



# Muscle oxygenation induced by cycling exercise does not accelerate recovery kinetics following exercise-induced muscle damage in humans: A randomized cross-over study



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## ABSTRACT

The aim of this study was to analyze the effects of inducing muscle oxygenation using an intermittent cycling exercise on recovery kinetics after exercise-induced muscle damage. Ten soccer players performed single-leg knee flexors exercise: 75 eccentric contractions. The day after, subjects performed an intermittent cycling exercise of 12 min (15 s work - 15 s rest) or recovered passively in a balanced and randomized cross-over design. Force, single and double-leg countermovement jumps, muscle soreness, perceived recovery and creatine kinase concentrations were assessed through a 72 h period. Oxygenation during cycling was assessed using Near Infrared Spectroscopy. Results showed an increase in knee flexors oxygenation using intermittent cycling ( $\Delta\text{HbO}_2 = 70.2 \pm 19.8\%$ ;  $\Delta\text{HHb} = 68.2 \pm 14.1\%$ ). Possibly small detrimental effect of cycling on eccentric force was found (ES = -0.58, 90% CI: -1.33 to 0.17). Small detrimental effects of cycling were found for soreness and perceived recovery. Implementing intermittent cycling exercise the day after muscle damage may be detrimental for recovery.

## 1. Introduction

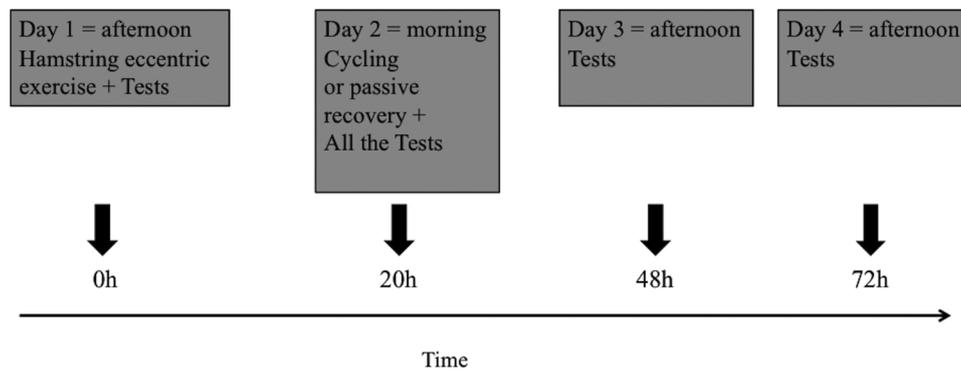
Exposure to eccentric contraction leads to a mechanical stress inducing muscle damage characterized by an insult to muscle fibers, damage to the ultrastructure of the muscle but also to the extracellular matrix and possibly to the capillaries (Clarkson and Hubal, 2002). Consequently, muscle function and performance are reduced for several days (Peake et al., 2017). During the period of recovery, an inflammatory response is also triggered in order to participate to the process of muscle regeneration (Peake et al., 2017). Skeletal muscle regeneration involves several cellular and molecular events, leading to the restoration of muscle mass, muscle vascularization, and innervation, as well as the recovery of contractile and metabolic properties of the muscle (Chargé and Rudnicki, 2004). The process of muscle regeneration is, in part, underpinned by satellite-cell activation and proliferation. The role of these cells is to repair the muscle following a damage by a fusion with existing fibres or creating new fibres (Hawke and Garry, 2001). This process may last for several days and can be influenced by some external factors. Among these factors, it has been proposed that muscle oxygenation may accelerate myogenic differentiation and muscle regeneration response (Mancinelli et al., 2011).

In the context of elite sport, this delay in recovery may be problematic if the time between two competitions is not enough to fully recover. For instance, soccer is a sport involving several actions such as jumping, sprinting, shooting, tackling that are made of eccentric contractions (Osgnach et al., 2010). As a consequence, participation to a soccer match leads to a decrease of performance that may last up to 96 h (Silva et al., 2018). During congested schedules, the period of recovery between two matches is 48 h–72 h, which is not enough to fully recover. As a consequence, injury risk is increased when compared with one match in a week (Dupont et al., 2010). To overcome this incomplete recovery, some athletes use recovery strategies following the completion of the exercise (Nédélec et al., 2013; Venter, 2014). Even if the beneficial effects of oxygenation on muscle regeneration is now accepted in scientific literature (Chaillou and Lanner, 2016), conflicting results have been found regarding the effects of exposure to hyperbaric oxygen therapy on recovery kinetics of muscle function following eccentric exercise (Staples et al., 1999; Harrison et al., 2001). In addition, studies focusing on this topic used hyperbaric oxygen therapy in order to increase the level of oxygenation.

