Age-related changes in physical and perceptual markers of recovery following high-intensity interval cycle exercise

Borges, Nattai R.; Reaburn, Peter R.; Doering, Thomas M.; Argus, Christos K.; Driller, Matthew W.

Published in:
Experimental Aging Research

DOI:
10.1080/0361073X.2018.1477361

Age-related changes in physical and perceptual markers of recovery following high-intensity interval cycle exercise

Submission Type: Original work

Running Head: Effect of age on recovery following high-intensity interval exercise

Nattai R. Borges[1, 2]

Peter R. Reaburn[1]

Thomas M. Doering[1]

Christos K. Argus[3, 4]

Matthew W. Driller[5]

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

[2] *School of Environmental and Life Sciences, University of Newcastle, Ourimbah, Australia*

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

[4]*ACT Brumbies Rugby, Canberra, Australia*

[5]*School of Health, Sport and Human Performance, The University of Waikato, Hamilton, New Zealand*

Corresponding Author

✉ Dr Nattai Borges
School of Environmental and Life Sciences
University of Newcastle
10 Chittaway Road
Ourimbah NSW 2258
Australia
Phone: +61 2 4921 6659
Email: Nattai.Borges@newcastle.edu.au

Abstract Word Count: 262
Number of References: 30
Text-Only Word Count: 3866
Number of Figures and Tables: 4

Abstract

Background

The purpose of this study was to compare physical performance, perceptual and haematological markers of recovery in well-trained masters and young cyclists across 48 hrs following a bout of repeated high-intensity interval exercise.

Methods

Nine masters (mean ± SD; age = 55.6 ± 5.0 years) and eight young (age = 25.9 ± 3.0 years) cyclists performed a high-intensity interval exercise session consisting of 6 x 30 second intervals at 175% peak power output with 4.5 minutes rest between efforts. Maximal voluntary contraction (MVC), 10 sec sprint (10SST), thirty-minute time trial (30TT) performance, creatine kinase concentration (CK) and perceptual measures of motivation, total recovery, fatigue, and muscle soreness were collected at baseline and at standardised time points across the 48 hr recovery period.

Results

No significant group-time interactions were observed for performance of MVC, 10SST, 30TT and CK ($P > 0.05$). A significant reduction in 10SST peak power was found in both masters ($P = 0.002$) and young ($P = 0.003$) cyclists at 1 hour post-exercise, however, both groups physically recovered at similar rates. Neither group showed significant ($P > 0.05$) or practically meaningful increases in CK ($\%\Delta < 10\%$). A significant age-related difference was found for perceptual fatigue ($P = 0.01$) and analysis of effect size (ES) showed that perceptual recovery was delayed with masters cyclists reporting lower motivation (ES ±90%CI = 0.69 ±0.77, *moderate*), greater fatigue (ES = 0.75 ±0.93, *moderate*) and muscle soreness (ES = 0.61 ±0.70, *moderate*) after 48 hours of recovery.

Conclusion

The delay in perceived recovery may have negative effects on long-term participation to systematic training.

Keywords: Older athletes; masters athletes; interval cycling; fatigue; creatine kinase; exercise physiology

Introduction

The ability to recover quickly from a training stimulus allows an athlete to better maintain training intensities and maximise physiological adaptations (Barnett, 2006; Borges, Reaburn, Driller, & Argus, 2015). It has previously been suggested that the ability to recover from a training stimulus becomes impaired in a normal ageing population (Ploutz-Snyder, Giamis, Formikell, & Rosenbaum, 2001; Roth et al., 1999). However, previous studies comparing sedentary or apparently healthy young and older individuals fail to take into account the effect of an increasingly sedentary lifestyle on recovery capacities into older age (Breuer, Hallmann, Wicker, & Feiler, 2010).

Recently there has been increasing research interest in masters athletes who are defined as athletes who systematically train and compete in organised forms of competitive sport designed for older athletes (Lepers & Stapley, 2016; Reaburn & Dascombe, 2009). Through continued participation in competitive sports and systematic training, masters athletes have historically demonstrated the ability to reduce and limit the declines in physical performance that occur with aging (Bieuzen, Hausswirth, Louis, & Brisswalter, 2010; Fell, Haseler, Gaffney, Reaburn, & Harrison, 2006; Tanaka & Seals, 2008). The beneficial effect of continued participation in competitive sports and systematic training has also been demonstrated in the adaptive ability of masters athletes to recover from training stimuli, with the majority of investigations reporting no significant differences in recovery kinetics of masters and young athletes following exercise (Bieuzen et al., 2010; Borges et al., 2015; Darr, Bassett, Morgan, & Thomas, 1988; Easthope et al., 2010; Fell et al., 2006).

