athletes described by Burke et al. (85). Performance in subsequent exercise sessions may depend on the success of muscle glycogen restoration strategies (76, 223). However, despite low overall CHO intakes for both the young and veteran athletes in the present investigation, when these athletes were required to complete thirty minutes of endurance cycling time trial exercise (TT30) on repeated days they maintained their performance over the three test days (Chapter VI). The lack of any significant drop in



endurance performance over the three days supports the suggestion that muscle glycogen replenishment was not limited due to the diets of these athletes.

Muscle glycogen replenishment is significantly better during the first few hours after exercise when exogenous CHO is provided (226). Consequently, in Chapter VI to assist muscle glycogen synthesis the participants were provided with a high CHO breakfast after each TT30. Whether this feeding protocol benefited muscle glycogen level for the athletes in the present study is unknown. It has been demonstrated that as long as the total intake over the 24 hours post exercise is sufficient, muscle glycogen replenishment after prolonged exercise may not be effected by delaying the initial feeding of CHO for two hours after exercise (339). The question raised in the present investigation is whether the daily CHO intake of the young and veteran athletes was sufficient for optimal muscle glycogen restoration between bouts of endurance exercise. The daily CHO intake of 875g by the athletes in the study of Parkin et al. (339) was much higher than the mean daily intake of the young and veteran athletes in the present study ( $405 \pm 130$ g and  $389 \pm 136$ g, respectively), and there seems to be a minimum or threshold level of daily CHO intake ( $525\text{--}648 \text{ g}\cdot\text{day}^{-1}$ ) necessary to ensure complete restoration of muscle glycogen (76, 126).

It could be argued that the low habitual CHO intake per gram of body mass in the athletes in the present study may lead to chronic limitations of muscle glycogen and endurance performance. It is possible that muscle glycogen may have been low at the beginning of the study before the first TT30. Theoretically, inadequate CHO intake during repeated days of exercise will lead to gradual depletion of muscle glycogen stores, and subsequent impairment of exercise endurance (76). In the present investigation the athletes were requested to avoid exercise for at least 24 hours prior to

participating in the study in an attempt to ensure optimum endurance performance during the first TT30. However, while muscle glycogen storage capacity can be achieved during 24 hours of recovery from prolonged exercise this appears to be dependent upon total CHO intake being above a threshold of 525-648 g over the 24 hour period (76, 126). This threshold value is well above the mean daily CHO intake recorded by the athletes in the present study (389-405 g.day<sup>-1</sup>). Consequently, it is feasible that these athletes, young and veteran, regularly fail to adequately restore muscle glycogen levels after intense daily endurance training and competition.

This above scenario of below threshold CHO intake could be argued as one of the reasons why there was no apparent decline in performance over the three days of endurance exercise tests, primarily due to a poor initial TT30 performance. However, while the current evidence supports that a high-CHO diet is the best dietary recommendation for endurance athletes (228), the literature does not strongly support the hypothesis that short-term or long-term reductions in dietary carbohydrate energy impairs training or athletic performance (402). Burke et al. (82) found that a mixed diet incorporating fat and protein did not influence muscle glycogen storage over 24 hours as long as total CHO intake is above the suggested threshold level. The athletes in the present study consumed a normal mixed diet of CHO, fat and protein, albeit with a lower than recommended CHO intake. Whether the normal mixed diet of the athletes in the present study provided sufficient energy for the replenishment of the muscle glycogen stores cannot be determined due to the lack of muscle biopsy data. Clearly these athletes were not meeting the recommended CHO intake of greater than 7 g.kgBM<sup>-1</sup>.day<sup>-1</sup> (85). However, there is also evidence that ingesting protein and carbohydrate together can enhance early muscle glycogen storage (225), and as such this may have assisted muscle glycogen replenishment and facilitated the maintenance

of endurance performance over the three days for the athletes in the present investigation.

From the dietary data provided by the athletes in the present investigation there was no clear evidence that the dietary intakes of the veteran athletes may lead to impaired recovery from training and competition. The higher percentage of energy intake from fats suggests this is an area requiring further research. Consumption of large amounts of fat may displace CHO rich food within the athlete's energy requirements and affect gastric comfort, thereby indirectly interfering with glycogen storage by promoting inadequate CHO intake (76). Both the young and veteran groups in the present study consumed less than the recommended dietary intake for CHO. Whether the dietary intake of these athletes would have effected performance and recovery is arguable due to the apparent ability of athletes to adapt to long-term low CHO mixed diets with minimal impact on training or competition performance (228, 402). Exercise performance over consecutive days of intense endurance exercise was maintained by the athletes in the present investigation (Chapter VI). Considering these athletes consumed a mixed diet that would be considered to contain sub-optimal CHO amounts for endurance exercise indicates that there is a need for further research in this area whereby veteran athletes consume differing quantities of daily CHO during repeated days of intense endurance exercise.

### ***Fatigue and Recovery: Performance measures***

To quantify the degree to which recovery was impaired with age, and could potentially contribute to declines in training and performance, comparisons were made between fitness and training matched populations of young and veteran athletes. After subjecting these two groups of well-trained endurance athletes to three consecutive days

of high-intensity endurance exercise, greater reductions in both specific and non-specific performance tests were expected in the veteran group of athletes. However, the hypothesised performance declines were not evident. There are several factors that may have contributed to absence of any performance decline in the young and veteran athletes in this study. These include the inherent variability of the test protocols (218), the possibility that the study design was not severe enough to elicit measurable fatigue and impairment of recovery, and the variability between individuals evident when monitoring exercise induced fatigue and recovery capacity (127).

The variability of laboratory tests can sometimes limit the statistical identification of meaningful performance changes in an athletic population (218). Hopkins and Hewson (219) calculated that the coefficient of variability (CV) of an endurance test to detect the smallest worthwhile change in running performance for top runners should be less than 1.5% to 2.5%, the range being dependent on the length of the test. However, Hopkins et al. (220) have previously reported that the CV for mean power in cycle ergometers tests can be in excess of 4% and as such test 'noise' could mask any changes in performance that were occurring. In the current investigation the average CV for the thirty minute time trial (TT30) was 2.1%, with a technical error of measurement of 2.2%. Therefore it was assumed that the TT30 was sensitive enough to detect a 5% reduction in performance and a 5% change would be greater than the normal performance variability in this well-trained population (219). Consequently, a 5% reduction in performance was considered the minimum detectable change that would be considered as clinically significant to the athletes in the present investigation.

Over the three days of testing the mean power output measured during the TT30 increased by 2.4% for the young group, but decreased by 0.3% for the veteran group.

These changes were both within the specified 5% minimum change, suggesting that there was no effect on performance capacity for either group. However, it is interesting to note that the mean power output was highest at T3 in the young group, while the veteran group mean was virtually unchanged over the three days. Hopkins et al. (220) emphasised the importance of a practice trial when assessing performance changes in athletes. These researchers described a 1.2% improvement in performance during a second performance test, but only 0.2% improvement in any subsequent trials. The lack of improvement in the veteran group may suggest non-statistical evidence of recovery impairment for this older group of athletes. Conversely, the lack of improvement from the first to second trial might be due to the greater competitive experience of the older group reducing performance variability. The latter suggestion is supported by the findings of Hopkins and Hewson (219) who found that for runners there was less variability in race times in older athletes with more experience.

An alternative hypothesis for the lack of change in TT30 performance over the three days may be due to the study design. The requirement for the athletes to abstain from any training other than the study protocols during the three days would have reduced the total volume normally performed while at the same time undertaking a high training intensity (time trials). Mujika and Padilla (321) have identified that the aim of a taper was to minimise cumulative fatigue while maintaining training adaptations and that this is best achieved by maintaining training intensity while reducing training volume. Therefore, it is possible that although the TT30 stressed the physiological systems and recovery mechanisms of both groups, the reduced training volume was actually providing a taper effect. The young cyclists in the present study improved 1.4% from T1 to T2 and a further 1% from T2 to T3. Although the learning effect mentioned above (220) is a plausible cause for this trend, the same changes were not

evident in the veteran athletes. Hence, the stable performance of the veteran group may have been a reflection of impaired recovery mechanisms limiting the potential for an improvement in TT30 performance due to a reduced training volume.