A study showing the efficiency of hyperbaric oxygenotherapy applied this strategy one hour immediately and everyday after exercise for

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Week 1 = one condition (active or passive) on one leg (dominant or non-dominant).

Week 2 = the other condition on the other leg.

Fig. 1. Schematic representation of the experimental protocol.

3 to 5 days (Staples et al., 1999). In the context of elite soccer, this protocol may be difficult to implement such a protocol, especially when matches are played at night and away. Adding one hour of hyperbaric oxygenotherapy may delay the time to go to bed and, consequently, be deleterious for sleep. This implies the need to find another way to increase the oxygen supply at the muscle level to accelerate recovery.

In the sport environment context, a recovery session is often planned the day after a competition (Dupont et al., 2010). Cycling continuously between 15 and 30 min at a low intensity is widely used in sport as a training session the day after a competition (Nédélec et al., 2013). However, previous studies have shown no effect of such training sessions on recovery kinetics of performance markers (Andersson et al., 2008). Belfry et al. (2012) compared the responses and mechanisms explaining the adjustments of  $\text{VO}_2$  between a continuous constant load cycling exercise and intermittent cycling exercise including light to moderate intensity recovery periods. Their results showed a better matching of  $\text{O}_2$  delivery to  $\text{O}_2$  consumption in the intermittent exercise. The authors explained these results by a recovery-dependent effect that improves microvascular blood flow distribution and/or  $\text{O}_2$  delivery during the work and recovery periods. Performing a continuous cycling exercise leads to a compressive effect on capillaries that may limit blood distribution and, consequently, muscle oxygenation (Sadamoto et al., 1983; Lutjemeier et al., 2005). Intermittent cycling seems to be a solution to increase muscle oxygenation and accelerate muscle regeneration the day after exercise-induced muscle damage without inducing a waste of time for athletes.

To our knowledge, no study has analyzed the effects of increasing the level of oxygenation at the muscular level by using an intermittent cycling exercise on recovery kinetics after exercise-induced muscle damage. The aim of this study was to analyze the effects of an intermittent cycling exercise on recovery kinetics after exercise-induced muscle damage.

## 2. Material and methods

### 2.1. Participants

Ten male soccer players (age:  $26.1 \pm 4.9$  years; height:  $176.4 \pm 4.7$  cm; body mass:  $77.2 \pm 9.1$  kg) participated in this study. They were not injured from hamstring during the last six months. They were asked not to undertake any physical activity at least 48 h prior to the completion of the first test (baseline). They were instructed not to eat protein, drink alcohol or caffeinated drinks, not use any other recovery strategies, including supplements, or perform any muscular activity in the 48 h before and across the 4 days of each experimental

session. Each subject answered a questionnaire before each session to check if these criteria were respected; if not, they were excluded from the study. All subjects provided written informed consent to participate in this study. This study was made in accordance with the local ethical committee on biomedical research (N<sup>o</sup>CCTIRS#10,544) and the standards set by the Declaration of Helsinki.

### 2.2. Experimental design

In a randomized and balanced cross-over design, subjects performed a knee flexor exercise on one leg: 5 sets of 15 maximal eccentric contractions on an isokinetic dynamometer (Con-Trex MJ, CMV AG, Dübendorf, Switzerland). Previous studies shown the effectiveness of this exercise in inducing muscle damage (Abaïdia et al., 2017a, 2017b). The day after this exercise (20 h after the exercise), on the morning, subjects performed an intermittent cycling exercise or a control condition. Subjects were tested immediately after the eccentric exercise (0 h), the day after eccentric exercise on the morning (20 h post-exercise) and every 24 h after eccentric exercise (for 72 h) on the following parameters: eccentric force of the knee flexors at  $60^\circ \cdot \text{s}^{-1}$ , isometric force of the knee flexors at  $60^\circ$ , single-leg countermovement jump, muscle soreness, perceived recovery and creatine kinase concentration. Two weeks after performing the protocol on one leg and in one condition, subjects performed the same protocol on the other leg and in the other condition (Fig. 1).