Despite the increasing volume of research investigating the recovery kinetics of masters athletes, the majority of previous research has involved quantifying recovery kinetics following either endurance- (Easthope et al., 2010; Fell et al., 2006; Fell, Reaburn, & Harrison, 2008) or resistance-based (Bieuzen et al., 2010) exercise. However, these studies may not relate to

masters athletes involved in sprint and high-intensity sports where repeated maximal efforts are required over a competition bout. Furthermore, masters athletes are regularly utilising high-intensity interval training (HIT) as a training method to improve aerobic and sprint performance (Hydren & Cohen, 2015; Laursen & Jenkins, 2002). Considering the increased metabolic demand of HIT (Gibala & McGee, 2008) a greater understanding of any recovery limitations following repeated high-intensity exercise bouts would be of importance to masters athletes aiming to optimise performance into older age. Additionally, considering the suggestion that recovery in masters athletes may be delayed when exercise induced muscle damage is present (Doering et al., 2016; Easthope et al., 2010), further knowledge of recovery rates following HIT with the higher metabolic demand, would further our current understanding of the extent that continued physical training can prevent declines in recovery rates following endurance type exercise. Hence, an investigation comparing the recovery kinetics of masters and young athletes following a bout of high-intensity interval exercise is warranted.

Therefore, the purpose of the present study was to compare physical performance, perceptual and haematological markers of recovery in well-trained masters and young cyclists following a bout of high-intensity interval exercise.

Methods

Overview

This study was divided into two segments; (i) preliminary testing consisting of two sessions separated by a minimum of 72 hrs and (ii) the experimental testing period consisting of three sessions held at the same time of day (± 2 hrs) over three consecutive days. All cycle exercise was performed on an electromagnetically braked cycle ergometer (Velotron, Racermate; Seattle, USA). A timeline of the present study is presented in Figure 1.

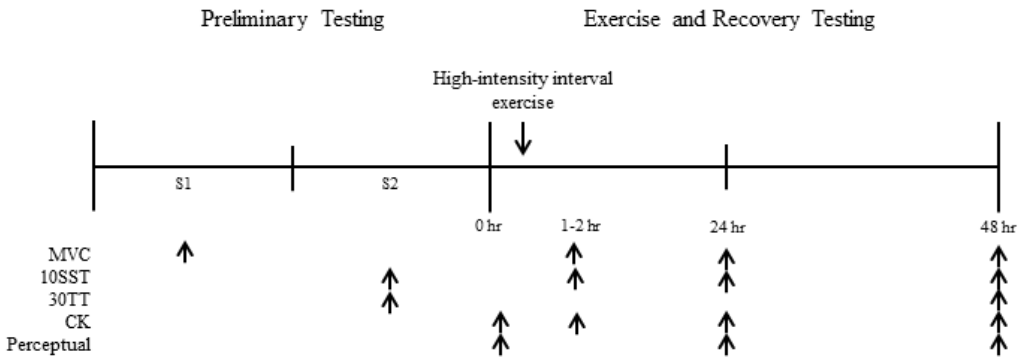

Figure 1 Timeline of the physical performance, perceptual and haematological measures of recovery during the experimental protocol. S1 = preliminary session 1; S2 = preliminary session 2

Subjects

Nine masters and eight young cyclists were recruited from local cycling and triathlon clubs. The participants' demographic data are presented in Table 1. To be eligible for the study all participants were required to be free from injury and medication that that may have affected their ability to perform exercise. Prior to inclusion all participants were informed about the potential risks and benefits of involvement in the study and were required to give written consent. Participants were matched on training volume (kilometres per week), maximal oxygen uptake ($\dot{V}O_2max$) and peak power output (PPO). The study was approved by the Central Queensland University Human Ethics Research Panel in accordance with the Helsinki Declaration.

Table 1 Mean ± standard deviation of demographic data for masters (n = 9) and young cyclists (n = 8)

	Masters (n = 9)	Young (n = 8)
Age (years)	55.6 ± 5.0†	25.9 ± 3.0
Mass (kg)	81.6 ± 8.5	79.1 ± 4.9
Height (cm)	178.9 ± 8.2	177.8 ± 5.8
Body fat (%)	10.6 ± 2.5	9.9 ± 1.3
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.2 ± 10.3	62.0 ± 9.8
PPO (W)	348.0 ± 29.9	364.2 ± 37.0
Relative PPO ($W \cdot kg^{-1}$)	4.3 ± 0.5	4.6 ± 0.5
Training per week (km)	228.0 ± 69.6	213.1 ± 128.7

PPO = maximal aerobic power. † Significant between-group difference (P < 0.05).

