

# Do Differences in Peak Oxygen Uptake in Men and Women Explain Recovery from Intermittent Exercise?

## 能以男女最大攝氧量的不同解釋其最大強度重複運動的恢復過程嗎？

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### Abstract

The purpose of the study was to examine if differences in peak oxygen uptake between men and women explain their recovery from maximal effort intermittent exercise. 24 men (25.3±2.7yrs; 1.75±0.06m; 69.3±8.9kg) and 24 women (23.2±2.2yrs; 1.63±0.06m; 53.5±7.6kg) participated in the study. On separate occasions, participants completed a peak oxygen uptake (peak  $\dot{V}O_2$ ) treadmill test and five 20s cycle sprints, which were separated by a 45s recovery interval. Peak  $\dot{V}O_2$ , PP and MP in the repeated sprints and blood lactate measurements were taken. Results showed that men had higher peak  $\dot{V}O_2$  than women (53.2±8.7 vs. 42.8±6.8 ml/kg BM/min,  $p<0.05$ ), but there was no sex difference recovery of Wingate Anaerobic Test power between successive sprints when PP and MP in the sprints were expressed as a percentage of the highest attained in the first sprint (64-88% in men versus 67-90% in women). Differences in peak  $\dot{V}O_2$  between men and women did not explain the recovery of men and women during intermittent maximal exercise.

### 摘要

本文的目的是研究能否以男女之間最大攝氧量的不同來解釋其最大強度重複運動的恢復過程。24名男性(年齡為25.3±2.7歲; 身高為1.75±0.06米; 體重為69.3±8.9公斤)及24名女性(年齡為23.2±2.2歲; 身高為1.63±0.06米; 體重為53.5±7.6公斤)在跑台上進行逐級遞增負荷的運動以測定其最大攝氧量(peak  $\dot{V}O_2$ ),並選擇不同的日期,在自行車功率儀上完成5次最快速度的踏車運動,各次運動之間以45秒的恢復時間為間隔,以測定受試者每次運動的最高功率和平均功率,並計算出其它各次運動的最高功率和平均功率占首次運動最高功率和平均功率的百分比。實驗結果顯示男性的最大攝氧量明顯高于女性,分別為53.2±8.7毫升/公斤體重/分與42.8±6.8毫升/公斤體重/分( $p<0.05$ ),但男女之間各次快速踏車運動的最高功率和平均功率的百分比無明顯差異,男性為64-88%,而女性為67-90%。本結果表明最大攝氧量的不同並不足以解釋男女之間最大強度重複運動的恢復過程。

### Introduction

Quick restoration of power or the capability to perform work or replicate performance following prior exercise, many

times over, is a pre-requisite for sustaining high performance in any team sport. It is also important for effective training and during performance in multi-event competitions (Chia, 2001). Team sports such as those mentioned require many repeated sprints of a short duration, such as during offensive

and defensive play in basketball or soccer, followed by low intensity activity periods, such as jogging back to position during recovery (Reilly, 1996). This routine of maximal intensity exercise bouts interspersed with limited active recovery may be repeated many times over in the game.

Research has established that prior exercise of a high intensity is fatiguing and may affect subsequent exercise performance, especially when the recovery interval is limited (Bogdanis, Nevill & Lakomy, 1996; Hitchcock, 1989; Sargeant & Dolan, 1987). The situation is exacerbated when the prior exercise involves multiple bouts of high intense exercise, which can impair or affect subsequent attainment of maximum power output (Chia, 2001).

Recovery of peak performance after exercise therefore depends on the mode, intensity and duration of the prior exercise, and also on the characteristics of the recovery interval between successive exercise bouts (Holmyard, Nevill, Lakomy & Sant' Ana, 1994; Gaitanos, Williams, Boobis & Brooks, 1993). For example, Dotan, Falk and Raz (2000) reported that active recovery after 40 seconds of cycling at 150% at peak oxygen uptake intensity resulted in lower blood lactate concentration compared to when a passive recovery was used.

Some studies alluded that enhanced oxygen availability during high intensity intermittent exercise decreases anaerobic metabolite concentration in the blood (Balsom, Ekblom & Sjodin, 1994a) and conversely, reduced oxygen availability during such exercise impairs performance (Balsom, Gaitanos, Ekblom & Sjodin, 1994b). However, a study that examined the recovery processes of seven male participants after repeated all-out intensity exercise at an altitude of 4 350 metres showed that prolonged exposure to high altitude did not impair the restoration of muscle power during two 20-second Wingate Anaerobic Tests, compared to the performance at sea level (Biou, Henry, Deberne, Letournel, Vaysse & Richalet, 1997). Related data on women are apparently non-existent.