### 2.3. Procedures

#### 2.3.1. Condition allocation

Subjects were grouped in a randomized and balanced order to both conditions: control and experimental (intermittent). Each condition was interspersed by at least two weeks. Dominant and non-dominant legs were exposed to each condition by a randomized and balanced order. To assign subjects to their groups, randomization of participants was conducted by using a random-numbers generator ([www.randomization.com](http://www.randomization.com)). The order of control and experimental sessions were also randomized and 4 combinations were allocated: non-dominant leg + control condition, dominant leg + intermittent, non-dominant leg + intermittent, dominant leg + control condition.

#### 2.3.2. Familiarization and tests

Before the experimentations, subjects were familiarized with the battery of tests and reference values were assessed twice. During two familiarization sessions, subjects performed 5 repetitions of the test at a low intensity and two repetitions at a maximal intensity. After these

familiarization sessions, two sessions of testing separated by 72 h were performed in order to determine: 1) the reference values and, 2) the level of reliability for eccentric force, isometric force, single-leg countermovement jump tests. For each test, verbal standardized encouragements were provided, subjects performed two trials and the best performance was recorded.

### 2.3.3. Warm-up

Before beginning the tests and the exercise task, subjects first completed a standardized cycling warm-up: 6 min at a perceived intensity of 11 (light) for 2 min, 13 (somewhat hard) for 2 min and 15 (hard) for 2 min on the Borg's rating of perceived exertion (Borg, 1970). Then, they performed 2 sets of 10 repetitions of concentric knee flexions at  $60^\circ \cdot s^{-1}$  at  $60 \text{ N} \cdot \text{m}^{-1}$  on an isokinetic dynamometer (Con-Trex MJ, CMV AG, Dübendorf, Switzerland). Sets were separated by one-minute recovery.

### 2.3.4. Exercise-induced muscle damage

Subjects performed one-leg knee flexors exercise made up of 5 sets of 15 maximal eccentric contractions at a speed of  $60^\circ \cdot s^{-1}$  interspersed by a 3 min recovery on an isokinetic dynamometer (Con-Trex MJ, CMV AG, Dübendorf, Switzerland) with the hip joint at  $75^\circ$  (Abaidia et al., 2017a, 2017b). Full extension of the leg was considered as  $0^\circ$  (range of motion  $0-90^\circ$ ). The distal shin pad of the dynamometer was attached 3–4 cm proximal to the lateral malleolus by using a strap. To minimize extraneous body movements, straps were applied across the chest, pelvis and mid-thigh. The alignment between the dynamometer rotational axis and the knee joint rotation axis (lateral femoral condyle) was checked at the beginning of each trial. Gravity effect torque was recorded for each subject throughout the range of motion in order to correct torque measurements during all tests.

### 2.3.5. Strength tests

Knee flexors eccentric strength at  $60^\circ \cdot s^{-1}$  and isometric strength at  $60^\circ$  (5 s) were assessed by the same dynamometer (Con-Trex MJ, CMV AG, Dübendorf, Switzerland). Force was tested immediately post-exercise (0 h), 20 h, 48 h and 72 h post-exercise.

### 2.3.6. Single-leg countermovement jump

The single-leg countermovement jump (CMJ-1 L) was performed on a 3D force plate (Kistler Instruments AG, 9260AA6, Winterthur, Switzerland) with a frequency of 1000 Hz. Subjects performed two trials interspersed by one-minute of recovery for each jump; these were performed immediately post-exercise (0 h), then at 20 h, 48 h and 72 h post-exercise. The foot of the tested leg was in contact with the platform, and the subjects kept their hands on the hips. Their knee was flexed to a self-selected depth in response to the instruction to jump as high as possible, and to land on the same foot. The force plate was calibrated according to the manufacturer recommendations.

### 2.3.7. Subjective ratings

Thirty minutes after the end of the eccentric exercise, subjects were instructed to rate the global exercise intensity using the modified rate of perception scale from 0 (rest) to 10 (maximal) (Foster, 1998).

Immediately after the eccentric exercise (0 h), 20 h, 48 h and 72 h after exercise, subjects were asked to rate their level of hamstring soreness using a Likert scale from 0 (not sore) to 10 (very, very sore) (Thompson et al., 1999).

Subjects rated their level of perceived recovery 20 h, 48 h and 72 h after exercise using a recovery scale from 0 (very well recovered) to 10 (very poorly recovered) (Abaidia et al., 2017a).

