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Peter Leo<sup>1</sup> · Andrea Giorgi<sup>2,3</sup> · James Spragg<sup>4</sup> · Borja Martinez Gonzalez<sup>5</sup> ·  
 Iñigo Mujika<sup>6,7</sup>

<sup>1</sup>Department Sport Science, University Innsbruck, Innsbruck, Austria; <sup>2</sup>Androni Giocattoli—Sidermec Professional Cycling Team, Turin, Italy; <sup>3</sup>Department of Internal Medicine, Specialist Medicine and Rehabilitation, Azienda USL Toscana-SouthEast, Siena, Italy; <sup>4</sup>HPALS, Department of Human Biology, University of Cape Town, Cape Town, South Africa; <sup>5</sup>Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy; <sup>6</sup>Department of Physiology, Faculty of Medicine and Nursing, University of the Basque Country, Leioa, Spain; <sup>7</sup>Exercise Science Laboratory, School of Kinesiology, Faculty of Medicine, Universidad Finis Terrae, Santiago, Chile

# Impact of prior accumulated work and intensity on power output in elite/international level road cyclists—a pilot study

## Introduction

Durability plays a pivotal role in understanding the physiological and performance attributes of endurance for competition outcomes in prolonged endurance sport events such as in cycling, running or triathlon. The demands of elite/international level road cycling often encompass more than 4 h of total race duration, >160 km in length and >2000 m of elevation gain (Mujika & Padilla, 2001; Padilla, Mujika, Orbañanos, & Angulo, 2000, 2008). This suggests that successful athletes require superior endurance “durability”, which has been recently investigated in both single day and multiple day stage racing (van Erp, Sanders, & Lamberts, 2021; Leo, Spragg, Simon, Mujika, & Lawley, 2021; Muriel et al., 2021). Innovation in technology such as power meters and heart rate monitors allow to perform an in-depth analysis of the cyclists’ performance capacity in the field (Achten & Jeukendrup, 2003; Passfield, Hopker, Jobson, Friel, & Zabala, 2017). Maximum performance capacity, i.e. the power profile of a cyclist, can be assessed in the field through the analysis of mean maximal power output over different durations (Sanders & van Erp, 2021). Several studies have descriptively analysed the power profile of elite/international level road cyclists during training and rac-

ing (van Erp et al., 2021; Leo et al., 2021; Pinot & Grappe, 2011; Quod, Martin, Martin, & Laursen, 2010; Spragg, Leo, & Swart, 2022), but the underlying physiological mechanisms for an athlete’s “durability” during prolonged endurance exercise are still debated (Maunder, Seiler, Mildenhall, Kilding, & Plews, 2021).

Recent studies (van Erp et al., 2021; Leo et al., 2021) have highlighted that the decline in mean maximum power output over durations from 1 s to 30 min could be an important marker for assessing endurance “durability” in elite/international level road cycling. However, to date this has only been assessed in race settings where other factors such as differing race tactics and rider roles may have influenced the race outcome. To the best of the authors’ knowledge these findings have not been repeated experimentally in elite/international level cyclists. Thus, despite the aforementioned findings no consensus exists on how endurance “durability” could be assessed in a standardized field-testing procedure. For this reason, the aim of this brief report is to investigate the impact of prior moderate intensity continuous work (MIC) versus high intensity cycling (HII) exercise on power output as a marker of endurance “durability” in elite/international level road cyclists. The authors hypothesize that HII protocol

will induce a greater decline in 12-min power output than the MIC protocol.