Juxtaposing the results of the cited studies, a hypothesis can be advanced that participants with higher peak oxygen uptake or aerobic fitness demonstrate better performance during intermittent maximal exercise by being better able to replicate the best performance in the initial bouts of maximal exercise. However such a hypothesis needs to be tested.

Previous research on the restoration or recovery of muscle power after prior exercise has focused on comparisons between boys and men (Hebestreit, Minura & Bar-Or, 1993) and girls and women (Chia, 2001). For instance, Hebestreit *et al* examined

the effect of recovery intervals of one minute, two minutes and 10 minutes on the performance of two 30-second cycle sprints. Chia, on the other had fixed the recovery interval at 45 seconds and examined the power generated in three successive 15-second cycle tests. In the two cited studies, the authors reported that young people recover faster from their maximal efforts than adults, even though the authors proposed different reasons in accounting for the results. Hebestreit *et al* argued that in boys, the restoration of PP and MP in the second 30-second WAnT was faster than men because they generated lower PP and MP, and had lower blood lactate concentration after exercise than men. Contrarily, Chia presented data showing that in spite of similar power and lactate profiles following three 20-second WAnTs, which were separated by a 45-second active recovery, girls demonstrated a swifter recovery in WAnT power than women.

Ratel, Duche, Hennegrave, Van Praagh and Bedu (2002) proposed that in repeated cycle sprints that were separated by 30 seconds of passive rest between sprints, boys recovered faster than men because they regulated the blood H<sup>+</sup> ions concentration better than adults by ventilating more during the initial rest intervals between sprints. Further research is warranted to explain the restoration of power in subsequent performance in men and women.

Apparently, no study has examined the differences in the restoration of muscle power during intermittent maximal exercise bouts that are separated a limited recovery period in men and women. Data that are exclusively male have often been extrapolated or generalised to the rest of the adult population in spite of an absence of female data, a situation that could lead to erroneous conclusions, in situations where there are sex differences exist. Comparative data of men and women that emanate from the present study would provide a more complete picture about the specific research question that is addressed.

The purpose of the study was to examine if differences in peak oxygen uptake between male and female participants explained the recovery in PP and MP in the WAnT during repeated sprints, in men and women.

## Method

### Participants

Twenty-four men and 24 women, with the appropriate informed written consent participated in the study. Participants were healthy and physically active adults but were not involved

in any form of weight training or sports training in the previous month before the study commencement. Body mass and stature of the participants were determined using calibrated beam balance scales (Avery 3306 ABV) and a stadiometer (Holtain), respectively.

### Testing Sequence

Participants completed a treadmill run test to volitional exhaustion on one test occasion to determine peak oxygen uptake. This was followed by a series of sessions to familiarise participants to repeated maximal effort sprinting using an abbreviated Wingate Anaerobic Test (WAnT) protocol. Another occasion was used to conduct the repeated sprints test. The entire test series was conducted over a period of two weeks.

### Determination of Peak Oxygen Uptake (Peak $\dot{V}O_2$ )

After a standardised familiarisation with treadmill running, participants were instructed to continue running on the treadmill (Milwaukee, WI) to the point of volitional fatigue. A modified Balke Test protocol was used. The test commenced at a constant treadmill speed of between 10 and 12 km.hr<sup>-1</sup>, with a 0% grade for the first minute and 2% for the second minute. The grade was increased 1% per minute thereafter. At a treadmill limit of 25%, the speed was then increased 13.4 m.min<sup>-1</sup> each minute. Volitional fatigue was induced between 15 and 20 minutes. The expired oxygen uptake was collected throughout the test analysed breath-by-breath and averaged over the last 30 seconds of each stage (Sensormedics 2900Z). The automated gas analysers were calibrated prior to each test using standard calibration procedures. Heart rate was monitored throughout the test and recorded at 15-second intervals, a short-range radio telemetric system (Polar Vantage NV). Volitional exhaustion and the attainment of peak  $\dot{V}O_2$  was confirmed when the terminal exercise heart rate was 95% of age and sex specific predicted maximum heart rate of the participants and that the participants exhibited signs of unsteady running gait and signs of maximum effort (e.g. facial flushing and profuse perspiration).