### 2.3.8. Creatine kinase

Before the exercise (Pre), then at 20 h, 48 h and 72 h post-exercise, fingertip blood samples ( $32 \mu\text{l}$ ) were collected in order to determine creatine kinase concentrations. Blood samples were placed on a

measurement strip and were analyzed using a Reflotron (Roche Diagnostics, Grenzacherstrasse, Switzerland). The Reflotron was calibrated according to the manufacturer recommendations. A previous study by Hørder et al. (1991) reported that this device was reliable (coefficient of variation of 4.2%) and valid, as the comparison between the Reflotron and other assays showed a correlation  $\geq 0.99$ .

### 2.3.9. Intermittent cycling exercise

The intermittent cycling exercise was made of 12 min cycling, alternating 15 s work with 15 s rest. Subjects were seated on a ergocycle (Technogym, Cesena, Italy) with a saddle height fixed at 95% of the trochanter length, at a pedaling rate of 120 rpm and with a clipless pedal condition. The saddle height, the pedaling rate and the clipless pedal condition were chosen to maximize the biceps femoris activation (Hug and Dorel, 2009). The intensity corresponded to a perceived exertion comprised between 11 (light) and 13 (somewhat hard) on the Borg's rating of perceived exertion (Borg, 1970).

### 2.3.10. Near infrared spectroscopy

During the intermittent exercise, near infrared spectroscopy device (Portamon, Artinis, Medical System, Zetten, the Netherlands) was used to examine muscle oxygenation of the biceps femoris muscle. The device was positioned on the thigh, at the proximal first third of the distance between the ischial tuberosity and the head of the fibula (McKeon et al., 2006). Resting oxyhemoglobin ( $\text{HbO}_2$ ) and deoxyhemoglobin (HHb) values before the intermittent exercise (30 s average) were standardized as 100% (Ohya et al., 2013). Changes in  $\text{HbO}_2$  ( $\Delta\text{HbO}_2$ ) and HHb ( $\Delta\text{HHb}$ ) during the recovery period of each repetition were calculated as the difference between the highest and the lowest value (average of the highest or lowest 1 s consecutive values).

## 2.4. Statistical analysis

Data are presented as mean  $\pm$  standard deviation (SD) and 90% confidence interval (90% CI). For reliability of eccentric force, isometric force, single-leg countermovement jump and double-leg countermovement jump, the coefficient of variation (CV), intraclass correlation coefficient (ICC), 90% confidence intervals (CI) and typical error (TE) were calculated (Hopkins, 2002a). Values for force, single-leg countermovement jump, double-leg countermovement jump and creatine kinase concentrations were normalized to 100%. Values of creatine kinase concentrations were log transformed. The effect of time and the effect of condition on the dependent variables – force, single-leg countermovement jump, double-leg countermovement jump, creatine kinase concentrations, soreness and perceived recovery were analysed using the following criteria:  $\geq 0$  to  $\leq 0.2$  = trivial;  $0.21$  to  $\leq 0.6$  = small;  $0.61$  to  $\leq 1.2$  = moderate;  $1.21$  to  $\leq 2$  = large;  $2.1$  to  $\leq 4$  = very large;  $> 4$  = nearly perfect (Hopkins, 2002b). Probability to have a higher effect of a condition compared to the other one was assessed qualitatively as follows:  $< 0.5\%$ , most unlikely or almost certainly not;  $0.5-5\%$ , very unlikely;  $5.1-25\%$ , unlikely or probably not;  $25.1-75\%$ , possibly;  $75.1-95\%$ , likely or probably;  $95.1-99.5\%$ , very likely;  $> 99.5\%$ , most likely or almost certainly. If the probability to have results in favour of both treatments were  $> 5\%$ , the true difference was assessed as unclear (Batterham and Hopkins, 2006). The percentage of chance was presented in favour of: control/trivial/intermittent.

## 3. Results

### 3.1. Reliability

Interday test-retest reliabilities for eccentric force, isometric force and CMJ-1 L values were calculated. Results are presented in Table 1.

**Table 1**  
Reliability of outcomes measured during the experimental protocol.

	Trial 1	Trial 2	Effect Size (90% CI)	Standardized TE (90% CI)	ICC (90% CI)	CV
Eccentric Force 60°.s <sup>-1</sup>	179.9 N.m <sup>-1</sup>	179.5 N.m <sup>-1</sup>	0.02 (90% CI = -0.72 to 0.75)	0.45 (90% CI = 0.34 to 0.67)	0.84 (90% CI = 0.63 to 0.94)	8.3%
Isometric Force 60°	122.5 N	123.8 N	-0.06 (90% CI = -0.80 to 0.67)	0.39 (90% CI = 0.30 to 0.59)	0.88 (90% CI = 0.71 to 0.96)	7.6%
CMJ-1L	15.7 cm	16.3 cm	-0.21 (90% CI = -0.95 to 0.52)	0.32 (90% CI = 0.23 to 0.53)	0.93 (90% CI = 0.79 to 0.98)	8.3%

Trial 1 and trial 2 are respectively the first and second trial performed by the subjects after the familiarization sessions for each outcome concerned.