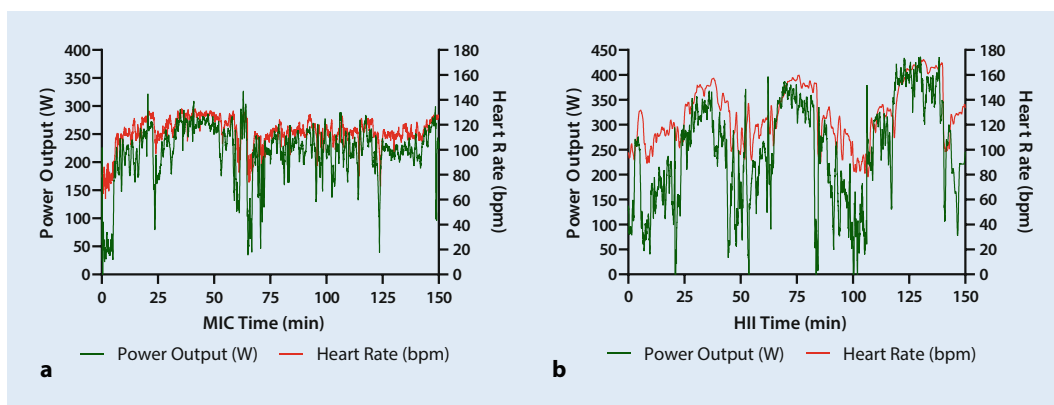
## Materials and methods

### Participants

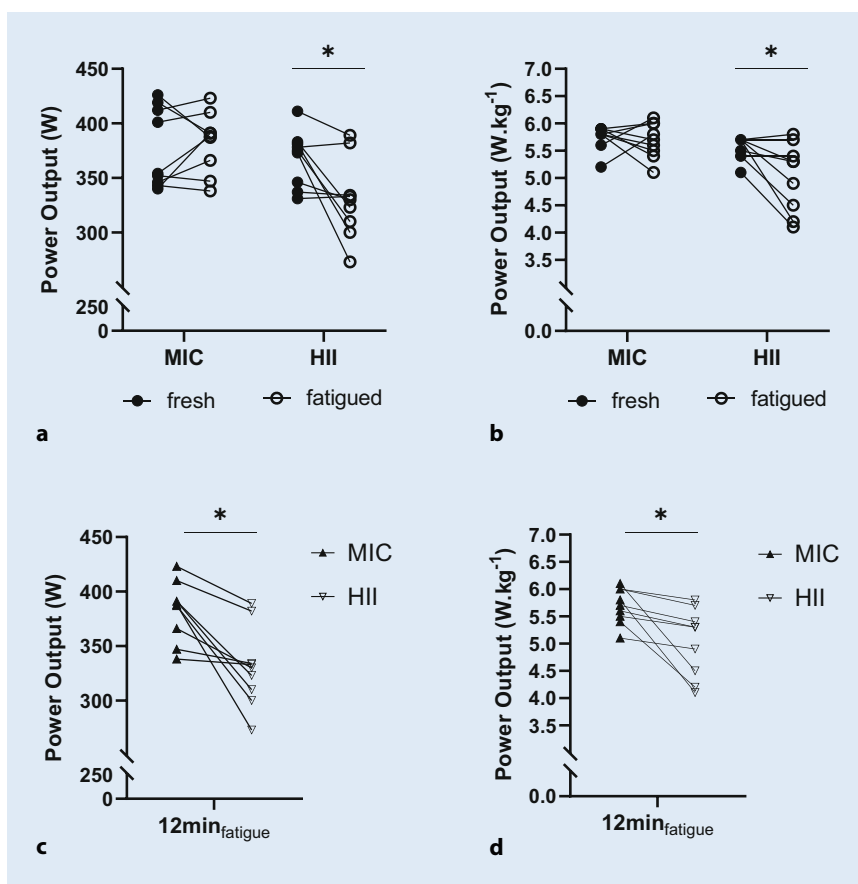
Nine elite/international level road cyclists (McKay et al., 2021) of a UCI (Union Cycliste Internationale) Pro-team (age  $26.2 \pm 4.0$  years; body mass:  $66.6 \pm 5.5$  kg; height:  $176 \pm 0.4$  cm) were recruited for a pilot study during two consecutive training camps over 10 consecutive days within 1 month of each other. All riders provided informed written consent for voluntary participation, in accordance with the requirements of the ethical review board of the University of Innsbruck and in line with the declaration of Helsinki.