Preliminary Testing

During the first preliminary testing session, participants were familiarised with all exercise and testing protocols and procedures. Additionally, anthropometric profiles were collected using Harpenden skinfold calipers (British Indicators Ltd, Sussex, UK). Participants then performed a baseline maximal voluntary isometric contraction (MVC) and a graded maximal exercise test (GXT).

The GXT commenced after a standardised warm up of 6 minutes at 100 Watts (W). The GXT started at a workload of 150 W and increased by 50 W every 3 minutes until volitional exhaustion. Expired gas was continuously analysed throughout using an indirect calorimetry system (TrueOne 2400, Parvo Medics, Inc.; Sandy, USA) calibrated according to the manufacturer's instructions prior to each test. Peak gas exchange values and PPO were obtained from the GXT (Hawley & Noakes, 1992). Before the GXT commenced, seat and handle bar length, height and tilt and type of pedals were adjusted according to the preference of the participant and recorded for use in all future testing sessions. Participants were then

given a three-day food diary to complete before the second preliminary session, which was subsequently analysed using *Foodworks 7* software (Xyris software; Brisbane, Australia). Based off the diet analysis, diets were manipulated and participants were asked to follow a prescribed diet to ensure that over the three day recovery testing period participants consumed a standardised $5g \cdot kg^{-1} \cdot day^{-1}$ of carbohydrates and $2g \cdot kg^{-1} \cdot day^{-1}$ of protein each day (Reaburn, 2014). After a minimum of 72 hrs following the first preliminary testing session, participants returned to complete a 10-second sprint (10SST) and 30-minute time trial (30TT) on the cycle ergometer.

Exercise and Recovery Testing

The exercise and recovery testing was held a minimum of 72 hrs after the second preliminary session. The exercise testing consisted of a bout of HIT on the cycle ergometer. Recovery markers of physical performance were then measured at 1 hour, 24 hrs and 48 hrs following HIT, while 30TT performance was measured at 48 hrs post-HIT only.

Upon arrival at the first session of exercise and recovery testing, participants were required to complete baseline perceptual ratings of motivation (MOT), fatigue (FAT), total quality of recovery (TQR) and muscle soreness (SOR). A baseline venous blood sample (10 mL) was then collected from the ante-cubital region for subsequent analysis of baseline creatine kinase concentration (CK).

A 6-minute warm-up was performed on the cycle ergometer at 100 W with 3-second maximal accelerations at the end of the each of the final 3 minutes of the warm-up. Participants then rested for 3 minutes while seated on the cycle ergometer before the commencement of the HIT protocol, which was adapted from previously used HIT protocols (Buchheit, Abbiss, Peiffer, & Laursen, 2012; Burgomaster et al., 2008; Laursen, Shing, Peake, Coombes, & Jenkins, 2002). The HIT protocol consisted of 6 x 30-second exercise bouts at an intensity of 175% of PPO.

Each exercise bout was interspersed with 4.5 minutes of rest in which subjects were allowed two minutes of active recovery at a self-selected cadence with a resistance of 50 W. Upon completion of the HIT protocol participants immediately stepped off the cycle ergometer and lay supine on a massage table adjacent to the ergometer for a standardised passive recovery in a darkened quiet room for 40 minutes.

An hour following cessation of HIT participants underwent the same warm-up protocol and performed a 10SST, MVC and another blood sample was obtained. At the same time on the following two days (24 and 48 hrs post-exercise), participants returned to complete perceptual markers, perform a 10SST and MVC, and provide another venous blood sample. During the 48 hrs post-exercise session the participants again completed a 30TT after providing their final venous blood sample.

Physical Performance Measures

To monitor the recovery kinetics of physical performance; 10SST performance was monitored as a measure of sport-specific power development MVC as a measure of non-specific muscular strength, and 30TT as a measure of sport-specific endurance performance in that order.

The 10SST was performed using the cycle ergometer's Wingate software version 1.0 (Racermate, Inc., Seattle, USA) with a load equivalent to 9% of each participant's body mass, as per the manufacturer's instructions based from the original recommendations of Inbar et al., (1996). Participants underwent the same warm-up described above that occurred prior to the HITT session. Subsequently, participants were then counted into the test by the investigator and were instructed to remain on the seat for the duration of the test. Strong verbal encouragement was given throughout the test and both absolute peak power (W) and peak power relative to body mass ($W \cdot kg^{-1}$) were used for subsequent data analysis.