**Table 2**  
Time effect of each outcome in comparison with baseline values.

Outcome	Condition	0 h	20 h	48 h	72 h
Eccentric Force 60°.s <sup>-1</sup>	Control	ES = -2.91 (90% CI = -1.9 to -3.9)	ES = -2.15 (90% CI = -1.2 to -3.1)	ES = -2.20 (90% CI = -1.3 to -3.1)	ES = -1.86 (90% CI = -1 to -2.7)
	Intermittent	ES = -2.99 (90% CI = -2 to -4)	ES = -3.47 (90% CI = -2.3 to -4.6)	ES = -2.12 (90% CI = -1.2 to -3)	ES = -1.83 (90% CI = -1 to -2.7)
Isometric force 60°	Control	ES = -3.86 (90% CI = -2.7 to -5.1)	ES = -2.58 (90% CI = -1.6 to -3.6)	ES = -2.56 (90% CI = -1.6 to -3.5)	ES = -2 (90% CI = -1.1 to -2.9)
	Intermittent	ES = -5.33 (90% CI = -3.8 to -6.9)	ES = -2.91 (90% CI = -1.9 to -3.9)	ES = -2.70 (90% CI = -1.7 to -3.7)	ES = -2.14 (90% CI = -1.2 to -3.1)
CMJ-1L	Control	ES = -0.98 (90% CI = -0.2 to -1.8)	ES = -0.51 (90% CI = 0.2 to -1.3)	ES = -1.56 (90% CI = -0.7 to -2.4)	ES = -0.89 (90% CI = -0.1 to -1.7)
	Intermittent	ES = -1.37 (90% CI = -0.6 to -2.2)	ES = -0.70 (90% CI = 0.1 to -1.5)	ES = -0.54 (90% CI = 0.2 to -1.3)	ES = -0.42 (90% CI = 0.3 to -1.2)
[CK]	Control	N/A	ES = 0.33 (90% CI = -1.2 to 3)	ES = 0.73 (90% CI = 0 to 1.5)	ES = 0.66 (90% CI = 1.4 to -0.1)
	Intermittent	N/A	ES = 0.67 (90% CI = 1.4 to -0.1)	ES = 0.57 (90% CI = 1.3 to -0.2)	ES = 0.93 (90% CI = 0.2 to 1.7)
Soreness	Control	ES = 2.69 (90% CI = 1.7 to 3.7)	ES = 2.84 (90% CI = 1.8 to 3.9)	ES = 3.45 (90% CI = 2.3 to 4.6)	ES = 2.63 (90% CI = 1.7 to 3.6)
	Intermittent	ES = 2.27 (90% CI = 1.4 to 3.2)	ES = 2.22 (90% CI = 1.3 to 3.1)	ES = 3.36 (90% CI = 2.2 to 4.5)	ES = 2.99 (90% CI = 1.9 to 4)
Perception of recovery	Control	N/A	N/A	ES = 3.46 (90% CI = 2.3 to 4.6)	ES = 3.47 (90% CI = 2.3 to 4.6)
	Intermittent	N/A	N/A	ES = 3.63 (90% CI = 2.5 to 4.8)	ES = 3.24 (90% CI = 2.2 to 4.3)

[CK] = creatine kinase concentrations. AU = arbitrary units. CMJ-2L = double-leg countermovement jump. CMJ-1 L = single-leg countermovement jump. This table presents a comparison of each time point mean value with baseline values in each condition. The information given is the time effect of the exercise. The effect sizes (ES) and confidence intervals (CI) represent the difference between a given time point and the baseline value for the considered outcome. N/A = non-applicable.

### 3.2. Time effect

Table 2 presents effect sizes and 90% CI of each time point (before exercise and 0 h, 24 h, 48 h, 72 h after exercise) in comparison with baseline values for eccentric force, isometric force, single-leg countermovement jump, soreness, perception of recovery and creatine kinase concentrations for each condition.

A large to very large effect of time was observed for eccentric and isometric force throughout the 72 h of recovery. Additionally, a small to moderate effect of time was observed for single-leg countermovement jump. Subjective ratings, namely soreness and perceived recovery, were very largely affected by time across the 72 h after exercise-induced muscle damage. A small to moderate effect of time was observed for creatine kinase concentration.