### Design

All participants were assigned to a randomized and counter-balanced cross over design during two training camps within 1 month of each other, participants completed a 12-min field test in a fresh ( $12 \text{ min}_{\text{fresh}}$ ) and fatigued state ( $12 \text{ min}_{\text{fatigue}}$ ) on both occasions. On day one a  $12 \text{ min}_{\text{fresh}}$  was conducted after a 30-min low intensity individual warm-up. On day two the cyclists performed



**Fig. 1** ◀ Illustration of a 150 min moderate intensity continuous work (MIC) and b 150 min high intensity intermittent work (HII)



**Fig. 2** ▲ a Absolute and b relative power output of the 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> between MIC and HII; c absolute and d relative power output of the 12 min<sub>fatigue</sub> in MIC and HII. 12 min<sub>fresh</sub> 12-min field test in fresh condition, 12 min<sub>fatigue</sub> 12-min field test in fatigued condition, MIC moderate intensity continuous work bouts, HII high intensity intermittent work bouts, Asterisk significantly different

a 150-min moderate intensity continuous work (MIC; < 70% peak HR [HR<sub>peak</sub>]) or a 150-min race simulation (breakaway group), including several randomly build in high intensity intermittent work bouts (HII) > 80% HR<sub>peak</sub> before completing 12 min<sub>fatigue</sub> (Fig. 1). The order of MIC and HII was randomized for the training camps. The recovery phase between both

the MIC and HII and the 12 min<sub>fatigue</sub> was 30-min at rating of perceived exertion (RPE) < 2 on the Borg Category-Ratio-10 scale. 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> were conducted on the same uphill climb with an average gradient of 5.5 ± 0.2%. All tests were performed in constant ambient conditions of 11–13 °C, 50–70% relative humidity, 1.021–1.024 mm Hg

barometric pressure and 1.6–3.0 m·s<sup>-1</sup> wind speed.

### Data analysis

Power output data were recorded at a 1 Hz sampling rate using a standardized crank arm system (Stages LR; Stages Cycling Europe, Kirchzarten, Germany) which has been validated in previous research (Maier, Schmid, Müller, Steiner, & Wehrli, 2017). Heart rate (HR) data were recorded via short range telemetry at a 1 Hz sampling rate (HRM-Dual, Garmin Ltd, Schaffhausen, Switzerland). Both HR and power output data were recorded via the same head unit (Rider 320, Bryton Inc, Taipei City, Taiwan). Data spikes and erroneous values of the recorded HR and power output were visually checked by two authors (Data spikes chart, WKO5, Peaksware LLC, Lafayette, CO, USA) and manually corrected if necessary. Prior to each test the cyclists performed a zero-offset calibration of their power meter according to the manufacturer's recommendations.

Prior work and intensity were calculated as total work and percentage of time (% time) spent in four power output bands: < 1.9 W·kg<sup>-1</sup>; 2.0–4.9 W·kg<sup>-1</sup>, 5.0–7.9 W·kg<sup>-1</sup>, > 8.0 W·kg<sup>-1</sup> (Metcalf et al. 2017). HR intensity distribution was assessed as %Time spent at the following HR bands: Zone 1, < 70% HR<sub>peak</sub>; Zone 2, 70–80% HR<sub>peak</sub>; Zone 3, > 80% HR<sub>peak</sub>. HR<sub>peak</sub> was defined as the highest recorded 30 s HR during 12 min<sub>fresh</sub> in each training camp. A commercially available cycling software (WKO5, Peaksware LLC, Lafayette, CO, USA) was used for data analysis.

P. Leo · A. Giorgi · J. Spragg ·  
 B. M. Gonzalez · I. Mujika

## Impact of prior accumulated work and intensity on power output in elite/international level road cyclists—a pilot study

### Abstract

**Background.** This study aimed to investigate the impact of the intensity of prior accumulated work on the decline in power output in elite/international level road cyclists, comparing the effects of prior continuous moderate intensity versus intermittent high intensity cycling.

**Methods.** Nine elite/international level road cyclists (age  $26.2 \pm 4.0$  years; body mass:  $66.6 \pm 5.5$  kg; height:  $176 \pm 0.4$  cm) conducted a 12-min field test (12 min<sub>fresh</sub>) during two consecutive training camps. Participants then performed both a 150-min moderate intensity continuous (MIC) work bout or a 150-min high intensity intermittent (HII) race simulation in randomized order, cross-over design. After each condition a 12-min field test (12 min<sub>fatigue</sub>) was completed.