The maintenance of TT30 performance over T1-T3 in Chapter VI may have been a result of the TT30 not being sufficiently physically demanding, or that the period between time trials was sufficient to enable complete recovery. To account for the lack of change found in the present study, another option may have been to use a more demanding time trial protocol, continue the study for a further day/s, or decrease the time period between time-trials.

Based on the findings of Chapter IV, veteran athletes reported that the mean recovery duration from training or competition was sixteen hours. Therefore, it may have been more appropriate to test the athletes at twelve rather than 24 hour intervals. Twelve hours between exercise sessions may have been an appropriate representation of the intense training regimes typically undertaken by the competitive cyclists participating in the current study. However, the diurnal variation in performance, and some of the other measured variables (16), may have limited the interpretation and comparison of data from the TT30 obtained at different times of the day.

An alternative approach may have been to use a different and more demanding test protocol to measure performance and induce fatigue. A longer (one hour) time trial, the inclusion of extra endurance exercise prior to completing a time-trial (230), a more demanding performance test by including maximal sprint efforts punctuated by continued endurance work (310, 389), or a different exercise modality that may induce more muscle damage such as downhill running (294), may have been better for increasing the fatigue effect prolonging the recovery period.

Another option may have been to use an older cohort of veteran athletes (>50 year old) that may be more affected by any age-induced impairment of recovery. This choice would have assisted in identifying any difference between the age groups for recovery between sessions. However, if the age difference between groups was too large this would have made it more difficult to match the groups for training and performance. Pimentel et al. (351) found a greater rate of age-related declines in training volume and performance in endurance-trained after 50 years of age. Hence, a group of well-trained cyclists over 50 years old training and performance matched with a group of young cyclist may be difficult, if not impossible to achieve. Furthermore, in the present study the proposed age-related decline in recovery was evident as early as 30 years of age as indicated by the significant difference in reported recovery time between the <30 and 30+ groups in Chapter IV.

A third potential factor that may have prevented identifying impaired recovery for the older athletes in the current investigation is the evidence for substantial individual variability in recovery duration and capacity (303). The estimated time to recover from training and competition reported in the survey (Chapter IV) was between one and 24 hours for the young group, and between one and 48 or more hours in the older group. This finding demonstrates substantial individual variability in recovery duration in endurance-trained athletes. Similarly, McLester et al. (303) investigated the time course of muscular endurance recovery in young and ageing resistance-trained athletes and identified that while the mean time for performance to return to pre-exercise levels was 48 hours, there was large individual variation in the ability to recover between exercise bouts. The optimum recovery time for the participants in the study of McLester et al. (303) varied from 48 hours to in excess of 96 hours.

The common perception amongst the athletes in Chapter IV that the time taken for recovery is increased with age was not supported by the measurement of performance changes during repeated days of intense endurance exercise in Chapter VI. The lack of significant differences between the two age groups for a variety of performance measures indicates that the well-trained older endurance athletes in the current investigation were recovering from each exercise session equally as well as the young group. The findings from Study One and Study Three combined suggest that there may actually be age-related differences in the perception and report of fatigue rather than actual physiological fatigue limiting performance during recovery from training and competition.

### ***Fatigue and Recovery: Perception and Report***

One of the arguments for the lack of decline in performance over the three days of repeated time trials in the present investigation was that the methodology prevented the identification of performance changes. However, the significant changes in perception and report of muscle soreness over the three days provides the argument that the repeated days of TT30 exercise was generating feeling of fatigue and impaired recovery. Both groups appeared to be experiencing an increase in the feelings of soreness in the legs as a direct result of the training and testing protocols. However, these changes in apparent soreness had little to no impact on performance at either the specific or non-specific tests. Subjective complaints of muscle soreness and fatigue have been found to increase during periods of intensified training (334), and are often described as sensitive early markers of overtraining syndrome (450). However, it has been suggested that the most reliable diagnostic indicator of overreaching or overtraining is a decline in performance (193). In the present study increased subjective



ratings of muscle soreness and fatigue were not accompanied by any reduction in performance highlighting the difficulties associated with monitoring training in athletes (450).

The finding in the present investigation that subjective ratings of recovery and fatigue significantly changed over three days of intense endurance time-trial exercise in veteran but not young athletes, and the greater increase in reported muscle soreness in the veteran athletes, supports the argument that perception of training and recovery changes with age. While performance parameters remained unchanged, veteran athletes were reporting significant increases in fatigue and soreness and reduced ratings of recovery. The reason for this disassociation between perceived fatigue and athletic performance is unclear. In a recent review Cheung et al. (108) identified that delayed onset muscle soreness (DOMS) can impact upon a variety of parameters including joint kinematics, strength, power, muscle recruitment patterns and risk of injury. However, in the current study any changes in these parameters on response to DOMS had no impact on TT30 performance or any of the non-specific performance tests.

Recent studies have linked DOMS with alterations in running kinetics and efficiency after downhill running (64, 143), and duathlon racing (93), which may theoretically cause reductions in athletic performance. Braun & Dutto (64) also found that downhill running leads to elevated levels of blood lactate when performing at the same relative exercise intensity and suggested that this was an indication of a shift to more anaerobic glycolytic means of energy production. However, the current study found no performance reduction, to suggest impaired cycling efficiency, in conjunction with the DOMS. In contrast to the findings of Braun and Dutto (64), for the athletes in the current investigation cycling performance was maintained with no increase in blood

lactate concentration. This would imply that there were no changes in the relative contribution of the different energy pathways during the TT30.

The most likely cause for the above disassociation between perception and report of soreness and fatigue and athletic performance might be due to age-related changes in the perceptual experience of pain (178, 179). There has been substantial empirical research investigating age-associated alterations in many pain related parameters (195, 197, 338, 349, 473). However, there are no studies that have investigated these parameters in well-trained athletes or in response to exercise-induced pain associated with DOMS.

Early research identified that with age there is an increase in the pain threshold (445), but more recent work has elaborated on these findings. Although pain threshold may increase with ageing there appears to be reduced efficacy of endogenous analgesic systems (464), a decreased tolerance of pain once threshold has been reached (178) and a slower resolution of post-injury hyperalgesia (482). All of these suggested age-related changes in pain interpretation may have contributed to the change in perception and report of soreness by the veteran cyclists in the current study. However, drawing comparisons between the findings of the above age-related research and the perception of DOMS experienced by the athletes in this investigation is difficult. The above studies have used many different types of pain stimuli in an attempt to measure the effect of age on pain perception (electrical, pressure, chemical), and the older participants in these studies are often much older (>55 years) than the athletes tested in the present study. Furthermore, the well-trained veteran athletes investigated in the present study are less likely to be representative of the normal ageing population with respect to neural function due to their high level of fitness and strenuous training

regimes (314, 399). Consequently, although there is substantial evidence of age-related changes in the perception and report of pain (178, 179) that may provide support for the differences in DOMS found between the young and veteran athletes in this study, further research is required to confirm these differences in an older athletic population.

### ***Summary and Conclusions***

Through a series of four studies the present thesis has investigated the commonly held perception amongst athletes and coaches that with ageing, there is an unavoidable decline in recovery mechanisms. Prior to the present investigation only one published study has investigated recovery from exercise in trained older athletes (303). The present investigation has vigorously explored the effect of age on adaptation and recovery in well-trained endurance athletes via questionnaire, dietary analysis, physiological performance and perception of recovery.

Impaired recovery can have severe implications for the training and adaptation processes that are crucial for athletic improvement. Too much training with insufficient recovery between sessions can lead to a level of performance lower than expected (89), most probably due to the reaching of a dynamic ‘breaking point’ where adaptation suddenly becomes maladaptation (244). While this may be a problem for athletes of all ages, an age-associated impairment of recovery would make the veteran athlete more susceptible to reaching this ‘breaking point’. Consequently, impaired recovery may ultimately lead to a reduction in total training stimulus which would limit the adaptation response and performance gains/maintenance.