MVC was measured during a 3-second maximal isometric contraction (0 rads/s) of the knee extensors in a seated position with the knee at 90° of flexion using an isokinetic dynamometer (Biodex system II; Biodex Inc., Shirley, USA). Participants were securely strapped and instructed to keep their arms folded across their chest to reduce extraneous movements. The knee axis was aligned with the dynamometer axis and the ankle was strapped to the dynamometer arm. Participants were allowed three submaximal efforts at increasing intensity as a warm up prior to three maximal attempts with strong verbal encouragement. The attempt with the highest peak torque (Nm) was deemed their MVC and used for subsequent data analysis.

As a marker of endurance performance, a 30TT was performed during the 48 hrs post-exercise session. The software used in these evaluations (CompuTrainer 3D Software, Version 1, Racermate, Inc.; Seattle, USA) allowed a self-selected gear ratio to be used by each participant. Participants were familiarised with the gearing system during a 6-minute self-selected warm up prior to the 30TT. Participants were instructed to commence each 30TT in the same self-selected preferred gear but were allowed to freely change gears during the 30TT. Participants were blinded to their performance during the 30TT but were informed about the duration of the 30TT elapsed at 10, 20, 25, and 28 minutes. Average power output (W) during the 30-minute period was used for data analysis.

Perceptual Measures

To monitor the participant's perceptual response to the exercise stimulus and subsequent recovery, commonly used subjective measures of MOT, FAT, TQR and SOR were obtained using the methods previously described (Fell et al., 2008). These subjective measures were selected as they have previously been suggested to be influenced by exercise-related fatigue based off previous recommendations (Hooper & Mackinnon, 1995). In brief, subjective Likert

scales were used to monitor MOT, FAT and TQR, and a 100 mm visual analogue scale labelled "no soreness" on the left and "extremely sore" on the right was utilised to assess subject SOR. Participants were instructed to place a vertical line on the on the visual analogue scale which represented their subjective level of muscle soreness and the distance of the vertical line from the left side of the scale was measured in mm.

Haematological Measures

As a marker of muscle damage during the recovery period venous blood was collected and subsequently analysed for CK concentration ($U \cdot L^{-1}$). All venous blood samples were taken from the antecubital region with the participant in a supine position. Samples were collected into 10 mL serum separator tubes (Becton-Dickinson, Oxford, United Kingdom) which were centrifuged (15 minutes at 1300g) following 30 minutes resting at room temperature as per the manufacturer's instructions. Following centrifugation, the resultant serum was stored at -80°C until analysed for CK concentration using a multi-analyzer system (Cobas Integra 400, Roche Diagnostics; Basel, Switzerland).

Statistical Analysis

All data are presented as mean ± standard deviation (SD), or ±90% confidence intervals (CI). The distribution of all data was tested with the Kolmogorov-Smironov normality test. Data was also visually inspected for skewness and kurtosis via frequency distributions and P-P plots to ensure normal distribution. Between-group differences (young vs. masters) for demographic data were analyzed using independent t-tests. Separate two-way repeated measures ANOVA were used to detect interactions between groups (age) and time points (recovery) for each of the physical performance, perceptual and hematological markers of recovery. When significant group-time interactions or main effects were found, a Tukeys post-hoc test was used to identify between- and within-group differences. All statistical analyses were conducted using Statistica

software package (StatSoft. Inc., Tulsa, USA). Statistical significance was accepted at $P < 0.05$ level. Effect sizes (ES) were used to characterize the magnitude of difference between groups against the following criteria: *trivial* <0.20; *small* = 0.2-0.59; *moderate* = 0.60-1.19; *large* = 1.20-1.99; *very large* >2.0. When the 90%CI of the ES crossed the threshold of ±0.2, effect was deemed *unclear* (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results

No significant between-group differences were observed for demographic data except for age ($P < 0.001$). However, a *moderate* effect size was found for $\dot{V}O_{2max}$ (ES ±90%CI = 0.63 ±0.79) and relative PPO (ES ±90%CI = 0.65 ±0.81) with masters cyclists exhibiting a lower $\dot{V}O_2$max and relative PPO (Table 1).

The physical performance and haematological responses, percentage change, and ES of the between-group change of the masters and young cyclists during the 48-hour recovery period are presented in Table 2. No significant interaction effects were found for MVC ($P = 0.94$), 10SST ($P = 0.52$) and 30TT average power ($P = 0.40$). Additionally, no significant interaction effects were found when 10SST was calculated relative to body mass ($P = 0.52$). Significant main effects for time were observed for MVC ($F(3,45) = 3.032$, $P = 0.04$), 10SST ($F(3,45) = 13.031$, $P < 0.001$). Post hoc analyses found a significant decrease in 10SST for both masters ($P = 0.002$) and young ($P = 0.003$) cyclists from baseline to 1-hour post exercise. No other within- or between-group differences were observed in post hoc analyses. Additionally, no significant interaction or main effects were observed for CK across the 48-

Table 2 Mean ± standard deviation, percent change and effect sizes of performance and haematological markers of recovery for masters (*n* = 9) and young (*n* = 8) cyclists at baseline and during recovery following the high-intensity interval exercise.