**Results.** Absolute and relative 12 min<sub>fresh</sub> power output were not significantly different between training camps ( $p > 0.05$ ). The 12 min<sub>fatigue</sub> power after HII was significantly lower than 12 min<sub>fatigue</sub> after MIC ( $\Delta = 14$  W;  $p = 0.014$ ). Participants recorded more percentage time (%Time) in heart rate (HR) zone 3 ( $\Delta = 9.2\%$ ;  $p = 0.003$ ) and power output band between 5.0–7.9 W · kg<sup>-1</sup> ( $\Delta = 8.9\%$ ;  $p = 0.002$ ) as well as higher total work ( $\Delta = 237$  kJ;  $p \leq 0.001$ ) during HII.

**Conclusion.** These findings reveal that the decline in power output is higher after HII compared to MIC cycling work bouts. This suggests that the quantification of total work and intensity should be used in conjunction to predict a distinctive decline in power output. Future research is required to better understand the mechanisms of endurance “durability” in elite/international level road cyclists.

### Keywords

Cycling · Workloads · Durability · Endurance · Power profile

## Statistical analysis

All data were checked for normality using the Shapiro–Wilk test. For descriptive purposes all data are presented as mean  $\pm$  standard deviation (mean  $\pm$  SD) or mean difference ( $\Delta$ ). A repeated measure analysis of variance (ANOVA) with a Bonferroni post hoc procedure compared absolute and relative 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> power output between MIC and HII conditions. In case of violation in sphericity a Greenhouse–Geisser correction was applied. Paired student t-tests compared %Time in HR zones, %Time in power output bands and total work between MIC and HII conditions. Effect sizes were included based on Cohen’s *d* for small (0.20 to 0.49), moderate (0.50 to 0.79) or large ( $> 0.80$ ) effects. Level of statistical significance was set at  $p < 0.05$  two tailed. Statistical analysis was conducted using an open access software package (JASP version 16.0, JASP Team, Amsterdam, The Netherlands). All figures and graphs were created with a commercial licensed software package (GraphPad Prism 8.0, GraphPad Software, San Diego, CA, USA).

## Results

Participants’ anthropometric and performance characteristics are listed in **Table 1** (mean  $\pm$  SD).

## Power output

No significant differences were found in absolute and relative 12 min<sub>fresh</sub> between the two training camps ( $p > 0.05$ ). Absolute and relative 12 min power outputs were not significantly different in 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> for MIC ( $p > 0.05$ ). Higher absolute and relative 12 min power outputs were found in 12 min<sub>fresh</sub> compared to 12 min<sub>fatigue</sub> for HII ( $\Delta = 46$  W,  $0.6$  W · kg<sup>-1</sup>;  $p = 0.002$ ,  $d = 1.39$ ,  $1.38$ ; **Fig. 2a, b**). Absolute 12 min<sub>fatigue</sub> ( $\Delta = 38$  W,  $p = 0.014$ ,  $d = 1.13$ ) and relative 12 min<sub>fatigue</sub> ( $\Delta = 0.5$  W · kg<sup>-1</sup>,  $p = 0.020$ ,  $d = 1.08$ ) were higher after MIC compared to HII work bouts (**Fig. 2c, d**).

## Training load

Prior %Time spent  $< 1.9$  W · kg<sup>-1</sup> and above  $> 8.0$  W · kg<sup>-1</sup> were not different between MIC and HII work bouts ( $p > 0.05$ ). Prior %Time spent between 2.0 and 4.9 W · kg<sup>-1</sup> was higher in MIC than in HII ( $\Delta = 13.9\%$ ,  $p \leq 0.001$ ,  $d = 1.71$ ). Prior %Time spent between 5.0 and 7.9 W · kg<sup>-1</sup> was lower in MIC than in HII ( $\Delta = 8.9\%$ ,  $p = 0.002$ ,  $d = 1.55$ ; **Fig. 3a**). %Time spent in HR Zone 1 prior to 12 min<sub>fatigue</sub> was higher in MIC than in HII ( $\Delta = 13.7\%$ ,  $p = 0.011$ ,  $d = 1.09$ ), while Zone 2 was not significantly different ( $p > 0.05$ ). In contrast %Time in Zone 3 prior to 12 min<sub>fatigue</sub> was higher in HII than in MIC ( $\Delta = 9.2\%$ ,  $p = 0.003$ ,  $d = 1.44$ ; **Fig. 3b**).

