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Article *in* International Journal of Sports Medicine · November 2011

Impact Factor: 2.07 · DOI: 10.1055/s-0031-1283181 · Source: PubMed

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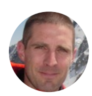

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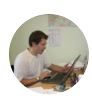

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Compression Sleeves Increase Tissue Oxygen Saturation But Not Running Performance

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Key words
- external compression
- near infra-red spectroscopy
- recovery
- exhaustion

Abstract

The purpose of this study was to determine the effects of calf compression sleeves on running performance and on calf tissue oxygen saturation (StO_2) at rest before exercise and during recovery period. 14 moderately trained athletes completed 2 identical sessions of treadmill running with and without calf compression sleeves in randomized order. Each session comprised: 15 min at rest, 30 min at 60% maximal aerobic velocity determined beforehand, 15 min of passive recovery, a running time to exhaustion at 100% maximal aerobic velocity, and 30 min of passive recovery. Calf StO_2 was determined by near infra-red spectroscopy and running performance by the time to exhaustion. Compression sleeves increased significantly StO_2 at rest before exercise (+6.4±1.9%) and during recovery from exercise (+7.4±1.7% and +10.7±1.8% at 20th and 30th min of the last recovery period, respectively). No difference was observed between the times to exhaustion performed with and without compression sleeves (269.4±18.4 s and 263.3±19.8 s, respectively). Within the framework of this study, the compression sleeves do not improve running performance in tlim. However the StO_2 results argue for further interest of this garment during effort recovery.

accepted after revision
May 19, 2011

Bibliography
DOI http://dx.doi.org/10.1055/s-0031-1283181
Int J Sports Med 2011; 32: 1–5 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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Introduction

In sports, the recovery is defined as the necessary period after a performance for the athletes to gain a state in which they are able to reproduce an equal performance [26]. Recovery focuses the attention of athletic trainers, on the one hand because it is essential to preserve the athlete's health, on the other hand because the reiteration of the performance, sometimes over very short periods, requires a perfect recovery between the events. Within this latter framework and because of their properties, the interest for compression garments is rising. Indeed, it is accepted that an external pressure applied to the calf reduces the venous pooling [10], lowers the blood lactate concentration during and after exercise [13] and thus facilitates exercise recovery [13]. This pressure is also associated with a reduction of shock waves generated during exercise practice on hard ground thus decreasing the risk of wounds [16].
Bochmann et al. [7] observed an increase in forearm perfusion flow during the application of a local compression amounting to 20 mmHg. A better tissue perfusion rate improves the recovery after exercise [8]. Thus, external compression should affect calf tissue oxygen saturation (StO_2) during the recovery after exercise, which may in turn improve the subsequent running performance.
However, few studies have estimated the effects of compression on StO_2 during exercise recovery. Thus, the aim of this study was to test the hypothesis that calf compression sleeves increase calf StO_2 and running performance. Near Infrared Spectroscopy was used to measure calf StO_2 at rest before a running exercise and during recovery [14]. To better highlight the effects of external compression, the running exercise was split in 2 phases: an initial exercise, intended to first tire the subject, and then a running time to exhaustion at 100% maximal aerobic velocity, to assess performance and obtain a fast exhaustion of the subject.

Methods

Subjects

14 young men (21.9±0.7 years, 177.6±1.9 cm, 67.2±2.4 kg) moderately trained in endurance (3.13±0.3 h per week), volunteered to take part in

the present study, after being fully informed about the study organization and implications. According to a medical interview, all were healthy with no history of cardiopulmonary disease or medication. The protocol complied with the Helsinki declaration and was approved by a local ethic committee [20].

Experimental protocol

The experimental protocol was composed of 3 sessions held 1 week apart. For each subject a session was realized on the same day of the week, at the same hour (between 2 PM and 6 PM), with similar environmental conditions (temperature: 22.1 ± 1.1 °C, hygrometry: 41.6 ± 2.3 %). The subjects' daily habits were unchanged during this period (food, load of training, etc).

Performing intensive training or competition was prohibited 72 h before each session.