### Familiarisation with Intermittent Maximal Effort Cycle Sprinting

Participants had at least four prior sessions with maximal cycle sprinting. In each session, participants completed a series three 20-second Wingate Anaerobic Tests (WAnTs) which were separated by a passive recovery interval of 45 seconds. Participants were instructed to avoid pacing and to give a maximal effort in every sprint effort. The familiarization sessions were also used to determine the optimal applied force for

each participant that elicited the highest power over the 20-second WAnT.

### Intermittent Maximal Exercise Protocol

The cycle sprints were conducted on a calibrated friction-loaded cycle ergometer (Monark 834E) that was interfaced to a computer. The instrumentation of the cycle ergometer to take into account the inertial and frictional characteristics of the system have been described elsewhere (Chia, Armstrong & Childs, 1997; Chia, 2000).

Saddle height was individually adjusted for each participant such that there was a slight bend at the knee when the pedal was at the lowest point of the cycle. Toe-clips were used to secure feet to the pedals.

Following a standardized warm-up, which consisted of four minutes of constant rate pedalling at 70-80 revolutions per minute (rpm) against a minimal applied force (with the load basket supported), participants completed three maximal sprints of three to five seconds against an individually determined applied resistance that was set at between 0.74 N/kg body mass and 0.98 N/kg body mass, to elicit the highest peak and mean power over a 20-second WAnT. This protocol has been described in detail elsewhere (Chia, Armstrong & Childs, 1997).

The test commenced from a rolling start (70-80 rpm) and participants were verbally encouraged as they sprinted at maximum effort without pacing during each of the five 20-second WAnTs. An active (back pedaling against a minimal resistance at a self-selected rpm) rest interval of 45 seconds separated the sprints. This test protocol has been described in detail elsewhere (Chia, 2001). At the end of the repeated sprints, participants recovered passively in an upright position on the saddle of the ergometer for five minutes after which they pedaled against a minimum resistance for another five minutes at a self-determined pedal rate.

### Blood Lactate Measurements

A post-warm-up blood sample was obtained from the thumb using a Softclix II device (Boehringer Mannheim) and serial sampling for blood lactate was done at one-minute intervals for five minutes after the completion of the five WAnTs. The blood samples were subsequently analysed in duplicate as whole blood lactate (BL) using an automated and self-calibrating analyzer (YSI 2300 StatPlus). Calibration was checked

regularly against commercially prepared standards of known concentration.

**Statistical Analyses**

Data garnered were stored in database and were subsequently analysed using the Statistical Package for Social Sciences (SPSS) for windows software (Version 10.0). Variables of interest were inertia-corrected PP integrated over 1 second and inertia-corrected mean power (MP) integrated over 20 seconds (Chia, Armstrong & Childs, 1997) for all of the five WAnTs. Power differences between the sprints were computed and recovery and fatigue indicators were computed based upon the extent (mean difference and mean percentage) of power recovery in a subsequent sprint compared to the previous sprint (Chia, 2001).

Descriptive data (means and standard deviation) of the participants, PP and MP achieved in the WAnTs were computed. Differences in power between sprints within each sex group (male or female) were analysed using repeated measures analysis of variance (RM-ANOVA) and sex differences in peak  $\dot{V}O_2$ , PP and MP were analysed using one-way analysis of variance (OW-ANOVA). Normality of distribution and the homogeneity of variance in the data sets were checked using the appropriate statistical tests (i.e. Shapiro-Wilks and Levene Tests, respectively). The level of statistical significance was set at  $p < 0.05$ .

**Results**

**Physical Characteristics and Peak  $\dot{V}O_2$  of the Participants**

Participant characteristics are summarized in Table 1. Male participants were older, taller and heavier than the female participants. Males also had higher peak  $\dot{V}O_2$  values than females.

**Table 1. Participant Characteristics.**

Variable	Male (N=24)	Female (N=24)
Age (yr)	25.3±2.7	23.2±2.2 *
Height (m)	1.75±0.06	1.63±0.06 *
Body mass (kg)	69.3±8.9	53.5±7.6 *
Peak $\dot{V}O_2$ (ml/kg BM/min)	53.2±8.7	42.8±6.8 *

\* Significantly different at  $p < 0.05$ .