### 3.3. Condition effect

Effect sizes (with 90% CI) and magnitude-based inferences values for condition effect are presented in Figs. 2–5. There was no effect of condition for isometric force, single-leg countermovement jump measures and creatine kinase concentration. A possibly small beneficial effect of condition was found in favour of passive recovery for eccentric force 20 h post-exercise (Fig. 2A). For subjective ratings, there was a likely small effect in favour of passive recovery on soreness 72 h after exercise-induced muscle damage (Fig. 4B). Passive recovery was likely

and possibly beneficial for perceived recovery at 20 h and 72 h (Fig. 4A). For creatine kinase, trivial effects of condition were observed throughout the 72 h after exercise-induced muscle damage (Fig. 5).

### 3.4. Near infrared spectroscopy

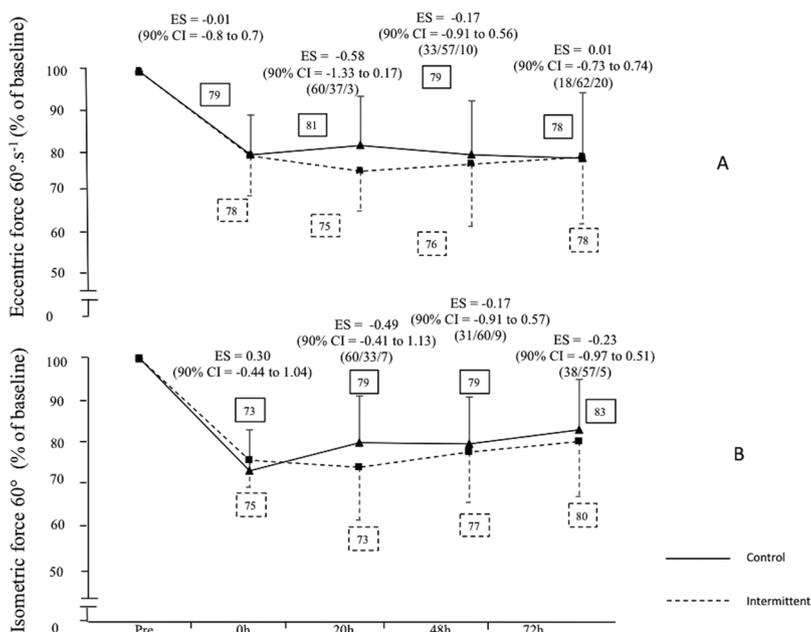
Throughout the intermittent cycling exercise, the mean difference between the higher and the lower value of HbO<sub>2</sub> during the recovery period ( $\Delta$ HbO<sub>2</sub>) was 70.2 ± 19.8% (Fig. 6). The mean difference between the higher and the lower value of HHb during the recovery period ( $\Delta$ HHb) was 68.2 ± 14.1% (Fig. 6).

### 3.5. Rate of perceived exertion after exercise-induced muscle damage

A small effect size (0.18; 90% CI = 0.9 to -0.6) was found for the difference of mean RPE collected after exercise for the intermittent condition (6.0 ± 1.1) and the control condition (5.8 ± 1.1).

## 4. Discussion

The aim of this study was to analyze the effects of an intermittent cycling exercise on recovery kinetics after exercise-induced muscle damage. As shown in Fig. 6, the intermittent cycling exercise was effective in increasing hamstring oxygenation. However, no effect of this strategy was found regarding recovery kinetics of isometric force.



**Fig. 2.** Time-evolution of eccentric force at 60° s<sup>-1</sup> (A) and isometric force at 60° (B) in intermittent and control conditions at baseline (Pre), immediately (0 h), 20 h, 48 h and 72 h after the exercise-induced muscle damage. ES = effect size between intermittent and control. Probabilities to have an effect are presented in bracket as: (control/trivial/intermittent). NA = non-applicable.

Subjective ratings, namely soreness and perceived recovery, were possibly to likely negatively influenced by the intermittent cycling exercise. In addition, intermittent exercise was possibly detrimental for eccentric force, when this parameter was measured after the intermittent cycling exercise. Results showed that the intermittent cycling exercise performed the day after exercise-induced muscle damage had no effect on CMJ-1 L performance recovery.