The first session was used to determine individual maximal aerobic velocity and maximal heart rate (HR_{max}). After a 10 min warm-up, the subjects performed an incremental exercise test on treadmill (Mirage Care Fitness, Bobigny, France), according to the protocol by Léger and Boucher [21], with a 12 % slope in order to limit the maximal speed attainable by the subjects. Beginning at 6 km/h, the velocity was then increased by 0.5 km/h each min. The test ended when the subjects could no longer sustain the imposed velocity. MAV was defined as the velocity performed during the last fully completed stage.

Average results for the group of subjects were 13.8 ± 1.5 km/h and 198.5 ± 2.1 bpm for MAV and HR_{max}, respectively.

The 2 other sessions were identical apart from the subjects being with or without the calf compression sleeves (CS) in randomized order. The design included 5 periods (**Fig. 1**): 15 min at rest (A), 30 min at 60 % MAV (60 %MAV), 15 min of recovery (B), a running time to exhaustion at 100 % MAV (tlim), and a last 30 min recovery period (C). The subject position during A, B and C was standardized: sitting with legs in the horizontal. The 2 running trials were carried out on a 12 % treadmill slope.

Compression sleeves

The CS used in the present study (Compressport, Geneva, Switzerland), were composed of 72 % nylon and 28 % elastane. The size of garments was chosen according to the individual calf size. The pressure applied on the calf was gradually increased from 15 mmHg at the medial ankle to 27 mmHg at the top of gastrocnemius (values provided by the manufacturer).

Tissue oxygen saturation

StO_2 was continuously and non-invasively measured with the NIRS technique of the InSpectra™ StO_2 Tissue Oxygenation Monitor, Model 650 (Hutchinson Technology, Hutchinson, MN, USA). The measurement principles of this technology have been described [18] and its accuracy and its reproducibility have been established previously [24]. The microcirculatory StO_2 assessment is defined as the ratio [HbO2]/[Hb]+[HBO2] expressed as percent, with HbO2 and Hb being oxy- and deoxygenated hemoglobin, respectively. The technology of the device does not allow to obtain direct values of HbO_2 and Hb.

StO_2 was recorded at the level of the side chief of the right gastrocnemius muscle, 12 cm below the fibula head [23]. A transparent film was placed between the skin and the probe to protect it from sweat [5].

StO_2 was recorded during A, B and C. StO_2 values were measured during A at 3, 6, 9, 12 and 15 min, during B at 5 and 10 min, and during C at 5, 10, 20 and 30 min (**Fig. 1**). The StO_2 value recorded for each time was the average of values recorded 10 s before to 10 s after this time. StO_2 values were analyzed with StO_2 Researcher's Analysis Software Version 4 (Hutchinson Technology, Hutchinson, MN, USA).

Effect of pressure on StO_2

During the exercise session performed without the CS, the probe was secured on the cleaned skin surface with tape without enclosing the calf. When the session was carried out with the CS, the probe was fixed the same way but placed between the skin and the CS. It has recently been shown that application of pressure to the skin surface of the human hand may activate non-nociceptive skin receptors in the underlying tissue layers and induce in turn cutaneous vasodilatation [1,19]. It was also observed that skin blood flow affects NIRS measures of muscle oxygen saturation [11]. Therefore, a device was set up to measure the part of skin blood flow in the StO_2 signal with CS (**Fig. 2**). In 8 control subjects, an increasing (5 mmHg/min up to 50 mmHg) external pressure was applied exactly on the probe, using a pneumatic compression. An adjustable cage prevented application of pressure on the limb, apart from the probe.

Running exercises

Heart rate (HR) was continuously recorded with a cardiac telemetry device Polar Team² Pro (Polar Electro, OY, Kempele Finland). During the 60 %MAV, the average HR recorded in the 2 last min was considered. During the tlim, the peak heart rate (HR_{peak}) was averaged over the last 10 s.

A scale of subjective perception of exercise (Borg CR10 Scale, [9]) was used to quantify the difficulty and the constraint perceived by subjects at the end of each exercise. This scale ranges from 0, note for which the subject does not feel any pain and any difficulty, to 10 or 11, maximum pain and difficulty.