From the Recovery Questionnaire utilised in the present investigation it is evident that the self-reported duration for recovery from training and competition is greater in athletes 30 years and older. Furthermore, in support of the above suggestion

that training stimulus may need to be reduced with age, the average weekly volume of training was negatively correlated with age in the present investigation. Whether the delayed recovery duration reported by the older athletes in the present study is the result a reduced training volume or reduced training is due to delayed recovery cannot be answered.

It is generally accepted that ageing of a cell, tissue, or organ system, leads to gradual declines in function, susceptibility to disease and injury increases, and the ability to recover from disease or injury decreases (74). However, in the present investigation when well-trained older athletes that performed the same weekly training as a matched group of young athletes undertook consecutive days of high-intensity endurance exercise both groups recovered fully between exercise sessions as demonstrated by an absence of decline in endurance performance. In contrast, over these three days of intense endurance exercise the subjective ratings of soreness, fatigue and quality of recovery, significantly changed in the older athletes only. The older athletes also reported a significantly greater change in soreness than the younger athletes investigated.

Different justifications have been presented as to why recovery from exercise could be slowed with ageing. These include an altered hormonal environment (252), greater damage and slower repair of skeletal muscle (152), and unfavorable protein metabolism (480). However, regular training provides a crucial physiological stimulus to prevent systemic declines, and the ability to maintain habitual physical activity levels with advancing age appears to be a critical determinant of changes in physiological functional capacity (421). Most comparisons of how recovery from training and competition is affected by ageing have previously been influenced by the training status

of the subjects tested. The current investigation has attempted to control for the affect of training status (and age-associated detraining) by investigating recovery in well-trained ageing endurance athletes.

Previous research has identified that with increasing age, healing following soft-tissue injuries, surgical repair, and the reconstruction of bones, joints, tendons, and ligaments often requires more time (74), and that recovery of skeletal muscle function after exercise-induced damage is impaired (68, 299). The current study has provided new insight into whether this healing process is also impaired in response to normal exercise training and competition in a highly-active well-trained older population.

The common beliefs with regard to training induced fatigue and recovery, and the strategies utilised to overcome these effects have been described. Due to the importance of adequate nutrition in recovery from physical exercise, dietary intake in young and ageing athletes has also been compared. It appears that for athletes aged over 30 years there is an accepted view that recovery will be prolonged as a result of ageing. However, it is unlikely that this slower recovery is a direct result of dietary insufficiencies in comparison with younger athletes. Finally, repeated days of high-intensity endurance exercise do not lead to reduced performance and impaired recovery in well-trained older athletes. However, the perception and report of soreness, fatigue and recovery in response to such exercise does appear to be influenced by the ageing process.

In conclusion, the current investigation has found;

- There is a significant decrease in training frequency and volume with age in well-trained endurance athletes and this may be associated with a significantly longer perceived duration for complete recovery in athletes 30 years and older.

- The nutritional intake of well-trained veteran endurance athletes is adequate for daily energy expenditure. However, veteran athletes in the present study had a higher proportion of their energy intake in the form of fat than younger athletes and also had an intake of saturated fat in the 90<sup>th</sup> percentile of their population norms.
- Veteran athletes can recover equally well as young athletes during repeated days of 30-minutes of intense endurance time trial exercise as measured by performance variables.
- The change in perception and report of muscle soreness, fatigue and recovery is significantly greater in well-trained veteran athletes than in training and performance matched young athletes during repeated days of intense endurance exercise.

### ***Recommendations for future research***

Future research is required to further investigate recovery from training and competition in the well-trained ageing athlete;

- An overreaching study using training and performance matched young and veteran athletes may be a valid way to investigate the effect of age on physiological response and recovery.
- An investigation manipulating CHO intake before and during repeated days of intense exercise in veteran athletes has not been undertaken. Given the apparently low CHO intake compared to the suggested requirements in the athletes in this investigation, high CHO intake may lead to a substantial increase in performance and recovery and may compensate to a degree for the perceived slower recovery reported by these older athletes.

- The significantly greater change in muscle soreness reported by the veteran athletes in the present study could be monitored during an overreaching study as suggested above, or alternatively, in response to exercise known to generate substantial muscle soreness such as marathon race or downhill running.

### ***Publications and Presentations Completed During the Candidature***

Fell, J. W., Gaffney, P. T., Reaburn, P., Haseler, L. J., & Harrison, G. J. Performance during consecutive days of laboratory time-trials in young and veteran cyclists. Accepted for publication (April 2005), The Journal of Sports Medicine and Physical Fitness.

Fell, J. W., Reaburn, P. & Harrison, G. J. Differences in the report and perception of fatigue in young and veteran athletes. Submitted for review November 2005, The Journal of Pain.

Fell, J. W. & Williams, A. D. Recovery from exercise in the older athlete. Submitted for review December 2005, Canadian Journal of Applied Physiology.

Fell, J. (2003). Recovery – Are you looking after yourself? The Ultimate Challenge (The Official Publication of Triathlon Queensland), September 2003.

Fell, J. W. & Loveless, D. (2005). Muscle soreness after downhill running: a preliminary study into the influence of age on perceived soreness. Australian Conference of Science and Medicine in Sport. Melbourne, October 13-16.

Fell J., Haseler L. J., Gaffney, P. T., Reaburn, P. and Harrison G. J. (2004). The effect of three consecutive days of time trial testing on performance measures in young and veteran cyclists. 2004 Pre-Olympic Conference, Aristotle University, Thessaloniki-Greece, August 6-11.

Fell J., Haseler L. J., Gaffney, P. T., Reaburn, P. and Harrison G. J. (2004). Do veteran athletes need more warm up for optimal explosive power? Australian Association for Exercise and Sports Science 2004 National Conference. From research to practice. Queensland University of Technology, Brisbane, April 14-16.



## **APPENDICES**

### **APPENDIX A: EXERCISE RECOVERY QUESTIONNAIRE (sample)**

Contact: Jamie Fell  
0417 613 509

## Exercise Recovery Questionnaire



Thank you for your time in answering a few questions with regard to exercise and recovery. This questionnaire is designed to obtain your views on intense exercise and the duration it takes for full physical recovery. **Full physical recovery means that there would be no impairment of performance under race conditions.** Please take your time and answer all the questions below as accurately as possible.

Gender   Age  Years

How long have you been involved in competitive sport?  Years

What sports?

How many training sessions do you participate in each week?  /Week

What is the duration that you spend training each week?  Hours

### Recovery

After competition or a hard training session do you feel.. *(circle as many options as appropriate)*

Tired    Fatigued    Stiff    Sore    Sick    Other *(please indicate)*

While these feelings persist do you think they would affect your performance if you were required to race/train hard again?

In total, how long do these feelings last for? *(Circle nearest time period)*

Up to an hour    Six hours    12 hours    24 hours    48 hours or more

If you are over 30 years of age, does full recovery take longer than when you were in your teens or twenties?

Do you use any specific strategies to reduce the duration of recovery from intense exercise?

If 'yes', what methods do you use to promote recovery? *(eg. Massage, dietary supplements...)*

### Nutrition *(circle the most appropriate response)*

|   |  |
|---|--|
| I eat before training                         | <input type="text" value="never"/> <input type="text" value="seldom"/> <input type="text" value="sometimes"/> <input type="text" value="often"/> <input type="text" value="very often"/> <input type="text" value="always"/> |
| I eat before competition                      | <input type="text" value="never"/> <input type="text" value="seldom"/> <input type="text" value="sometimes"/> <input type="text" value="often"/> <input type="text" value="very often"/> <input type="text" value="always"/> |
| I eat or use a sport drink during training    | <input type="text" value="never"/> <input type="text" value="seldom"/> <input type="text" value="sometimes"/> <input type="text" value="often"/> <input type="text" value="very often"/> <input type="text" value="always"/> |
| I eat or use a sport drink during competition | <input type="text" value="never"/> <input type="text" value="seldom"/> <input type="text" value="sometimes"/> <input type="text" value="often"/> <input type="text" value="very often"/> <input type="text" value="always"/> |

### Cyclists only

|                      |   |                         |  |
|----------------------|---|-------------------------|--|
| Years cycling?       | <input type="text" value="...."/> Years | Longest ride each week? | <input type="text" value="....."/> km  |
| Kilometres per week? | <input type="text" value="....."/> km   | Fastest 40km            | <input type="text" value="....."/> min |
| Rides per week?      | <input type="text" value="....."/>      |                         |  |

If you average over 200 km per week, compete, would like to have your fitness and training thresholds measured in our study into the relationship between ageing and recovery please provide your name and a contact telephone number below.

|       |                 |
|-------|-----------------|
| Name: | Contact Number: |
|-------|-----------------|

## **APPENDIX B: FOOD RECORD**

### **Food Record Instructions**

#### **READ THE FOLLOWING INSTRUCTIONS CAREFULLY**

Record amounts of and description of ALL food and drink consumed over three consecutive days.