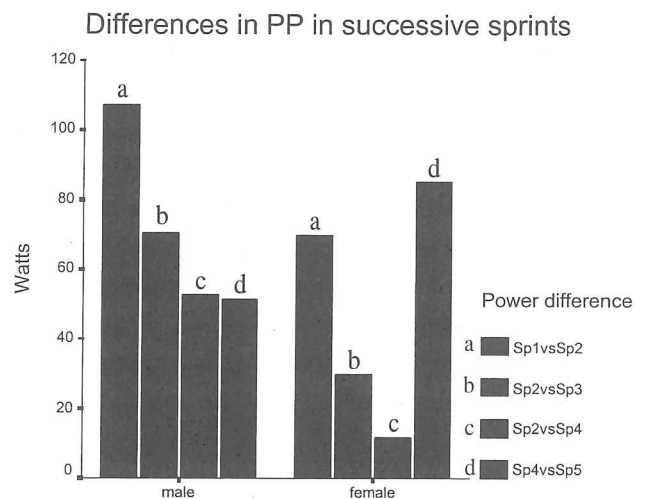
**Normality of Distribution and Homogeneity of the Data Sets**

Peak  $\dot{V}O_2$  data, peak power and mean power in WAnTs were normally distributed (i.e. Shapiro-Wilks statistic,  $p > 0.05$ ) and there was homogeneity of variance for PP and MP (i.e. Levene statistic,  $p > 0.05$ ).

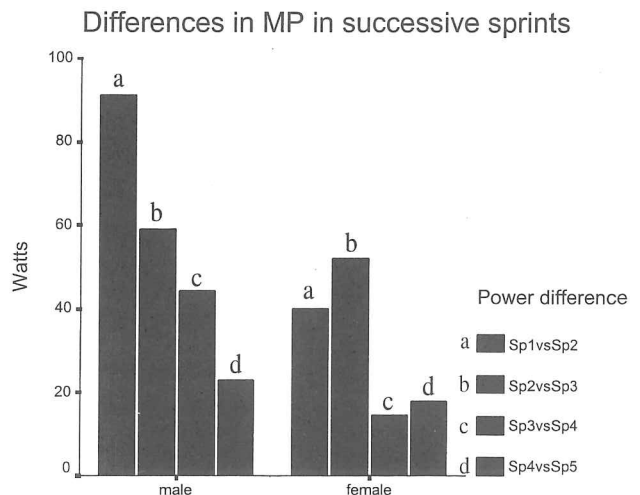
**Power Differences between Successive Sprints**

The mean differences and the standard deviations of the differences in PP and MP between successive sprints (e.g. PP and MP differences between Sprint 1 and Sprint 2, Sprint 2 and Sprint 3, etc) are illustrated in Figure 1 and Figure 2.

**Figure 1. Differences in PP between Successive Sprints in Men and Women. Differences in PP between Successive Sprints are Significantly Different at  $p < 0.05$ .**



**Figure 2. Differences in MP between Successive Sprints in Men and Women. Differences in MP between Successive Sprints are Significantly Different at  $p < 0.05$ .**



Repeated measures ANOVA for PP and MP in males and females, with or without body mass entered as the covariate, revealed significant differences ( $p < 0.05$ ) in the mean differences in PP and MP that were attained between successive sprints in the WAnT.

With PP and MP attained in successive sprints expressed as a percentage of the highest PP and MP achieved in Sprint 1 (indicated within brackets), however, the men and women showed similar profiles for recovery of PP and MP. This is summarized in Table 2.