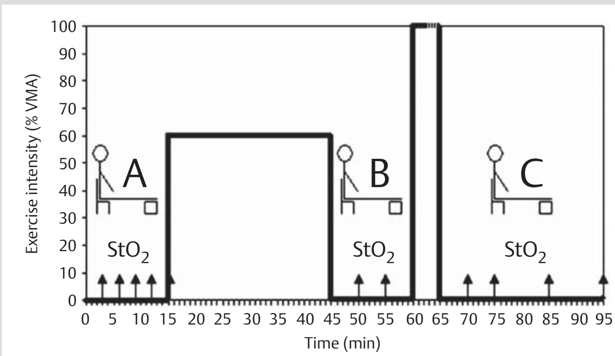

Fig. 1 Design of the study.

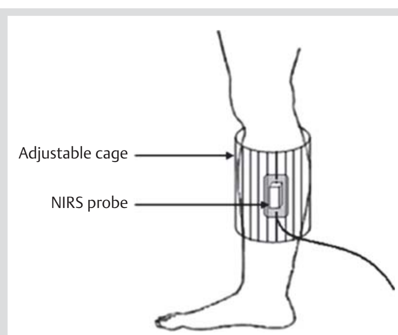

Fig. 2 Set-up used to check how external pressure affects skin blood flow.

To observe a possible CS impact on running performance, limit times (tlim) were recorded with and without CS. To avoid any bias, the subjects were kept unaware of their running time.

Statistical analysis

The normality of value distribution within series was assessed with the Kolmogorov-Smirnov test. Two-way analysis of variance with repeated measures (ANOVA) was used to compare StO_2 values over the time (A, B and C) and conditions (CS and control).

One-way repeated measures ANOVA was used to compare StO_2 values recorded with different pressure grades. Bonferroni post-hoc procedures were used when necessary. Student's t-test was used to compare HR and CR10 observed in both conditions. Statistical analysis was performed using SigmaStat for Windows 3.1 (Systat Software Inc., San Jose, CA, USA). All results are presented as mean ± SEM. Statistical significance was set at $p < 0.05$.

Results

Tissue oxygen saturation (Fig. 3)

Within each condition (without or with CS) no difference was found between A3, A6, A9, A12 and A15. Therefore these values were averaged and, in further analysis of results, the average named A was considered as the baseline A value.

Without CS, StO_2 was higher at B5 and C5 than during A. With longer recovery time, StO2 decreased and was no more different from A at C20 and C30.

With CS, StO_2 was higher at B5 and C5 than during A. With longer recovery time, StO_2 remained not significantly different from C5 and was still higher than A StO_2 at C30.

During A, wearing the CS led to higher StO_2 values than without CS (+6.4 ± 1.9 %). During C, an influence of CS on StO_2 was apparent from the 10^{th} min. Indeed, with CS StO_2 was higher at C10 (+3.1 ± 1.1 %), C20 (7.4 ± 1.7 %) and C30 (10.7 ± 1.8 %).

In both conditions, StO_2 was higher at B5 than at C5.

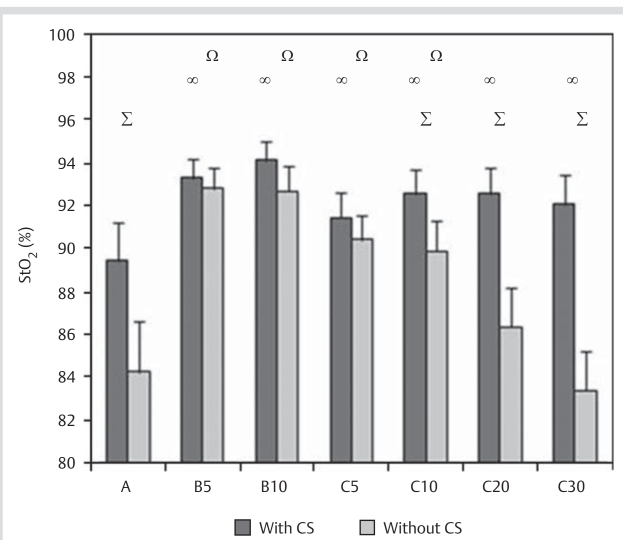

Fig. 3 Comparison between StO_2 values recorded with and without CS. ∑: Significantly different between With vs. Without CS at the same time. ∞ : Significantly different between A vs. B and C, with CS. Ω : Significantly different between A vs. B and C, without CS.