Absolute ( $\Delta = 26$  W,  $p \leq 0.001$ ,  $d = 3.03$ ) and relative ( $\Delta = 0.4$  W · kg<sup>-1</sup>,  $p \leq 0.001$ ,  $d = 2.82$ ) average power output and accumulated total work ( $\Delta = 237$  kJ,  $p \leq 0.001$ ,  $d = 3.03$ ) before 12 min<sub>fatigue</sub> were higher in HII than in MIC (**Fig. 3c, d**).

## Discussion

The main finding of the present study was that prior MIC and HII work bouts have differing effects on 12 min<sub>fatigue</sub>. While no differences were found in absolute and relative 12 min<sub>fresh</sub> power output between the two training camps, absolute and relative power outputs in 12 min<sub>fatigue</sub> were lower after the 150 min HII race simulation session compared to the 150 min MIC work bout. Recent research focussed on the decline in power output after prior accumulated work in elite/international level road cycling through the analysis of race derived power output data (van Erp et al., 2021; Leo et al., 2021; Mateo-March et al., 2022; Muriel et al., 2021; Spragg et al., 2022). However, to the best of the authors’ knowledge this is the first study to experimentally confirm these findings in elite/international level cyclists. Recent research demonstrated that U23 cyclists experienced a decline in the power profile already after 1500 kJ, while elite/international level road cyclists only suffered reductions in their power profile after  $\sim 2500$  kJ (van Erp et al., 2021; Leo et al., 2021; Muriel et al., 2021). However, due to the research de-

**Table 1** Participants' descriptive performance characteristics

	Body mass (kg)	HR <sub>peak</sub> (bpm)	12 min <sub>fresh</sub> (W)	12 min <sub>fatigue</sub> (W)	12 min <sub>fresh</sub> (W·kg <sup>-1</sup> )	12 min <sub>fatigue</sub> (W·kg <sup>-1</sup> )
MIC	66.3 ± 5.8	200 ± 5	377 ± 36	368 ± 25*	5.6 ± 0.3	5.5 ± 0.2**
HII	66.6 ± 5.5	198 ± 7	382 ± 27***	330 ± 36*,***	5.7 ± 0.2****	5.0 ± 0.6**,****

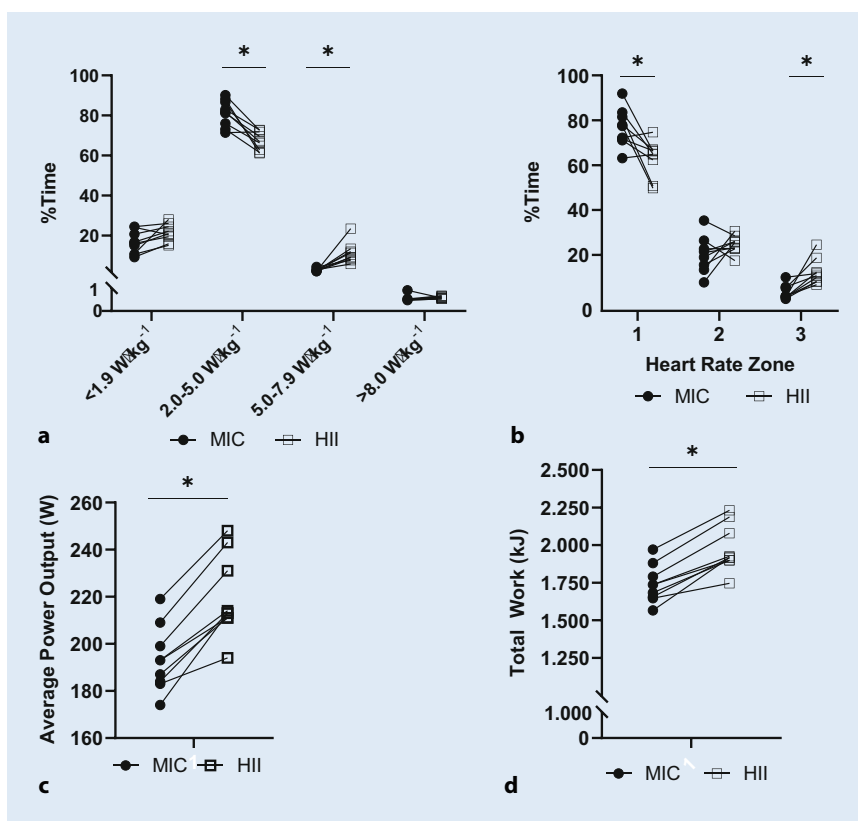
12 min<sub>fresh</sub> average 12 min field test absolute and relative power output in fresh condition, 12 min<sub>fatigue</sub> average 12 min field test absolute and relative power output in fatigued condition, HR<sub>peak</sub> peak heart rate, MIC moderate intensity continuous work bouts, HII high intensity intermittent work bouts, SD standard deviation