Record at the time of eating and NOT from memory at the end of the day.

If you have left the diary elsewhere, jot down what you ate and add it to the diary when you can.

Include all meals and snacks, e.g. biscuits, chocolate, sweets, ice-creams.

Include all the drinks, e.g. water, tea, coffee, beer, sports drinks, fruit juice.

Record any additions to foods such as sauces, dressings, gravy, pickles, sugar, honey or butter.

When eating a dish made of several ingredients e.g. casserole, record the ingredients on a separate page (on the notes page). Also give the approximate proportion of ingredients and the total number of servings per recipe.

#### **DESCRIBE FOODS ACCURATELY**

Record cooking methods, e.g. boiled, fried, baked etc. and list type and amount of fat or oil used for cooking.

|  |                    |             |
|--|--------------------|-------------|
| Record brand names and descriptions e.g. | Weetbix            | NOT cereal  |
|  | Trim milk          | NOT milk    |
|  | Ginger nut biscuit | NOT biscuit |
|  | Tip Top Hi Fibre   | NOT bread   |

Name the types of cheese, fish or meat (e.g. cheddar, flake fillet, topside mince)

#### **DESCRIBE THE AMOUNTS AS ACCURATELY AS POSSIBLE**

Following are suggestions on how to record amounts

In household measurements:

State the number of teaspoons, tablespoon, OR cups for foods such as vegetables, cereals, stewed fruit, spreads etc. *Note: use level metric measures. A metric tablespoon is 15ml – not the spoon you serve food with at the table.*

Weights marked on packages. Many foods have their weight marked on the packaging and this can be quoted, e.g. half a 425 g can of baked beans.

Bread – indicate the type of slice, ie. sandwich, medium toast, thick.

**IT IS VERY IMPORTANT THAT YOU DO NOT ADJUST WHAT YOU EAT AND DRINK BECAUSE YOU ARE KEEPING A RECORD. REMEMBER, WE ARE INTERESTED IN YOUR EATING HABITS NOT THE PERFECT DIET!!**

**Please leave the shaded columns blank**

**(Use the other side of this page for recording the ingredients, ingredient proportions and serving size of composite dishes such as casseroles, stir fries etc.**

**APPENDIX C: CALCULATIONS FOR  
ESTIMATION OF BASAL ENERGY  
EXPENDITURE/BASAL METABOLIC RATE**

## Harris Benedict Equations

Men:  $BEE \text{ (kJ/day)} = 4.18 \times (66 + (13.7 \times bm) + (5 \times h) - (6.8 \times a))$

Women  $BEE \text{ (kJ/day)} = 4.18 \times (655 + (9.6 \times bm) + (1.8 \times h) - (4.7 \times a))$

bm = body mass in kg, h = height in cm, a = age in years (Frankenfield et al., 1998)

## Schofield Equations

**Equations for estimating basal metabolic rate (BMR) in MJ/day from body weight (kg) of adults and children over the age of 10 years**

|         | Age (years) | Equation*         |
|---------|-------------|-------------------|
| Males   | 10-18       | $0.074wt + 2.754$ |
|         | 18-30       | $0.063wt + 2.896$ |
|         | 30-W        | $0.048wt + 3.653$ |
|         | over 60     | $0.049wt + 2.459$ |
| Females | 10-18       | $0.056wt + 2.898$ |
|         | 18-30       | $0.062wt + 2.036$ |
|         | 30-W        | $0.034wt + 3.538$ |
|         | Over 60     | $0.038wt + 2.755$ |

*Notes*

\* Equations taken from Schofield et al. (1985)

wt is body weight in kg; BMR value is in MJ/day

**Average daily energy expenditure of adults and children over the age of 10 at different levels of activity expressed as multiples of basal metabolic rate (BMR)**

| Daily energy expenditure as multiples of BMR |         |           |         |           |
|--|---------|-----------|---------|-----------|
|  | Males   |           | Females |           |
| Activity level                               | Average | (range)   | Average | (range)   |
| Bed rest                                     | 1.2     | (1.1-1.3) | 1.2     | (1.1-1.3) |
| Very sedentary                               | 1.3     | (1.2-1.4) | 1.3     | (1.2-1.4) |
| Sedentary/maintenance                        | 1.4     | (1.3-1.5) | 1.4     | (1.3-1.5) |
| Light  | 1.5     | (1.4-1.6) | 1 * 5   | (1.4-1.6) |
| Light-moderate                               | 1.7     | (1.6-1.8) | 1.6     | (1.5-1.7) |
| moderate                                     | 1.8     | (1.7-1.9) | 1.7     | (1.6-1.8) |
| Heavy  | 2.1     | (1.9-2.3) | 1.8     | (1.7-1.9) |
| Very heavy                                   | 2.3     | (2.0-2.6) | 2.0     | (1.8-2.2) |

(<http://www.nhmrc.gov.au/publications/diet/n6p4.htm#app2>, Retrieved 30<sup>th</sup> August 2005)

## **APPENDIX D: THE MODIFIED D-MAX LACTATE THRESHOLD**



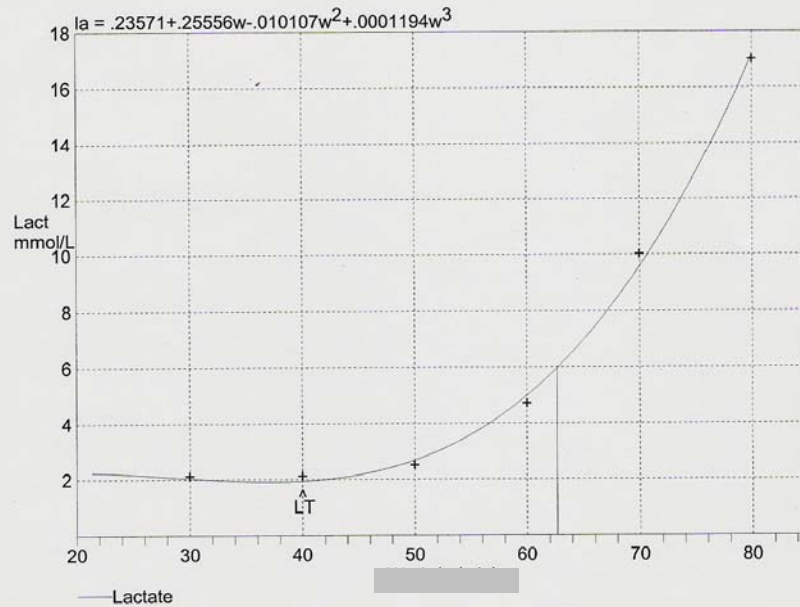
# ADAPT

Automatic Data Analysis for Progressive Tests

4/11/03 Q  
CYCLING (M)

Height: 176.1 cm  
Weight: 73.1 kg  
S'fold : mm

Temp: C  
Press: Hpa  
Dob: 25/07



## Training Heart Rates

lactate  
fit=1.  
U3 134-149  
U2 150-165  
U1 166-180  
AT 181-183  
Trans >183