Effect of pressure on StO_2

StO_2 increased with increasing pressures applied on the probe. At 20 mmHg, a pressure similar to that exerted by CS on the probe, a 3.3 ± 0.4 % increase in StO_2 was recorded. The highest pressure (50 mmHg) led to the highest increase (+ 8.8 ± 1.9 %).

Running exercises

The average HR over the last 2 min of the 60 %MAV test, was not different with (175.44 ± 3.0 bpm) or without (175.33 ± 3.3 bpm) the CS. The CS did not change the subjective perception of exercise (4.7 ± 0.4 units and 4.3 ± 0.2 units with and without CS, respectively). During tlim, no difference was observed between HR_{max} reached with (197.6 ± 1.9 bpm) and without CS (196.8 ± 2.0 bpm). All recorded CR10 notes ranged between 10 and 11, and they were strictly identical in the 2 sessions.

No significant difference was found in tlim (269.4 ± 18.4 s and 263.3 ± 19.8 s with and without CS, respectively). With the CS, 8 athletes performed a longer tlim whereas for 5 athletes, the tlim was shorter.

Discussion

Main results about StO_2

5 min after the end of each exercise (B5 and C5), StO_2 was higher than at rest before exercise for both with and without CS. This finding is in agreement with another study that reported an increased StO_2 3 min after a maximal exercise [17]. This is related to the large increase in muscular blood volume immediately after exercise and associated with large oxygen availability. Using NIRS, a reactive hyperemia was observed 5 min after exercise in rowers [12]. This transient increase of local circulatory flow participated to the compensation of local oxygen deficit contracted during exercise, to reconstitution of energy stocks and to the evacuation of the metabolites resulting from muscle contraction [15].

With and without CS, StO_2 was lower at C5 than B5, to compensate the higher contribution of anaerobic energy production during the exhausting exercise tlim compared to the submaximal 60 %MAV exercise [4].

Positive effects of CS on calf StO_2 were observed at rest before exercise (+ 6.4 ± 1.9 %) and during the prolonged recovery period after exercise [7]. Without CS, StO_2 decreased gradually from 5 min post exercise to reach the pre-exercise value after 20 min of recovery. On the other hand, StO_2 remained higher than pre-exercise value throughout the recovery period with CS. The higher StO_2 may rely on several mechanisms including: a higher muscle flow rate and changes in skin blood flow.

Higher flow rate

It has been reported that perfusion of the human forearm increased during application of external compression over a pressure range of 13–23 mmHg [7]. This pointed to an autoregulatory myogenic response following the decrease in vascular transmural pressure [22]. Thus, an increased perfusion likely contributed to the observation of a higher StO_2 with CS, particularly at rest before exercise. This increased perfusion highlights a positive effect of CS that may be beneficial for exercise recovery [10].

Changes in skin blood flow

The device used in the present experiment calculated StO_2 in vessels situated in the skin and muscle underneath [11, 25]. Thus the higher StO_2 observed with CS may have resulted mainly from changes in skin blood flow. Increasing the external pressure applied to the skin by 5 mmHg/min causes an increase in skin blood flow in the area submitted to pressure [1, 19]. In these studies, an average pressure of 37.5 mmHg led to the highest skin blood flow. Accordingly, in the present study it was observed that a 20 mmHg pressure applied on the probe increased StO_2 by 3.3 ± 0.4 %.

It is also possible that any pressure applied directly on the probe can change the area of investigation under the probe, and finally the light signal received by the probe. Indeed, in the present study, during the incremental pressure protocol, the highest pressure applied (50 mmHg) led to the highest increase in StO2.

Skin blood flow also changes with ambient temperature: cold reflex-wise triggers cutaneous vasoconstriction and heat causes vasodilatation [27]. StO_2 may thus be affected by changes in skin temperature [11, 25]. Tew et al. [25] observed that when skin temperature (over the vastus lateralis) increased from 32.9 °C ± 0.6 to 36.0 ± 0.3 °C and to 39.4 ± 0.6 °C, the resting StO_2 increased also from 69 ± 8 % to 71 ± 7 % and 73 ± 6 %, respectively. In a complementary study, during 15 min of quiet rest, CS caused a significant increase in calf temperature (from 28.7 ± 0.4 °C to 30.3 ± 0.2 °C) (unpublished observations). These findings suggest that CS slightly affect StO_2 measures at rest through temperature changes. Calf temperature was not measured during recovery periods, but after exercise CS could decrease skin heat dispersal. Consequently the higher temperature related to the skin blood flow during recovery would raise StO_2 values and enlarge the difference between StO_2 values with and without CS during period C.