	Baseline		**1 hr Post**		**24 hr Post**		**48 hr Post**	
	Masters	Young	Masters	Young	Masters	Young	Masters	Young
MVC (Nm)	225 ± 42	250 ± 43	207 ± 45	237 ± 47	215 ± 36	238 ± 45	214 ± 38	242 ± 34
%Δ			-7.8	-5.3	-4.5	-4.7	-5.0	-3.2
ES (±90%CI)			0.09 ±0.41 *Unclear*		0.04 ±0.47 *Unclear*		0.07 ±0.46 *Unclear*	
10SST (W)	1011 ± 73	1085 ± 117	955 ± 85*	1027 ± 110*	995 ± 92	1051 ± 105	990 ± 86	1075 ± 118
%Δ			-5.5	-5.3	-1.6	-3.2	-2.1	-1.0
ES (±90%CI)			0.02 ±0.36 *Unclear*		0.17 ±0.34 *Trivial*		0.09 ± 0.37 *Unclear*	
30TT (W)	232 ± 34	241 ± 25					230 ± 29	251 ± 25
%Δ							-0.9	3.8
ES (±90%CI)							0.22 ±0.43 *Unclear*	
CK ($U \cdot L^{-1}$)	161 ± 66	229 ± 92	170.7±70.2	249.6±101.5	178 ± 86	234 ± 73	147 ± 58	224 ± 95
%Δ			5.9	9.0	10.4	2.1	-8.9	-2.1
ES (±90%CI)			0.12 ±0.10 *Trivial*		0.14 ±0.52 *Unclear*		0.11 ±0.59 *Unclear*	

MVC = maximal voluntary contraction, 10SST = 10 second sprint, 30TT = thirty minute time trial, CK = Creatine Kinase, %Δ = percent change, ES = effect size of the between-group differences in the change from baseline value. *significantly different to baseline value. Significance accepted at P < 0.05 level.

hour recovery period. All ES comparisons for the between-group change from baseline values for physical performance and CK were *unclear* and *trivial* (Table 2).

The perceptual results showed no significant interaction effect for MOT (P = 0.69), TQR (P = 0.18) or SOR (P = 0.12) but a significant interaction effect for FAT (F(2,30) = 4.956, P = 0.01) was found. Significant main effects for time were observed for SOR (F(2,30) = 4.617, P = 0.02) and TQR (F(2,30) = 3.843, P = 0.03). However, post hoc analyses revealed no significant differences across time points or between groups (P > 0.05) (Figure 2). Effect size comparison of the between-group change from baseline revealed at the 24 hr response a higher FAT response in the young cyclists (ES = 1.29 ±1.17, *large)*. However, at the 48 hour time point *moderate* differences in ES were found with masters cyclists reporting lower MOT (ES = 0.69 ±0.77), greater FAT (ES = 0.75 ±0.93) and greater SOR (ES = 0.61 ±0.70) than the younger cyclists.