## Heartrate & %VO2max

|     |     |
|-----|-----|
| 125 | 42  |
| 130 | 44  |
| 135 | 48  |
| 140 | 51  |
| 145 | 55  |
| 150 | 59  |
| 155 | 66  |
| 160 | 71  |
| 165 | 75  |
| 170 | 79  |
| 175 | 82  |
| 180 | 86  |
| 185 | 90  |
| 190 | 94  |
| 195 | 97  |
| 200 | 100 |

| At       | Work | Lact | vo2  | %vo2<br>max | hr  | %hr<br>max |
|----------|------|------|------|-------------|-----|------------|
| LT       | 40   | 2.1  | 2.69 | 59          | 150 | 75.        |
| AT(lact) | 63   | 6.   | 4.02 | 88          | 182 | 91.        |

VO2max (l/min) = 4.59  
VO2max (ml/kg/min) = 62.79

## **APPENDIX E: KOLMOGOROV-SMIRNOV TEST OF NORMALITY**

| <b>Tests of Normality: Recovery Survey (Study One)</b> |              |                           |           |             |
|--|--------------|---------------------------|-----------|-------------|
|  |              | <b>Kolmogorov-Smirnov</b> |           |             |
| <b>Variable</b>  | <b>GROUP</b> | <b>Statistic</b>          | <b>df</b> | <b>Sig.</b> |
| <b>age</b>   | Under30      | .184                      | 35        | <b>.004</b> |
|  | Over30       | .127                      | 58        | <b>.022</b> |
| <b>trgyears</b>  | Under30      | .104                      | 35        | .200        |
|  | Over30       | .145                      | 58        | <b>.004</b> |
| <b>trgsess</b>   | Under30      | .146                      | 35        | .056        |
|  | Over30       | .174                      | 58        | <b>.000</b> |
| <b>trgtime</b>   | Under30      | .206                      | 35        | <b>.001</b> |
|  | Over30       | .138                      | 58        | <b>.008</b> |
| <b>recovery duration</b>                               | Under30      | .218                      | 35        | <b>.000</b> |
|  | Over30       | .190                      | 58        | <b>.000</b> |
| <b>logtryrs</b>  | Under30      | .163                      | 35        | <b>.020</b> |
|  | Over30       | .167                      | 58        | <b>.000</b> |
| <b>logtrses</b>  | Under30      | .122                      | 35        | .200        |
|  | Over30       | .132                      | 58        | <b>.014</b> |
| <b>logtrtim</b>  | Under30      | .157                      | 35        | <b>.028</b> |
|  | Over30       | .131                      | 58        | <b>.015</b> |
| <b>logrecovery</b>                                     | Under30      | .197                      | 35        | <b>.001</b> |
|  | Over30       | .185                      | 58        | <b>.000</b> |

| Tests of Normality: Diet Study (Study Two) |         |                    |    |             |
|--|---------|--------------------|----|-------------|
|  |         | Kolmogorov-Smirnov |    |             |
| Variable                                   | GROUP   | Statistic          | df | Sig.        |
| HEIGHT                                     | young   | 0.18               | 10 | 0.20        |
|  | veteran | 0.15               | 14 | 0.20        |
| MASS                                       | young   | 0.24               | 10 | 0.12        |
|  | veteran | 0.13               | 14 | 0.20        |
| SCHOFIELD DEE                              | young   | 0.20               | 10 | 0.20        |
|  | veteran | 0.24               | 14 | <b>0.02</b> |
| H-B DEE                                    | young   | 0.18               | 10 | 0.20        |
|  | veteran | 0.20               | 14 | 0.12        |
| BMR Schofield                              | young   | 0.20               | 10 | 0.20        |
|  | veteran | 0.23               | 14 | <b>0.05</b> |
| EI/BMR                                     | young   | 0.16               | 10 | 0.20        |
|  | veteran | 0.22               | 14 | 0.08        |
| FOODMASS                                   | young   | 0.15               | 10 | 0.20        |
|  | veteran | 0.24               | 14 | <b>0.02</b> |
| EI   | young   | 0.16               | 10 | 0.20        |
|  | veteran | 0.22               | 14 | 0.06        |
| EI/DEE H-B                                 | young   | 0.15               | 10 | 0.20        |
|  | veteran | 0.27               | 14 | <b>0.01</b> |
| PROTEIN g                                  | young   | 0.21               | 10 | 0.20        |
|  | veteran | 0.24               | 14 | <b>0.02</b> |
| PROTEIN %                                  | young   | 0.13               | 10 | 0.20        |
|  | veteran | 0.17               | 14 | 0.20        |
| FAT g                                      | young   | 0.22               | 10 | 0.18        |
|  | veteran | 0.17               | 14 | 0.20        |
| SAT  | young   | 0.24               | 10 | 0.10        |
|  | veteran | 0.23               | 14 | <b>0.04</b> |
| POLY                                       | young   | 0.26               | 10 | 0.06        |
|  | veteran | 0.19               | 14 | 0.20        |
| MONO                                       | young   | 0.20               | 10 | 0.20        |
|  | veteran | 0.26               | 14 | <b>0.01</b> |
| FAT %                                      | young   | 0.18               | 10 | 0.20        |
|  | veteran | 0.13               | 14 | 0.20        |
| CHOLEST                                    | young   | 0.22               | 10 | 0.17        |
|  | veteran | 0.14               | 14 | 0.20        |
| CHO g                                      | young   | 0.21               | 10 | 0.20        |
|  | veteran | 0.24               | 14 | <b>0.03</b> |
| SUGAR                                      | young   | 0.22               | 10 | 0.19        |
|  | veteran | 0.15               | 14 | 0.20        |
| STARCH                                     | young   | 0.14               | 10 | 0.20        |
|  | veteran | 0.21               | 14 | 0.09        |
| CHO %                                      | young   | 0.10               | 10 | 0.20        |
|  | veteran | 0.16               | 14 | 0.20        |
| H <sub>2</sub> O                           | young   | 0.24               | 10 | 0.10        |
|  | veteran | 0.21               | 14 | 0.09        |
| Continued....                              |         |                    |    |             |

| Tests of Normality: Diet Study (cont.) |         |           |    |             |
|--|---------|-----------|----|-------------|
| Variable                               | group   | statistic | df | Sig         |
| ALCOHOL                                | young   | 0.48      | 10 | <b>0.00</b> |
|  | veteran | 0.36      | 14 | <b>0.00</b> |
| ALCOHOL %                              | young   | 0.48      | 10 | <b>0.00</b> |
|  | veteran | 0.40      | 14 | <b>0.00</b> |
| FIBRE                                  | young   | 0.29      | 10 | <b>0.02</b> |
|  | veteran | 0.19      | 14 | 0.19        |
| THIAMIN                                | young   | 0.26      | 10 | <b>0.05</b> |
|  | veteran | 0.25      | 14 | <b>0.02</b> |
| RIBOFLAVIN                             | young   | 0.22      | 10 | 0.19        |
|  | veteran | 0.21      | 14 | 0.10        |
| NIACIN                                 | young   | 0.28      | 10 | <b>0.02</b> |
|  | veteran | 0.16      | 14 | 0.20        |
| NIAC EQIV                              | young   | 0.28      | 10 | <b>0.02</b> |
|  | veteran | 0.22      | 14 | 0.08        |
| VITAMIN C                              | young   | 0.23      | 10 | 0.13        |
|  | veteran | 0.18      | 14 | 0.20        |
| FOLATE                                 | young   | 0.23      | 10 | 0.14        |
|  | veteran | 0.16      | 14 | 0.20        |
| VITAMIN A                              | young   | 0.19      | 10 | 0.20        |
|  | veteran | 0.28      | 14 | <b>0.00</b> |
| RETINOL                                | young   | 0.21      | 10 | 0.20        |
|  | veteran | 0.22      | 14 | <b>0.06</b> |
| BETA CAROTENE                          | young   | 0.27      | 10 | <b>0.03</b> |
|  | veteran | 0.17      | 14 | 0.20        |
| Na                                     | young   | 0.17      | 10 | 0.20        |
|  | veteran | 0.14      | 14 | 0.20        |
| K                                      | young   | 0.32      | 10 | <b>0.00</b> |
|  | veteran | 0.12      | 14 | 0.20        |
| Mg                                     | young   | 0.19      | 10 | 0.20        |
|  | veteran | 0.17      | 14 | 0.20        |
| Ca                                     | young   | 0.20      | 10 | 0.20        |
|  | veteran | 0.16      | 14 | 0.20        |
| Ph                                     | young   | 0.28      | 10 | <b>0.03</b> |
|  | veteran | 0.15      | 14 | 0.20        |
| Fe                                     | young   | 0.20      | 10 | 0.20        |
|  | veteran | 0.18      | 14 | 0.20        |
| Zn                                     | young   | 0.19      | 10 | 0.20        |
|  | veteran | 0.12      | 14 | 0.20        |