**Table 2. PP and MP Achieved in Subsequent Sprints Expressed as a Percentage of PP and MP Achieved in Sprint 1.**

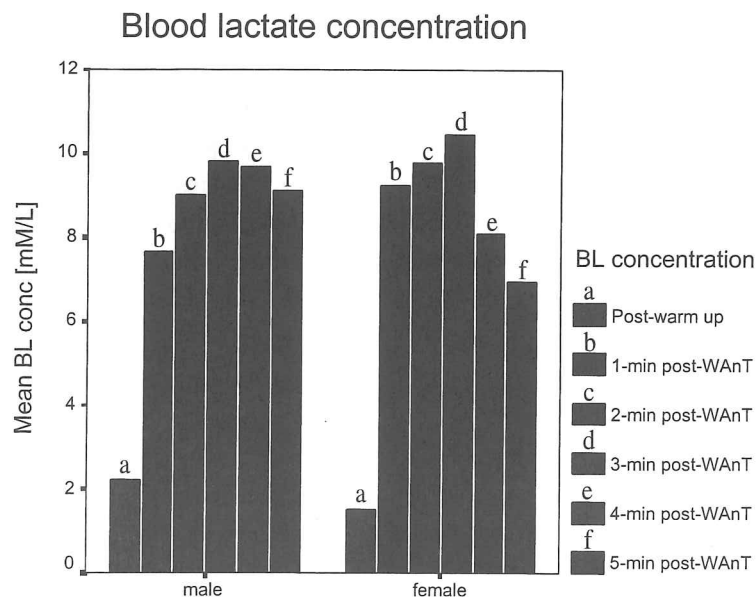
Variable	Sex	Sp2/Sp1	Sp3/Sp1	Sp4/Sp1	Sp5/Sp1
PP (W)	Male	88±9%	78±13%	71±11%	65±13%
	Female	87±14%	89±16%	89±11%	72±16%
MP (W)	Male	84±6%	77±12%	67±9%	64±11%
	Female	90±5.3%	77±10%	74±13%	67±14%

**Blood Lactate Concentration (BL<sub>conc</sub>)**

The post-warm-up and post-exercise blood lactate concentrations after the five 20s WAnTs, obtained serially at 1-minute intervals during an active recovery are summarized in Figure 3. Post-exercise blood lactate concentration peaked

by three minutes in men and 4 minutes after the WAnTs in women, respectively. Thereafter, BL<sub>conc</sub> declined. There was no sex difference in blood lactate concentration ( $p > 0.05$ ).

**Figure 3. Blood lactate concentration post-warm-up and sampled at 1-minute intervals after the five 20s WAnTs. RM-ANOVA revealed no sex difference in post-WAnTs blood lactate concentration. Peak BL<sub>conc</sub> was attained by 4 minutes post exercise in men and in women (since BL<sub>conc</sub> in men at 3 min vs. 4 mins,  $p > 0.05$ ).**



## Discussion

Measurements made on participant characteristics showed that the men were significantly older, taller and heavier than the women (see Table 1). The men also had higher peak oxygen uptake. (see Table 1) The results are typical of those reported elsewhere (Armstrong & Welsman, 1997).

Intense repeated exercise, which are interspersed with limited recovery result in an accumulation of blood lactate in male and female adults (Chia, 2001; Hebestreit *et al*, 1993). Some researchers (Ratel *et al*, 2002) suggest that elevated post exercise blood lactate concentration and the associated decrease in blood pH, is directly associated with local muscle fatigue by possibly affecting the contractile mechanism (Falk *et al*, 1995). Others believe that the associations between blood lactate, blood pH and muscle fatigue are indirect (Sahlin & Ren, 1989).

In adults, albeit exclusively male, the recovery of force and power output after intense isometric contraction (Hitchcock, 1989) and after treadmill sprinting (Holmyard, *et al*, 1994) has been explained. In essence, the restoration of force or power in subsequent performance is said to parallel the time course of the resynthesis of creatine phosphate (CP) in the muscle (Harris, Edwards, Hultman, Nordesjo & Nylind, 1976; Gaitanos, Williams, Boobis & Brooks, 1993), rather than the time course for the clearance of blood lactate. Holmyard *et al* (1994) reported that after a 30-second maximal treadmill sprint followed by a passive rest interval of 30 seconds, a high proportion of PP could be restored in a subsequent six-second-treadmill sprint, even when blood lactate concentration was nearly 10 times that of the pre-sprint values. The half time for CP resynthesis is estimated at 22 seconds while full replenishment is estimated at 170 seconds (Harris *et al*, 1976). On the other hand, the return of elevated levels of blood lactate to pre-exercise levels might take several hours (Dotan, Falk & Raz, 2000).

Comparisons in power recovery in a second or successive WAnT of different durations, and of different recovery intervals, have been made between boys and men (Hebestreit, Minura & Bar-Or, 1993), and between girls and women (Chia, 2001). Despite differences in the methodology between the cited studies, the juxtaposed data suggest that prior exercise such as that performed during a WAnT has a fatiguing or detrimental effect on subsequent power generation in the WAnT for active recovery intervals of 45 seconds (Chia, 2001), one minute, two minutes and 10 minutes (Hebestreit, Minura & Bar-Or, 1993).