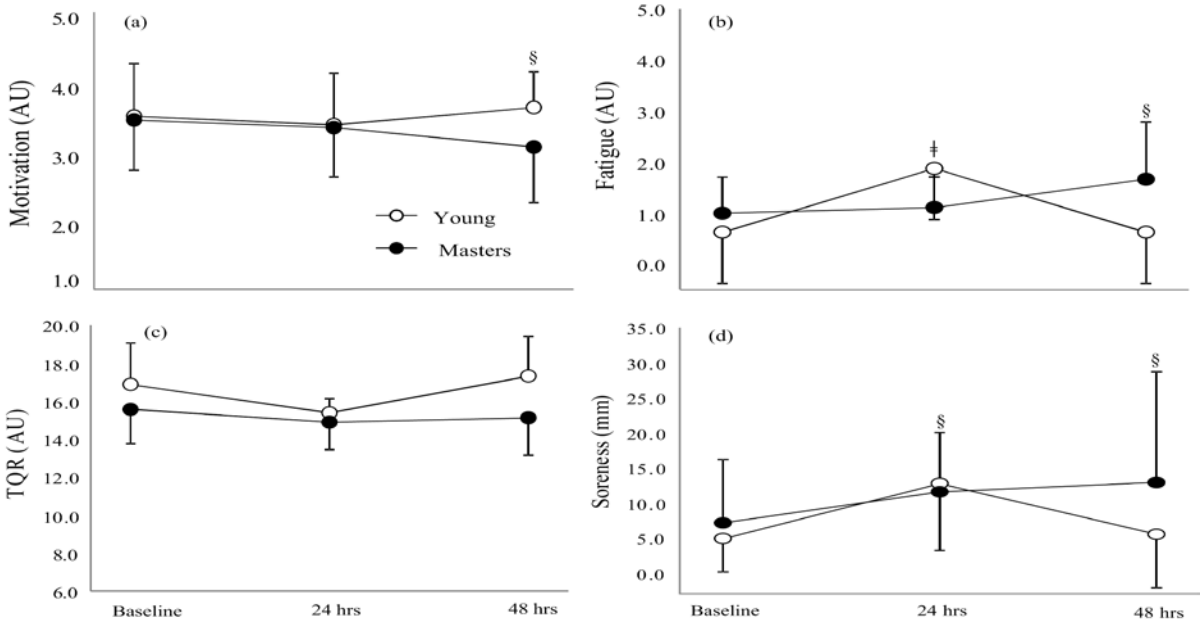

Figure 2 Perceptual measures of (a) motivation, (b) fatigue, (c) total quality of recovery (TQR) and (d) muscle soreness for masters and young cyclists at baseline, 24 and 48 hours post-exercise. § *moderate* effect size (ES = 0.60 – 1.19), ǂ *large* effect size (ES = 1.20 - 1.99) in the between-group difference from baseline

Discussion

The purpose of the present study was to compare physical performance, perceptual and haematological markers of recovery in well-trained masters and young cyclists following high-intensity interval exercise. The main findings of the present study were: (i) no significant age-related differences between young and masters cyclists in recovery of either sport-specific or non-specific physical performance following HIT (ii) a significant interaction effect for perceptual fatigue levels and between-group ES analysis showing lower reported motivation, and greater levels of fatigue and muscle soreness 48 hrs following a high-intensity exercise bout in the masters athletes, and (iii) no significant age-related differences in the CK response throughout the recovery period.

No significant age-related differences in the recovery of physical performance were found in the present study evidenced by the lack of significant group-time interactions for MVC, 10SST or 30TT. Acute fatigue effects were clearly demonstrated through the significant decrease in 10SST performance for both groups and decreases in MVC performance greater than 5% in both masters and young cyclists 1 hour following the high-intensity interval exercise protocol. Effect size analyses demonstrated *trivial* and *unclear* differences for the between-group change from baseline for all performance measures across the recovery period. These findings lead the authors to suggest that both the masters and young cyclists in the present study physically fatigued and recovered at similar rates following HIT.

Although the physical performance results of the present study are supported by previous investigations following endurance cycling (Fell et al., 2006) and resistance training exercise (Bieuzen et al., 2010), the results contrast those of a previous study that monitored MVC following a 55km trail run in young and masters ultra-endurance runners (Easthope et al., 2010). Easthope et al., (2010) observed a 24 hr delay in the recovery of muscle strength in the masters runners compared to the younger runners which could be attributed to the accumulated

eccentric load placed on the lower body musculature during the event. In contrast, the present study used cycling exercise that has minimal eccentric loading that has been linked consistently to muscle damage (Proske & Morgan, 2001). Thus the authors speculate that muscle-damaging exercise such as long-distance endurance running, in contrast to cycling, may lead to longer recovery times in older versus younger athletes. This suggestion has been recently been supported by evidence from our laboratory showing that protein synthesis rates were lower in masters triathletes than younger triathletes following exercise designed to induce muscle damage (Doering, Reaburn, Phillips, & Jenkins, 2015; Doering et al., 2016). Taken together, this evidence warrants further investigation into recovery kinetics of physical performance of masters athletes after exercise that specifically induces muscle damage to gain further insight into the recovery of physical performance of masters athletes.

Although similar recovery rates of physical performance were reported in the present study differences were observed in perceptual measures of recovery with a significant interaction observed in perceptual FAT ($P = 0.01$). Although post-hoc analyses did not reveal any significant between- or within-group differences for any perceptual recovery measure, visual inspection of the data (Figure 2) and ES analysis of the between-group change from baseline values demonstrates that the younger cyclists perceived greater FAT 24 post-exercise with a *large* associated ES (1.29 ±1.17). However, at the 48 hour time point the young cyclists' perceptual measures returned to baseline while the masters athletes exhibited increasing levels of perceived FAT (ES = 0.75 ±0.93) and SOR (ES = 0.61 ±0.70) as well as decreased MOT (ES = 0.69 ±0.77, *moderate*) compared to the younger cyclists. Although these differences were not significantly different ($P > 0.05$), the ES analysis suggest that at the 48-hour period the masters cyclists showed a delay in perceived recovery.