| Tests of Normality: Performance Study (Study Three) |         |                    |    |             |
|---|---------|--------------------|----|-------------|
|   |         | Kolmogorov-Smirnov |    |             |
| Variable  | GROUP   | Statistic          | df | Sig.        |
| VJ pre  | young   | .195               | 20 | <b>.045</b> |
|   | veteran | .135               | 14 | .200        |
| MVIC pre  | young   | .116               | 20 | .200        |
|   | veteran | .247               | 14 | <b>.021</b> |
| 10ST W pre  | young   | .136               | 20 | .200        |
|   | veteran | .183               | 14 | .200        |
| 10ST kJ pre   | young   | .160               | 20 | .195        |
|   | veteran | .195               | 14 | .155        |
| VJ post   | young   | .228               | 20 | <b>.008</b> |
|   | veteran | .217               | 14 | .072        |
| MVIC post   | young   | .116               | 20 | .200        |
|   | veteran | .184               | 14 | .200        |
| MVIC N.kg <sup>-1</sup> pre                         | young   | .207               | 20 | <b>.024</b> |
|   | veteran | .122               | 14 | .200        |
| 10ST W post   | young   | .141               | 20 | .200        |
|   | veteran | .219               | 14 | .067        |
| TT30 watts  | young   | .160               | 20 | .192        |
|   | veteran | .206               | 14 | .112        |
| TT30 hr   | young   | .131               | 20 | .200        |
|   | veteran | .215               | 14 | .079        |
| TT30 lact   | young   | .092               | 20 | .200        |
|   | veteran | .243               | 14 | <b>.024</b> |
| TT30 w.kg <sup>-1</sup>                             | young   | .135               | 20 | .200        |
|   | veteran | .277               | 14 | <b>.005</b> |
| CK  | young   | .167               | 20 | .147        |
|   | veteran | .208               | 14 | .102        |
| logCK   | young   | .119               | 20 | .200        |
|   | veteran | .136               | 14 | .200        |

| <b>Tests of Normality: Perception Study (Study Four)</b> |              |                           |           |             |
|--|--------------|---------------------------|-----------|-------------|
|  |              | <b>Kolmogorov-Smirnov</b> |           |             |
| <b>Variable</b>  | <b>GROUP</b> | <b>Statistic</b>          | <b>df</b> | <b>Sig.</b> |
| <b>motivation</b>  | young        | .301                      | 27        | <b>.000</b> |
|  | veteran      | .312                      | 26        | <b>.000</b> |
| <b>SOR pre</b>   | young        | .103                      | 27        | .200        |
|  | veteran      | .159                      | 26        | .088        |
| <b>fatigue</b>   | young        | .187                      | .301      | <b>.016</b> |
|  | veteran      | .200                      | 26        | <b>.009</b> |
| <b>TQR</b>   | young        | .186                      | 27        | <b>.018</b> |
|  | veteran      | .214                      | 26        | <b>.003</b> |
| <b>SOR post</b>  | young        | .122                      | 27        | .200        |
|  | veteran      | .160                      | 26        | .084        |
| <b>TT30 RPE</b>  | young        | .105                      | 27        | .200        |
|  | veteran      | .233                      | 26        | <b>.001</b> |
| <b>SOR change</b>  | young        | .098                      | 27        | .200        |
|  | veteran      | .153                      | 26        | .123        |

**APPENDIX F: DAILY DIETARY INTAKE IN  
YOUNG AND VETERAN CYCLISTS, RUNNERS  
AND MULTISPORT ATHLETES.**



| Sex | Subject | Group   | Sport   | Schof | H-B   | EI/ BMR | Energy | Protein |          | Fat |     |      |      |          | Choles | CHO |        |        |          |
|-----|---------|---------|---------|-------|-------|---------|--------|---------|----------|-----|-----|------|------|----------|--------|-----|--------|--------|----------|
|     |         |         |         | kJ    | kJ    |         | kJ     | g       | % intake | g   | Sat | Poly | Mono | % intake | g      | g   | Sugars | Starch | % intake |
| m   | V1      | veteran | Cyclist | 12986 | 12650 | 1.94    | 14001  | 117     | 14       | 144 | 57  | 18   | 60   | 40       | 333    | 361 | 179    | 180    | 44       |
| f   | V2      | veteran | Cyclist | 9930  | 10028 | 2.04    | 11227  | 88      | 13       | 92  | 35  | 11   | 38   | 32       | 210    | 364 | 142    | 221    | 55       |
| m   | V3      | veteran | Cyclist | 14533 | 14605 | 1.38    | 11133  | 107     | 16       | 102 | 33  | 17   | 43   | 36       | 410    | 290 | 135    | 152    | 44       |
| m   | V4      | veteran | Multi   | 13366 | 13461 | 2.13    | 15853  | 118     | 13       | 137 | 57  | 23   | 42   | 34       | 113    | 491 | 222    | 247    | 53       |
| m   | V5      | veteran | Cyclist | 13211 | 12290 | 1.74    | 12739  | 122     | 16       | 112 | 40  | 17   | 42   | 34       | 489    | 374 | 206    | 165    | 50       |
| m   | V6      | veteran | Cyclist | 13453 | 12989 | 1.39    | 10355  | 124     | 20       | 70  | 28  | 8    | 28   | 26       | 363    | 322 | 134    | 185    | 53       |
| m   | V7      | veteran | Cyclist | 12995 | 12574 | 1.96    | 14165  | 239     | 29       | 151 | 33  | 29   | 60   | 42       | 674    | 252 | 100    | 122    | 30       |
| m   | V8      | veteran | Cyclist | 14248 | 14172 | 1.79    | 14148  | 157     | 19       | 133 | 50  | 16   | 56   | 37       | 476    | 333 | 157    | 174    | 40       |
| m   | V9      | veteran | Runner  | 12710 | 12570 | 2.57    | 18169  | 201     | 19       | 131 | 62  | 14   | 42   | 28       | 535    | 567 | 245    | 320    | 53       |
| m   | V10     | veteran | Runner  | 12381 | 11407 | 3.32    | 22835  | 227     | 17       | 216 | 106 | 24   | 71   | 37       | 560    | 636 | 297    | 334    | 47       |
| f   | V11     | veteran | Runner  | 9630  | 9363  | 1.62    | 8667   | 81      | 16       | 82  | 24  | 16   | 36   | 37       | 232    | 220 | 108    | 111    | 43       |
| m   | V12     | veteran | Runner  | 12001 | 11267 | 1.78    | 11900  | 132     | 19       | 83  | 26  | 12   | 36   | 27       | 592    | 382 | 190    | 191    | 55       |
| m   | V13     | veteran | Multi   | 13142 | 12816 | 3.21    | 23429  | 186     | 13       | 227 | 130 | 23   | 58   | 38       | 418    | 611 | 287    | 324    | 44       |
| m   | V14     | veteran | Multi   | 12822 | 12283 | 1.50    | 10707  | 125     | 20       | 118 | 53  | 13   | 42   | 43       | 479    | 242 | 112    | 128    | 38       |
| m   | Y1      | young   | Cyclist | 13933 | 14394 | 2.39    | 18495  | 224     | 21       | 167 | 74  | 14   | 64   | 35       | 761    | 483 | 191    | 273    | 44       |
| m   | Y2      | young   | Cyclist | 12470 | 12576 | 1.37    | 9516   | 98      | 18       | 79  | 33  | 9    | 29   | 32       | 280    | 279 | 106    | 170    | 50       |
| m   | Y3      | young   | Multi   | 14013 | 13489 | 1.58    | 12318  | 86      | 12       | 101 | 40  | 13   | 39   | 32       | 173    | 407 | 224    | 180    | 56       |
| m   | Y4      | young   | Multi   | 12629 | 12755 | 2.38    | 16674  | 163     | 17       | 130 | 32  | 33   | 52   | 30       | 811    | 514 | 266    | 245    | 52       |
| m   | Y5      | young   | Cyclist | 13502 | 13633 | 1.96    | 14689  | 135     | 16       | 126 | 55  | 18   | 43   | 33       | 356    | 444 | 222    | 222    | 51       |
| m   | Y6      | young   | Multi   | 13468 | 13456 | 1.75    | 13090  | 112     | 14       | 79  | 30  | 11   | 26   | 23       | 189    | 473 | 267    | 194    | 61       |
| f   | Y7      | young   | Multi   | 10885 | 11133 | 1.93    | 11643  | 92      | 13       | 82  | 31  | 13   | 29   | 28       | 381    | 409 | 237    | 169    | 60       |
| f   | Y8      | young   | Runner  | 10606 | 10672 | 1.49    | 8787   | 91      | 18       | 58  | 14  | 13   | 26   | 26       | 127    | 239 | 108    | 129    | 46       |
| f   | Y9      | young   | Multi   | 10551 | 10626 | 1.61    | 9417   | 91      | 17       | 86  | 20  | 25   | 35   | 36       | 161    | 192 | 117    | 71     | 35       |
| m   | Y10     | young   | Multi   | 14750 | 14745 | 1.85    | 15161  | 124     | 14       | 61  | 18  | 16   | 21   | 16       | 79     | 605 | 277    | 326    | 68       |
|     |         | Veteran | Mean    | 12672 | 12320 | 2.03    | 14238  | 145     | 17       | 129 | 52  | 17   | 47   | 35       | 420    | 389 | 180    | 204    | 46       |
|     |         |         | SD      | 1389  | 1436  | 0.61    | 4485   | 50      | 4        | 47  | 31  | 6    | 12   | 5        | 158    | 136 | 65     | 76     | 7        |
|     |         | Young   | Mean    | 12681 | 12748 | 1.83    | 12979  | 122     | 16       | 97  | 35  | 17   | 36   | 29       | 332    | 405 | 201    | 198    | 52       |
|     |         |         | SD      | 1529  | 1490  | 0.35    | 3270   | 43      | 3        | 35  | 18  | 7    | 14   | 6        | 258    | 130 | 68     | 73     | 9        |