\*significantly different between 12 min<sub>fatigue</sub> MIC and HII for absolute power

\*\*significantly different between 12 min<sub>fatigue</sub> MIC and HII for power normalized to body mass

\*\*\*significantly different between 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> for HII absolute power

\*\*\*\*significantly different between 12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> for HII power normalized to body mass



**Fig. 3** ▲ **a** Power output intensity distribution, **b** heart rate zone distribution, **c** average power output and **d** total work prior to the 12-min field test in fatigued conditions. MIC moderate intensity continuous work bouts, HII high intensity intermittent work bouts, %Time percentage time in power output bands and heart rate zones, Asterisk significantly different

sign of these studies it was not possible to rule out the influence of different rider roles. For example those riders who had finished their team job may have ridden to the finish with the goal of simply finishing the stage rather than competing further. Alongside the accumulation of total work, the intensity and workout structure (continuous vs. intermittent) at which this work is performed should not be neglected. In the present study the average decline in power output between

12 min<sub>fresh</sub> and 12 min<sub>fatigue</sub> was 15.7% in the HII compared to 2.4% in the MIC protocol, indicating that HII work bouts induced a greater decline in power output than MIC work bouts. Internal and external workload characteristics indicated 13.6% more accumulated total work and 9.2% more time in HR Zone 3 during the HII work bout. Moreover, the HII work bout recorded 9.0% more time in the 5.0 and 7.9 W·kg<sup>-1</sup> power output bin prior to the 12 min<sub>fatigue</sub> test than during

MIC. Whilst more work was completed during the HII work bout the authors do not feel that that the additional work per se was the main driver of the difference in 12 min<sub>fatigue</sub> between MIC and HII. Therefore, the authors believe that these findings demonstrate that both prior accumulated work and intensity need to be quantified accordingly in order to properly interpret the decline in power output and assess cyclists' "durability". The underlying physiological mechanisms to explain the decline in power output over time have been investigated in laboratory experiments in moderately trained athletes (Black et al., 2017; Clark et al., 2018), and have been attributed to a combination of both muscle metabolic and neuromuscular factors which differ dependant on the exercise intensity domain at which prior exercise is undertaken. As hypothesized, the results of the present study reveal that the accumulation of high intensity internal and external work induced a greater decline in 12 min power output than the accumulation of total work alone.

Despite these promising findings, the present pilot study is not without its limitations. Assessing RPE during MIC and HII work bouts would have contributed to a better understanding of the psychophysiological requirements of the prior fatiguing task alongside HR recordings. In addition, the results should be interpreted cautiously due to the small sample size of nine cyclists whilst a work matched HII and MIC protocol would have allowed for better direct comparison between the resultant decline in 12 min power output as a result of exercising at differing intensities.

The authors recommend future research in this field to better understand the complex interplay of power output capabilities under the umbrella of prior accumulated internal and external work and intensity metrics.

## Corresponding address



**Peter Leo**  
Department Sport Science,  
University Innsbruck  
Innsbruck, Austria  
peter.leo@uibk.ac.at



**Andrea Giorgi**  
Department of Internal  
Medicine, Specialist Medicine  
and Rehabilitation, Azienda  
USL Toscana-SouthEast  
Siena, Italy  
andreagiorgi4@gmail.com

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## Declarations

**Conflict of interest.** P. Leo, A. Giorgi, J. Spragg, B.M. Gonzalez and I. Mujika declare that they have no competing interests.

All studies mentioned were in accordance with the ethical standards indicated in each case.

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