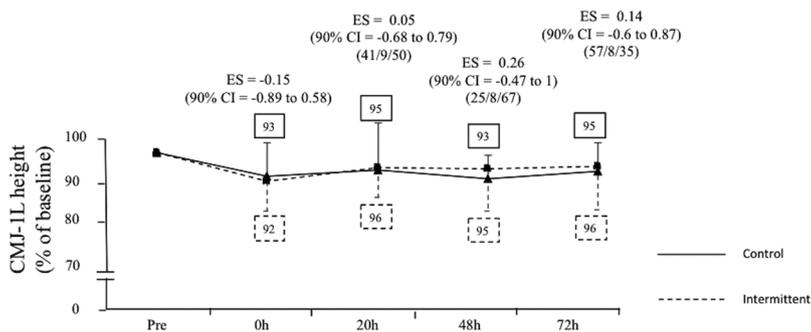
Consistent with previous studies using the similar protocol (Abaïdia et al., 2017a, 2017b), the eccentric exercise induced a very large decrease of eccentric and isometric force immediately post-exercise. As neuromuscular function is considered to be the best tool to assess the level of muscle damage (Warren et al., 1999), it can be concluded that the eccentric exercise performed in this study was effective in inducing muscle damage.

In this study, the near infrared spectroscopy has been used to evaluate the level of oxygenation during the intermittent cycling exercise performed the day after exercise-induced muscle damage. To our knowledge, this study is the first to assess hamstring oxygenation during intermittent cycling exercise and the first to show that the level of oxygenation of the biceps femoris during each recovery period of the intermittent exercise was increased.

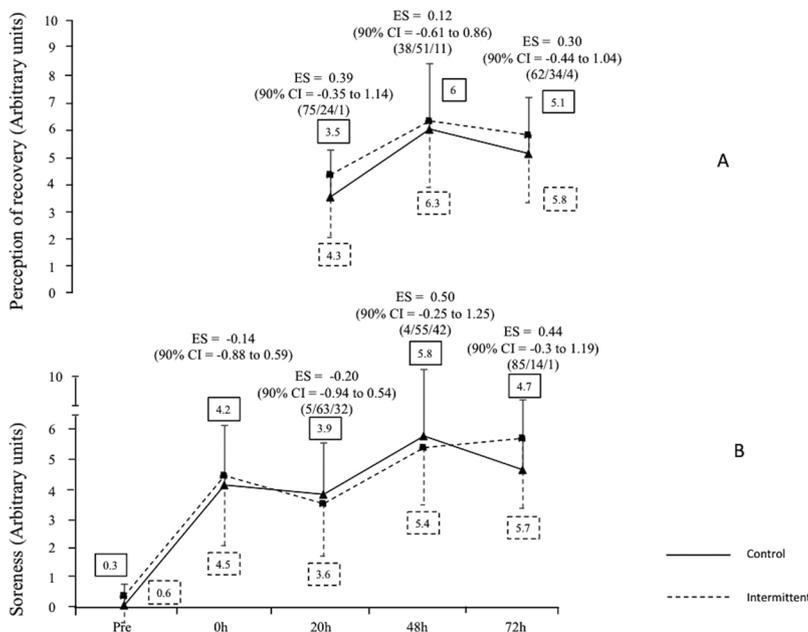
When comparing the control condition with the intermittent cycling exercise, results of this study showed that, when testing the level of force immediately after the intermittent cycling exercise (20 h), a possibly detrimental effect was observed. These results are consistent with the study of Harrison et al. (2001) who found no significant effect of hyperbaric oxygen therapy on forearm flexors strength recovery following eccentric exercise. Contrary to these results, Staples et al. (1999)

found a beneficial effect of oxygen therapy on recovery kinetics of quadriceps muscle following exercise-induced muscle damage. Difference in results may be explained by several factors. The muscular group used to perform the eccentric exercise and the amplitude of muscle damage were different between the studies.