| S     | Water | Alcohol |          | Fibre | Thia | Ribofl | Niacin | Niacin<br>equiv. | Vitamin<br>C | Total<br>Folate | Vit. A<br>equiv | Retinol | B<br>Carotene | Na   | K    | Mg  | Ca   | P    | Fe | Zn | CHO      | Protein  |
|-------|-------|---------|----------|-------|------|--------|--------|------------------|--------------|-----------------|-----------------|---------|---------------|------|------|-----|------|------|----|----|----------|----------|
|       | g     | g       | % intake | g     | mg   | mg     | mg     | mg               | mg           | ug              | ug              | ug      | ug            | mg   | mg   | mg  | mg   | mg   | mg | mg | g/kg/day | g/kg/day |
| V1    | 1775  | 12      | 2        | 40    | 2.7  | 2.8    | 32     | 59               | 125          | 443             | 1602            | 632     | 5800          | 2401 | 4711 | 649 | 1002 | 2415 | 23 | 17 | 4.9      | 1.6      |
| V2    | 1367  | 0       | 0        | 32    | 2.2  | 2.8    | 23     | 42               | 85           | 283             | 754             | 354     | 2387          | 2938 | 3452 | 455 | 900  | 1758 | 20 | 12 | 6.3      | 1.5      |
| V3    | 1215  | 12      | 3        | 44    | 2.3  | 2.1    | 34     | 55               | 180          | 457             | 555             | 188     | 2195          | 2261 | 4391 | 473 | 374  | 1708 | 21 | 14 | 3.1      | 1.2      |
| V4    | 2548  | 0       | 0        | 62    | 6.3  | 8.0    | 52     | 76               | 329          | 751             | 688             | 214     | 2835          | 5070 | 6913 | 762 | 1434 | 2792 | 27 | 20 | 6.2      | 1.5      |
| V5    | 1404  | 0       | 0        | 31    | 2.7  | 4.7    | 31     | 57               | 70           | 369             | 546             | 435     | 664           | 3760 | 5411 | 476 | 1452 | 2433 | 16 | 16 | 4.9      | 1.6      |
| V6    | 1240  | 0       | 0        | 22    | 3.7  | 4.3    | 35     | 59               | 156          | 431             | 880             | 309     | 3422          | 3040 | 4397 | 310 | 900  | 1736 | 19 | 16 | 4.0      | 1.6      |
| V7    | 1388  | 0       | 0        | 29    | 1.6  | 2.8    | 50     | 96               | 289          | 469             | 732             | 283     | 2710          | 2813 | 6558 | 692 | 1659 | 2809 | 36 | 22 | 3.4      | 3.2      |
| V8    | 1957  | 21      | 4        | 43    | 2.2  | 2.7    | 41     | 72               | 175          | 526             | 766             | 377     | 2338          | 3306 | 5649 | 559 | 1051 | 2515 | 21 | 19 | 3.8      | 1.8      |
| V9    | 4904  | 0       | 0        | 56    | 5.4  | 6.2    | 45     | 90               | 130          | 824             | 1850            | 849     | 6018          | 5279 | 6691 | 713 | 2291 | 3463 | 34 | 26 | 8.0      | 2.8      |
| V10   | 4878  | 0       | 0        | 52    | 5.4  | 4.7    | 60     | 108              | 230          | 546             | 1686            | 1046    | 3791          | 5719 | 5913 | 686 | 2215 | 3468 | 36 | 27 | 9.5      | 3.4      |
| V11   | 2446  | 13      | 4        | 27    | 1.3  | 1.8    | 19     | 34               | 152          | 233             | 602             | 349     | 1519          | 1684 | 3219 | 481 | 968  | 1685 | 14 | 11 | 4.1      | 1.5      |
| V12   | 3072  | 0       | 0        | 33    | 2.2  | 3.5    | 27     | 55               | 112          | 410             | 563             | 315     | 1483          | 3758 | 5326 | 503 | 1083 | 2123 | 19 | 19 | 6.1      | 2.1      |
| V13   | 4415  | 42      | 5        | 54    | 3.2  | 4.1    | 52     | 90               | 92           | 699             | 847             | 606     | 1437          | 4677 | 5482 | 857 | 1478 | 3520 | 32 | 25 | 8.0      | 2.4      |
| V14   | 1616  | 0       | 0        | 24    | 2.3  | 2.4    | 24     | 50               | 87           | 217             | 934             | 691     | 480           | 3829 | 4277 | 379 | 1415 | 2076 | 13 | 14 | 3.3      | 1.7      |
| Y1    | 1675  | 0       | 0        | 50    | 3.9  | 4.1    | 52     | 97               | 106          | 520             | 762             | 564     | 1180          | 6944 | 5790 | 571 | 1585 | 3370 | 33 | 29 | 6.3      | 2.9      |
| Y2    | 1012  | 0       | 0        | 27    | 2.9  | 3.5    | 28     | 48               | 40           | 503             | 835             | 359     | 2856          | 2788 | 3119 | 312 | 852  | 1605 | 21 | 16 | 4.4      | 1.5      |
| Y3    | 1513  | 0       | 0        | 36    | 2.3  | 2.2    | 19     | 36               | 33           | 430             | 388             | 249     | 814           | 2713 | 3365 | 344 | 1210 | 1843 | 19 | 13 | 5.2      | 1.1      |
| Y4    | 2244  | 0       | 0        | 54    | 7.8  | 7.8    | 38     | 75               | 518          | 665             | 1282            | 767     | 3070          | 4449 | 7191 | 681 | 1094 | 2379 | 27 | 23 | 7.9      | 2.5      |
| Y5    | 1974  | 0       | 0        | 32    | 2.8  | 3.2    | 30     | 57               | 202          | 585             | 990             | 635     | 2121          | 4231 | 4037 | 406 | 1753 | 2267 | 25 | 20 | 6.1      | 1.8      |
| Y6    | 2206  | 0       | 0        | 30    | 7.3  | 4.7    | 24     | 45               | 82           | 249             | 1572            | 303     | 7599          | 3673 | 4052 | 562 | 1686 | 1895 | 21 | 16 | 6.5      | 1.5      |
| Y7    | 1237  | 0       | 0        | 28    | 2.2  | 2.7    | 26     | 44               | 158          | 385             | 1750            | 322     | 8554          | 2598 | 3584 | 308 | 874  | 1806 | 16 | 11 | 6.3      | 1.4      |
| Y8    | 3139  | 29      | 10       | 25    | 1.8  | 3.1    | 25     | 44               | 59           | 475             | 416             | 78      | 2029          | 3274 | 3550 | 397 | 1082 | 1701 | 15 | 11 | 3.8      | 1.5      |
| Y9    | 4294  | 41      | 13       | 35    | 1.5  | 2.0    | 25     | 44               | 256          | 460             | 2636            | 203     | 14559         | 2115 | 4013 | 515 | 932  | 1786 | 17 | 13 | 3.1      | 1.5      |
| Y10   | 2301  | 0       | 0        | 77    | 6.7  | 8.3    | 56     | 83               | 101          | 1106            | 785             | 143     | 3853          | 4623 | 5861 | 914 | 1963 | 3290 | 39 | 22 | 7.2      | 1.5      |
| Vmean | 2445  | 7       | 1        | 39    | 3.1  | 3.8    | 38     | 67               | 158          | 475             | 929             | 475     | 2648          | 3610 | 5171 | 571 | 1302 | 2464 | 24 | 18 | 5.4      | 2.0      |
| V sd  | 1357  | 12      | 2        | 13    | 1.5  | 1.7    | 13     | 22               | 78           | 183             | 444             | 254     | 1672          | 1212 | 1151 | 157 | 520  | 670  | 8  | 5  | 2.0      | 0.7      |
| Ymean | 2160  | 7       | 2        | 40    | 3.9  | 4.2    | 32     | 57               | 156          | 538             | 1142            | 362     | 4664          | 3741 | 4456 | 501 | 1303 | 2194 | 23 | 17 | 5.7      | 1.7      |
| Y sd  | 966   | 15      | 5        | 16    | 2.4  | 2.2    | 12     | 20               | 146          | 229             | 690             | 224     | 4327          | 1411 | 1347 | 191 | 407  | 645  | 8  | 6  | 1.5      | 0.6      |