Main results about running performance

In this study, CS did not significantly influence the running performance, in spite of a small improvement with CS (+2.3 %). Although such an improvement can still be compared with the results obtained in another study [13], our result has to be considered in regard to the protocol design and more specifically to the running conditions (slope and speed). The results may have been different in other running conditions. However, such results are in accordance with the literature which does not point to any particular trend [2, 13]. Several explanations are given. Firstly, a lot of different protocols (duration, intensity and type of exercises, different kind of garments) were used which makes it difficult to compare results.

In another study, compression stockings (ECS) worn during recovery from a first exercise increased the subsequent performance [13]. There are at least 3 reasons which could explain the difference to the results of this present study. Firstly, the first exercise in the study of Chatard et al. was a 5-min maximal exercise which induced a high blood lactate concentration. In the present study the intensity of the first exercise was likely too low to induce a high lactate production rate and a significant exhaustion (CR10 was 4.7 ± 0.4 units and 4.3 ± 0.2 units with and without CS, respectively). It is possible that the beneficial effect of wearing ECS between 2 exercises is related to the level of exhaustion reached during the first exercise period. Secondly, the area compressed by the garment was lower in the present study (calf vs. entire leg in the study of Chatard et al.) which may impact differently the venous return and muscle perfusion [3]. Finally, the psychological determinants of the different types of exercise used can be considered as a third reason to explain the discrepancy between the results. Indeed, during a time limit exercise at fixed intensity (as used in the present study) and during a maximal intensity exercise of fixed duration (as used in the study of Chatard et al.) the psychological determinants of the performance are completely different, which can influence greatly the reliability of the test. During a time limit performed at VO_2max, individual variations higher than 100 s exist between 2 sessions (in the present study, the differences were between 5 and 108 s), due to large psychological determinants for this kind of exercise[6].

In conclusion, the major finding of this investigation was a significant increase in calf StO_2 with CS at rest before exercise and during a prolonged recovery of 30 min after an exhaustive running exercise. This increase in calf StO_2 is probably explained by an increase in perfusion flow and by changes in skin blood flow (pressure and temperature effects). This has to be confirmed by another study using NIRS technology with infusion of a dye or application of an occlusion to directly measure the blood flow. Conversely, no improvement in running performance was found. The poor reproducibility of the tlim test represents another limit of this study. Future studies are needed to precisely define the physiological mechanisms which lead to StO_2 increase and to verify if athletic performance could be enhanced by CS.

Acknowledgements

The authors declare that they have no conflict of interest. They wish to thank the subjects for their time and enthusiastic cooperation and C Capitan and V Dupuis for their help. The present study was supported by the EA3920 'Cardiovascular Physiopathology and prevention' and Compressport®.

References

1 *Abraham P, Fromy B, Merzeau S, Jardel A, Saumet JL.* Dynamics of local pressure-induced cutaneous vasodilation in the human hand. Microvasc Res 2001; 61: 122–129
2 *Ali A, Caine MP, Snow BG.* Graduated compression stockings: physiological and perceptual responses during and after exercise. J Sports Sci 2007; 25: 413–419
3 *Benko T, Cooke EA, McNally MA, Mollan RA.* Graduated compression stockings: knee length or thigh length. Clin Orthop Relat Res 2001: 197–203
4 *Berry MJ, Bailey SP, Simpkins LS, TeWinkle JA.* The effects of elastic tights on the post-exercise response. Can J Sport Sci 1990; 15: 244–248
5 *Bhambhani YN.* Muscle oxygenation trends during dynamic exercise measured by near infrared spectroscopy. Can J Appl Physiol 2004; 29: 504–523
6 *Billat V, Renoux JC, Pinoteau J, Petit B, Koralsztein JP.* Reproducibility of running time to exhaustion at VO2max in subelite runners. Med Sci Sports Exerc 1994; 26: 254–257
7 *Bochmann RP, Seibel W, Haase E, Hietschold V, Rodel H, Deussen A.* External compression increases forearm perfusion. J Appl Physiol 2005; 99: 2337–2344
8 *Bogdanis GC, Nevill ME, Lakomy HK, Graham CM, Louis G.* Effects of active recovery on power output during repeated maximal sprint cycling. Eur J Appl Physiol 1996; 74: 461–469
9 *Borg G, Ljunggren G, Ceci R.* The increase of perceived exertion, aches and pain in the legs, heart rate and blood lactate during exercise on a bicycle ergometer. Eur J Appl Physiol 1985; 54: 343–349
10 *Bringard A, Denis R, Belluye N, Perrey S.* Effects of compression tights on calf muscle oxygenation and venous pooling during quiet resting in supine and standing positions. J Sports Med Phys Fitness 2006; 46: 548–554
11 *Buono MJ, Miller PW, Hom C, Pozos RS, Kolkhorst FW.* Skin blood flow affects in vivo near-infrared spectroscopy measurements in human skeletal muscle. Jpn J Physiol 2005; 55: 241–244
12 *Chance B, Dait MT, Zhang C, Hamaoka T, Hagerman F.* Recovery from exercise-induced desaturation in the quadriceps muscles of elite competitive rowers. Am J Physiol 1992; 262: C766–C775