Age-related differences in perceived recovery have previously been reported by Fell et al. (2008) who showed masters cyclists reported significantly higher perceptual fatigue and

muscle soreness as well as poorer perceptual recovery compared to younger cyclists. A delayed perceptual recovery could have an effect on training practices and prolong an acute return to training in the masters cyclists. Interestingly, the lack of meaningful between-group physical performance differences during recovery between the masters and younger cyclists in the present study, despite differences in perceptual measures, suggests that although masters athletes may perceive greater levels of FAT, SOR and decreased MOT this may not have a direct meaningful influence on the recovery of physical performance.

Although the HIT protocol induced changes in perceptual SOR, values for CK remained unchanged for both masters and young cyclists in the present study (Table 2). This result suggests that the HIT session was not sufficient to induce significant muscle damage, which could be attributed to the largely concentric nature of cycle exercise. Nonetheless, there were no significant age-related differences found for CK with no significant interaction effect. Although, CK values were higher for the young cyclists it was deemed to be not practically significant with normal reference values for CK in athletes suggested to be 82 – 1083 $U \cdot L^{-1}$ (Mougios, 2007). Furthermore, previous studies reporting muscle damage in masters athletes have reported increases of 542% and 1050% of baseline CK values following marathon (Martin et al., 2015) and trail running (Easthope et al., 2010), which again, when compared to the 10% increase seen in the present study suggests that the CK values in the present study were not representative of exercise induced muscle damage. Finally, the current study supports previous research that showed similar CK concentrations (100 – 200 $U \cdot L^{-1}$) over three days of consecutive endurance cycling with no significant difference in the CK response of masters athletes and young cyclists (Fell et al., 2006).

Conclusion

The present study is the first to compare the physical, perceptual and haematological recovery kinetics in well-trained masters and young athletes following a bout of HIT. Although the masters athletes were relatively young (<55yrs) the results of the present study demonstrated that although the masters and young cyclists in this study exhibited similar recovery rates of physical performance when subjected to a bout of HIT, masters cyclists perceived a delay in recovery. The results of the present study suggest that coaches and masters athletes may have to allow for greater recovery durations between sessions to allow for psychological recovery in masters athletes. Additionally, these results warrant the use of perceptual measures when monitoring the training load of masters athletes as physiological measures alone may not be sensitive enough to quantify recovery in a masters cohort. Finally, greater care may be required when training incudes exercise related muscle damage as previous studies have suggested that this may lead to a delayed physical recovery in a masters cohort.

References

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes: does it help? *Sports Medicine, 36*(9), 781-796.

Bieuzen, F., Hausswirth, C., Louis, J., & Brisswalter, J. (2010). Age-related changes in neuromuscular function and performance following a high-intensity intermittent task in endurance-trained men. *Gerontology, 56*(1), 66-72. doi: 10.1159/000262286.

Borges, N., Reaburn, P., Driller, M., & Argus, C. (2016). Age-related changes in performance and recovery kinetics in masters athletes: a narrative review. *Journal of Aging and Physical Activity,* 24, 149-157.

Breuer, C., Hallmann, K., Wicker, P., & Feiler, S. (2010). Socio-economic patterns of sport demand and ageing. *European Reviews of Aging and Physical Activity, 7*(2), 61-70.

Buchheit, M., Abbiss, C. R., Peiffer, J. J., & Laursen, P. B. (2012). Performance and physiological responses during a sprint interval training session: relationships with muscle oxygenation and pulmonary oxygen uptake kinetics. *European Journal of Applied Physiology, 112*(2), 767-779. doi: 10.1007/s00421-011-2021-1.

Burgomaster, K. A., Howarth, K. R., Phillips, S. M., Rakobowchuk, M., Macdonald, M. J., McGee, S. L., & Gibala, M. J. (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *The Journal of Physiology, 586*(1), 151-160. doi: 10.1113/jphysiol.2007.142109.

Darr, K. C., Bassett, D. R., Morgan, B. J., & Thomas, D. P. (1988). Effects of age and training status on heart rate recovery after peak exercise. *The American Journal of Physiology, 254*(2 Pt 2), H340-H343.

Doering, T., Reaburn, P., Phillips, S., & Jenkins, D. (2015). Post-exercise dietary protein strategies to maximize skeletal muscle repair and remodeling in masters endurance

athletes: a review. *International Journal of Sport Nutrition and Exercise Metabolism. 26*(2), 168-178.

Doering, T. M., Jenkins, D. G., Reaburn, P. R., Borges, N. R., Hohmann, E., & Phillips, S. M. (2016). Lower integrated muscle protein synthesis in masters compared to younger athletes. *Medicine and Science in Sports and Exercise. 48*(8), 1613-1618.