The present data set confirmed the cited observations. For instance, from Figure 1, Figure 2 and Table 2, PP and MP attained by men and women in subsequent WAnTs, declined from WAnT 1 to WAnT 5. In men, the mean differences in PP and MP achieved in WAnT 1 and WAnT 5 were  $48 \pm 35$  W and  $21 \pm 16$  W, respectively. The corresponding mean differences for women were  $86 \pm 70$  W for PP and  $21 \pm 16$  W for MP (see Figures 1 & 2). Even though the mean difference in PP and MP between WAnT 1 and WAnT 5 in men and women were significantly different, when PP and MP achieved in WAnT 5 were expressed as a percentage of that attained in WAnT 1, men and women demonstrated similar patterns of percentage power restoration or recovery (PP:  $65 \pm 13$  vs.  $72 \pm 16\%$ ; MP:  $64 \pm 11$  vs.  $67 \pm 14\%$ , see Table 2). The similar pattern of power restoration during successive sprints in men and women is interesting considering that PP and MP differences between successive sprints was markedly greater in men than in women. That means that men had a greater magnitude of power to recovery from whereas women had less. Yet post-exercise peak blood lactate concentration between men and women was not significantly different (see Figure 2). A number of explanations may be considered.

During intermittent maximal exercise, it has been reported that enhanced oxygen availability reduced anaerobic metabolite concentration in the blood, and conversely reduced oxygen availability negatively affected subsequent sprint performance (Balsom *et al*, 1994a; 1994b). There is however, evidence to the contrary (e.g. Biou *et al*, 1997). In the cited study, the authors reported that reduced atmospheric oxygen availability at high altitude did not impair the restoration of power generated in two 20-second WAnTs compared to the results of a similar experiment conducted at sea level.

In the present study, the men had significantly higher body mass-related peak  $\dot{V}O_2$  than women (see Table 1). However, this did not translate to a better restoration of PP and MP in subsequent sprints for men compared to women (see Table 2). The present result is in agreement with the findings of Aziz, Chia and Teh (2000), which examined the relationship between maximal oxygen uptake and repeated sprint performance indices in 17 field hockey and 23 soccer players. The researchers reported that there is only a 12% shared variance, between maximum oxygen uptake and total sprint time for eight 40-metre sprints that were separated by a 30-second recovery period. Importantly, Aziz, Chia and Teh (2000), reported that higher aerobic fitness did not contribute the repeated sprint performance of the adult male participants. Contrarily, McMahon (1998) reported that in 20 male rugby players, maximum

oxygen uptake is an important determinant of the ability to perform intermittent maximal exercise and also for the recovery between sprints.

Differences in the intermittent sprint protocol, participant characteristics and the nature of the recovery between the cited studies and the present study might have accounted for the dissimilar findings. On the balance of evidence, findings appear to be equivocal with regards to whether a high level of aerobic fitness *per se* facilitated the restoration of muscle power in subsequent exercise. In the present study, the data did not support this hypothesis. It is plausible that there might be a threshold value for aerobic fitness that is beneficial for repeated sprints performance. Thereafter other physiological processes such as the oxygen uptake transients during high intensity exercise and during the recovery intervals might be more important than the level of aerobic fitness, but further research in this area is advised.

In Figure 2, it can be seen that blood lactate concentration generated by the repeated maximal exercise peaked by four minutes post-exercise in both men and women (since  $BL_{conc}$  in men at 3 min vs. 4 mins,  $p > 0.05$ ). However, it should be noted that peak blood lactate concentration after exercise is dependent on the type, intensity and duration of the preceding exercise (Chia, Armstrong & Childs, 1997), the nature and type of the recovery (Dotan, Falk & Raz, 2000), and sampling and analytical procedures (Armstrong & Welsman, 1997). Moreover, blood lactate concentration is a function of its production and its clearance from the blood, and should only be taken as a blunt indicator of the processes that occurred at the muscle level during the preceding exercise. The interpretation of blood lactate concentration is therefore fraught with difficulties (Armstrong & Welsman, 1997) and prudence is advised when explanations based on blood lactate concentration are made.

## Conclusion

Despite higher peak oxygen uptake and greater power differences between repeated sprints in men and women, men and women showed similar patterns of percentage power restoration during intermittent maximal exercise. Future research should examine physiological factors other than peak oxygen uptake such as the oxygen uptake transients during the recovery period between sprints, which might help explain the recovery of men and women during intermittent maximal exercise.

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