## Data not included in analyses

| EI below cut-off 1 |         |         |         | EI below cut-off 1 |       |         | EI below cut-off 1 |         |          | EI below cut-off 1 |     |      |      |          | EI below cut-off 1 |     |        |        |          |
|--------------------|---------|---------|---------|--------------------|-------|---------|--------------------|---------|----------|--------------------|-----|------|------|----------|--------------------|-----|--------|--------|----------|
| Sex                | Subject | Group   | Sport   | Schof              | H-B   | EI/ BMR | Energy             | Protein |          | Fat                |     |      |      |          | Choles             | CHO |        |        |          |
|                    |         |         |         | kJ                 | kJ    |         | kJ                 | g       | % intake | g                  | Sat | Poly | Mono | % intake | g                  | g   | Sugars | Starch | % intake |
| m                  | V15     | veteran | Runner  | 12537              | 12381 | 1.28    | 4126.78            | 111     | 21       | 61                 | 30  | 7    | 17   | 27       | 203                | 267 | 125    | 139    | 51       |
| f                  | V16     | veteran | Runner  | 11206              | 9786  | 1.19    | 1567.31            | 59      | 16       | 84                 | 32  | 11   | 36   | 51       | 135                | 126 | 45     | 81     | 34       |
| m                  | Y11     | young   | Cyclist | 15510              | 15620 | 1.30    | 2311.15            | 115     | 17       | 92                 | 42  | 11   | 30   | 32       | 316                | 337 | 155    | 144    | 51       |
| m                  | Y12     | young   | Runner  | 13702              | 12416 | 1.00    | 2746.4             | 98      | 23       | 25                 | 9   | 4    | 8    | 14       | 131                | 257 | 86     | 169    | 61       |
| m                  | Y13     | young   | Cyclist | 15449              | 14593 | 0.85    | 1846.5             | 56      | 14       | 35                 | 12  | 6    | 12   | 20       | 108                | 264 | 145    | 117    | 65       |

| S   | Water | Alcohol |          | Fibre | Thia | Ribofl | Niacin | Niacin equiv. | Vitamin C | Total Folate | Vit. A equiv | Retinol | B Carotene | Na   | K    | Mg  | Ca   | P    | Fe | Zn | CHO      | Protein  |
|-----|-------|---------|----------|-------|------|--------|--------|---------------|-----------|--------------|--------------|---------|------------|------|------|-----|------|------|----|----|----------|----------|
|     | g     | g       | % intake | g     | mg   | mg     | mg     | mg            | mg        | ug           | ug           | ug      | ug         | mg   | mg   | mg  | mg   | mg   | mg | mg | g/kg/day | g/kg/day |
| V15 | 3612  | 0       | 0        | 36    | 2.1  | 2.5    | 31     | 54            | 473       | 438          | 1073         | 82      | 5927       | 1594 | 5168 | 472 | 508  | 1595 | 20 | 15 | 3.9      | 1.6      |
| V16 | 1261  | 0       | 0        | 19    | 0.9  | 0.8    | 14     | 26            | 171       | 213          | 951          | 265     | 4100       | 1892 | 2276 | 241 | 660  | 990  | 8  | 8  | 2.4      | 1.1      |
| Y11 | 1407  | 0       | 0        | 18    | 1.6  | 1.9    | 16     | 39            | 22        | 242          | 862          | 588     | 1628       | 4640 | 2620 | 261 | 1385 | 1754 | 9  | 11 | 3.7      | 1.3      |
| Y12 | 2305  | 0       | 0        | 38    | 2.7  | 3.4    | 26     | 45            | 134       | 517          | 920          | 57      | 5164       | 2471 | 3232 | 434 | 1241 | 1882 | 15 | 13 | 3.7      | 1.4      |
| Y13 | 1117  | 0       | 0        | 25    | 1.8  | 1.6    | 16     | 27            | 71        | 321          | 443          | 186     | 1531       | 2549 | 3101 | 287 | 644  | 1014 | 13 | 7  | 3.2      | 0.7      |

## **APPENDIX G: BREAKFAST MENU**

**Breakfast menu during the three days of repeated time trial exercise**

| <b>Food</b>                 | <b>Regular Serve</b>  | <b>CHO content of regular serve</b> |
|-----------------------------|-----------------------|-------------------------------------|
| Orange Juice                | 1 glass, 200 mL       | 17 grams                            |
| Weet-bix                    | 2 biscuits, 30 grams  | 20.1 grams                          |
| Low fat milk                | ½ cup, 125 mL         | 8.2 grams                           |
| Vogels fruit and nut bread  | 2 slices, 85 grams    | 33.1 grams                          |
| Banana                      | medium, 150 grams     | 32.3 grams                          |
| Honey                       | 2 teaspoons, 15 grams | 12.5 grams                          |
| Strawberry Jam (100% fruit) | 2 teaspoons, 15 grams | 7.7 grams                           |
| Apricot Jam (100% fruit)    | 2 teaspoons, 15 grams | 7.7 grams                           |

**Typical breakfast**

2 glasses of orange juice

4 Weet-bix with milk and honey

2 slices of fruit and nut bread with honey or jam

1 banana

= ***160 grams of CHO***

All participants were encouraged to consume a minimum of 100 grams of CHO after each testing session.

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