Easthope, C. S., Hausswirth, C., Louis, J., Lepers, R., Vercruyssen, F., & Brisswalter, J. (2010). Effects of a trail running competition on muscular performance and efficiency in well-trained young and master athletes. *European Journal of Applied Physiology, 110*(6), 1107-1116.

Fell, J., Haseler, L., Gaffney, P., Reaburn, P., & Harrison, G. (2006). Performance during consecutive days of laboratory time-trials in young and veteran cyclists. *Journal of Sports Medicine and Physical Fitness, 46*(3), 395-402.

Fell, J., Reaburn, P., & Harrison, G. (2008). Altered perception and report of fatigue and recovery in veteran athletes. *Journal of Sports Medicine and Physical Fitness, 48*(2), 272-277.

Gibala, M. J., & McGee, S. L. (2008). Metabolic adaptations to short-term high-intensity interval training: a little pain for a lot of gain?. *Exercise and Sport Sciences Reviews, 36*(2), 58-63.

Hawley, J., & Noakes, T. (1992). Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. *European Journal of Applied Physiology and Occupational Physiology, 65*(1), 79-83. doi: 10.1007/BF01466278.

Hooper, S. L., & Mackinnon, L. T. (1995). Monitoring overtraining in athletes. *Sports Medicine, 20*(5), 321-327.

Hopkins, W., Marshall, S., Batterham A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-12.

Hydren, J. R., & Cohen, B. S. (2015). Current scientific evidence for a polarized cardiovascular endurance training model. *The Journal of Strength and Conditioning Research, 29*(12), 3523-3530. doi: 10.1519/jsc.0000000000001197.

Inbar, O., Bar-Or, O., & Skinner, J. (1996). The Wingate anaerobic test: development, characteristics, and application. *Champaign (IL): Human Kinetics*.

Laursen, P. B., & Jenkins D. G. (2002). The scientific basis for high-intensity interval training. *Sports Medicine, 32*(1), 53-73.

Laursen, P. B., Shing, C. M., Peake, J. M., Coombes, J. S., & Jenkins, D. G. (2002). Interval training program optimization in highly trained endurance cyclists. *Medicine and Science in Sports and Exercise, 34*(11), 1801-1807.

Lepers, R., & Stapley, P. J. (2016). Master athletes are extending the limits of human endurance. *Frontiers in Physiology, 7, 613*.

Martin, T. G., Pata, R. W., D'Addario, J., Yuknis, L., Kingston, R., & Feinn, R. (2015). Impact of age on haematological markers pre-and post-marathon running. *Journal of Sports Sciences, 33*(19), 1988-1997..

Mougios, V. (2007). Reference intervals for serum creatine kinase in athletes. *British Journal of Sports Medicine, 41*(10), 674-678.

Ploutz-Snyder, L. L., Giamis, E. L., Formikell, M., & Rosenbaum, A. E. (2001). Resistance training reduces susceptibility to eccentric exercise-induced muscle dysfunction in older women. *Journal of Gerontology, 56*(9), B384-390.

Proske, U., & Morgan, D. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology, 537*(2), 333-345.

Reaburn, P., & Dascombe, B. (2009). Anaerobic performance in masters athletes. *European Reviews of Aging & Physical Activity*, *6*(1), 39-53.

Reaburn, P. R. (2014). *Nutrition and performance in masters athletes*: CRC Press.

Roth, S. M., Martel, G. F., Ivey, F. M., Lemmer, J. T., Tracy, B. L., Hurlbut, D. E., . . . Rogers, M. A. (1999). Ultrastructural muscle damage in young vs. older men after high-volume, heavy-resistance strength training. *Journal of Applied Physiology, 86*(6), 1833-1840.

Tanaka, H., & Seals, D. R. (2008). Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms. *The Journal of Physiology, 586*(1), 55-63. doi: 10.1113/jphysiol.2007.141879.

Table and Figure Legend

Table 1 Mean ± standard deviation of demographic data for masters (*n* = 9) and young cyclists (*n* = 8)

Table 2 Mean ± standard deviation, percent change and effect sizes of performance and haematological markers of recovery for masters (*n* = 9) and young (*n* = 8) cyclists at baseline and during recovery following the high-intensity interval exercise

Figure 1 Timeline of the physical performance, perceptual and haematological measures of recovery during the experimental protocol. S1 = preliminary session 1; S2 = preliminary session 2

Figure 2 Perceptual measures of (a) motivation, (b) fatigue, (c) total quality of recovery (TQR) and (d) muscle soreness for masters and young cyclists at baseline, 24 and 48 hours post-exercise. § *moderate* effect size (ES = 0.60 – 1.19), ǂ *large* effect size (ES = 1.20 - 1.99) in the between-group difference from baseline