13 *Chatard JC, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guezennec CY.* Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. Eur J Appl Physiol 2004; 93: 347–352
14 *De Blasi RA, Ferrari M, Natali A, Conti G, Mega A, Gasparetto A.* Noninvasive measurement of forearm blood flow and oxygen consumption by near-infrared spectroscopy. J Appl Physiol 1994; 76: 1388–1393
15 *Di Prampero PE, Boutellier U, Pietsch P.* Oxygen deficit and stores at onset of muscular exercise in humans. J Appl Physiol 1983; 55: 146–153
16 *Doan BK, Kwon YH, Newton RU, Shim J, Popper EM, Rogers RA, Bolt LR, Robertson M, Kraemer WJ.* Evaluation of a lower-body compression garment. J Sports Sci 2003; 21: 601–610
17 *Dupouy C, Dussault C, Kahn JF, Tinet E, Avrillier S, Ollivier JP, Jouanin JC.* Evaluation of vastus lateralis oxygenation during incremental exercise using near infrared spectroscopy of haemoglobin. Sci Sports 2007; 22: 97–103
18 *Ferrari M, Mottola L, Quaresima V.* Principles, techniques, and limitations of near infrared spectroscopy. Can J Appl Physiol 2004; 29: 463–487
19 *Fromy B, Abraham P, Saumet JL.* Non-nociceptive capsaicin-sensitive nerve terminal stimulation allows for an original vasodilatory reflex in the human skin. Brain Res 1998; 811: 166–168
20 *Harriss DJ, Atkinson G.* International Journal of Sports Medicine – ethical standards in sport and exercise science research. Int J Sports Med 2009; 30: 701–702
21 *Leger L, Boucher R.* An indirect continuous running multistage field test: the Universite de Montreal track test. Can J Appl Sport Sci 1980; 5: 77–84
22 *Lott ME, Herr MD, Sinoway LI.* Effects of transmural pressure on brachial artery mean blood velocity dynamics in humans. J Appl Physiol 2002; 93: 2137–2146
23 *Olivier N, Weissland T, Rogeza J, Legrand R, Berthoin S, Thevenon A, Prieur F.* Effect of a one leg cycling aerobic training on muscle oxygenation and blood volume after knee surgery. Sci Sports 2009; 24: 323–326
24 *Quaresima V, Lepanto R, Ferrari M.* The use of near infrared spectroscopy in sports medicine. J Sports Med Phys Fitness 2003; 43: 1–13
25 *Tew GA, Ruddock AD, Saxton JM.* Skin blood flow differentially affects near-infrared spectroscopy-derived measures of muscle oxygen saturation and blood volume at rest and during dynamic leg exercise. Eur J Appl Physiol 2010; 110: 1083–1089
26 *Vaile J, Halson S, Gill N, Dawson B.* Effect of hydrotherapy on recovery from fatigue. Int J Sports Med 2008; 29: 539–544
27 *Wilcock IM, Cronin JB, Hing WA.* Physiological response to water immersion: a method for sport recovery? Sports Med 2006; 36: 747–765