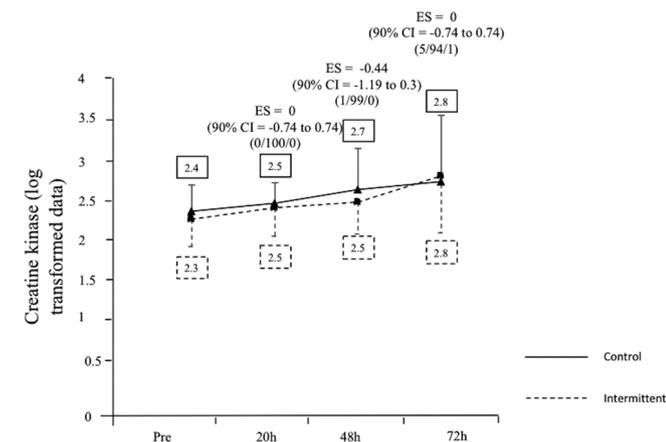
As previously described (Belfry et al., 2012), the intermittent cycling exercise was effective in supplying oxygen to the muscle but was not effective to accelerate recovery kinetics of muscle performance. As discussed by Chaillou and Lanner (2016), the availability of oxygen influence satellite cells activity during the skeletal muscle regeneration process. Results of previous studies showed in humans that exposure to hypobaric hypoxia inhibited the activity of muscle satellite cells (Mancinelli et al., 2011). However, several variables may directly influence the ability of oxygen to aid in the recovery from exercise-induced muscle damage, such as the magnitude of muscle damage, the need for a reduction in the inflammatory processes, and the need for an increase in the oxygen diffusion gradient for optimal healing (Paulsen et al., 2012; Harrison et al., 2001). In the study of Stults-Kolehmainen et al. (2014), less stressed students showed a faster rate of recovery indicating that central factors need to be taken into account when dealing with recovery (Stults-Kolehmainen et al., 2014). In our study, the intermittent cycling exercise had a detrimental effect on perceived recovery at 72 h after the exercise. This parameter integrates psychological and physiological factors that may influence the state of recovery (Laurent et al., 2011). Performing an exercise, even at a low intensity, may be perceived by the subjects as adding a supplement of fatigue and influencing psychological factors by perturbing the perception of recovery.



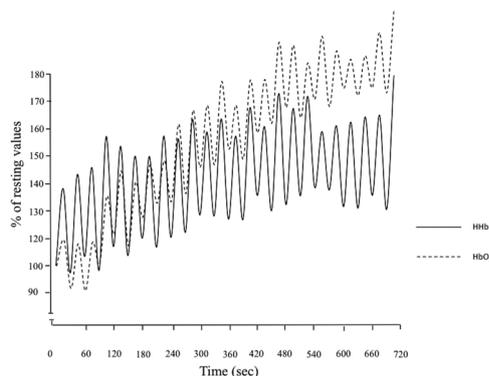
**Fig. 3.** Time-evolution of single leg (CMJ-1 L) countermovement jump in intermittent and control conditions at baseline (Pre), immediately (0 h), 20 h, 48 h and 72 h after the exercise-induced muscle damage. ES = effect size between intermittent and control. Probabilities to have an effect are presented in bracket as: (control/trivial/intermittent). NA = non-applicable.



**Fig. 4.** Time-evolution of perceived recovery (A) and muscle soreness (B) in intermittent and control conditions at baseline (Pre), immediately (0 h), 20 h, 48 h and 72 h after the exercise-induced muscle damage. ES = effect size between intermittent and control. Probabilities to have an effect are presented in bracket as: (control/trivial/intermittent). NA = non-applicable.



**Fig. 5.** Time-evolution of creatine kinase concentrations in intermittent and control conditions at baseline (Pre), 20 h, 48 h and 72 h after the exercise-induced muscle damage. ES = effect size between intermittent and control. Probabilities to have an effect are presented in bracket as: (control/trivial/intermittent). NA = non-applicable.



**Fig. 6.** Time-evolution of mean oxyhemoglobin (HbO<sub>2</sub>) and deoxyhemoglobin (HHb) during the intermittent cycling exercise. Results are expressed as percentage of resting values.

A

B

— Control  
- - - Intermittent

Muscle soreness could represent a negative feedback loop, enjoining the body to limit the involvement in a given activity and, consequently, performance (Knicker et al., 2011). In this study, the level of muscle soreness increased throughout the 72 h after exercise in both conditions, with a peak between 48 and 72 h. However, statistical analysis showed a small but likely detrimental effect of the intermittent cycling exercise at 72 h after exercise.

This study presents a limitation. the sample size was too small for some of the variables studied. A statistical power test was performed, retrospectively, for the following variables: eccentric force (power = 1), isometric force (power = 1), CMJ-1 L (power = 0.14), and CMJ-2 L (power = 0.20).

In conclusion, this study showed that implementing an intermittent cycling exercise the day after exercise-induced muscle damage may be detrimental for eccentric force recovery kinetics and subjective ratings. Results also showed no effect of the cycling exercise on single-leg countermovement jump height. From a practical point of view, implementing this kind of training session with large oxygenation does not induce faster recovery kinetics the day after a competition.

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