Compression Socks and Functional Recovery Following Marathon Running: A Randomized Controlled Trial

Stuart A. Armstrong,[1] Eloise S. Till,[2] Stephen R. Maloney,[3] and Gregory A. Harris[4]

[1]Anglesea Sports Medicine, Hamilton, New Zealand; [2]Albury Emergency Department, Albury Wodonga Health, Albury, Australia; [3]Department of Physiotherapy, Monash University, Melbourne, Australia; and [4]MP Sports Physicians, Melbourne, Australia

Abstract

Armstrong, SA, Till, ES, Maloney, SR, and Harris, GA. Compression socks and functional recovery following marathon running: A randomized controlled trial. *J Strength Cond Res* 29(2): 528–533, 2015—Compression socks have become a popular recovery aid for distance running athletes. Although some physiological markers have been shown to be influenced by wearing these garments, scant evidence exists on their effects on functional recovery. This research aims to shed light onto whether the wearing of compression socks for 48 hours after marathon running can improve functional recovery, as measured by a timed treadmill test to exhaustion 14 days following marathon running. Athletes ($n = 33$, age, 38.5 $\pm$ 7.2 years) participating in the 2012 Melbourne, 2013 Canberra, or 2013 Gold Coast marathons were recruited and randomized into the compression sock or placebo group. A graded treadmill test to exhaustion was performed 2 weeks before and 2 weeks after each marathon. Time to exhaustion, average and maximum heart rates were recorded. Participants were asked to wear their socks for 48 hours immediately after completion of the marathon. The change in treadmill times (seconds) was recorded for each participant. Thirty-three participants completed the treadmill protocols. In the compression group, average treadmill run to exhaustion time 2 weeks after the marathon increased by 2.6% (52 $\pm$ 103 seconds). In the placebo group, run to exhaustion time decreased by 3.4% (-62 ± 130 seconds), $P = 0.009$. This shows a significant beneficial effect of compression socks on recovery compared with placebo. The wearing of below-knee compression socks for 48 hours after marathon running has been shown to improve functional recovery as measured by a graduated treadmill test to exhaustion 2 weeks after the event.

Key Words aerobic fitness, recovery markers, delayed onset muscle soreness, time to exhaustion, treadmill test, muscle damage

Address correspondence to Stuart A. Armstrong, drsarmstrong@gmail.com.

29(2)/528–533

Journal of Strength and Conditioning Research

Introduction

The belief that compression garments can aid recovery for athletes has been increasingly popular across various sporting disciplines. There is a great deal of data to indicate compression garments should improve recovery because of their favorable biochemical and physiological benefits (1–4,6,8,10,11,20,21,23,24), but there are dearth of data to show an actual functional benefit. This trial aims to address whether compression garments conferred a functional benefit.

Functional recovery can be considered sport specific and rather than analyze a change in static or dynamic muscle strength to determine recovery, functional recovery is measured by looking at completion of exercise specific to the athlete's sport. It has been shown that $\dot{V}O_2$max is a poor predictor of subsequent marathon time, but peak velocity during a graded treadmill test correlates well with subsequent marathon time (19). Peak velocity during a graded treadmill test can be equated to the time to exhaustion during the same test, as there is a progressive increase in velocity throughout the test.

Following exhaustive exercise, participants frequently experience significant delayed onset muscle soreness (DOMS). This is typically present 1–5 days after exertion (1,6,24) and is closely correlated with ultrastructural muscle damage as demonstrated on postexertion muscle biopsy (13,25). This has also been indicated by increased levels of creatinine kinase (CK), interleukin 6 (IL-6), and lactate levels following exercise (21). Marathon running has been shown to increase IL-6 levels by up to 100-fold from baseline (20). Creatinine kinase levels have been shown to be closely correlated with both IL-6 levels and the degree of muscle damage (5).

Following endurance exercise, there is considerable venous pooling in the lower limbs (12), this leads to a dramatic fall in venous return and an increase in the time to excretion of muscle damage waste products such as CK and lactate. These "waste" products are thought to cause damage to healthy muscle cells.

Compression socks have been shown to have beneficial effects on self-reported DOMS when worn following running or plyometric exercise (2,11). They have also been shown to decrease measured levels of CK and lactate when worn following exercise (3,23). This indicates enhanced repair of the body's musculature at low levels of tissue damage as experienced following exhaustive running (16). They have a well-documented effect of increasing lower-limb venous return and decreasing venous pooling postexercise, which has been associated with dramatic increases in lower-limb oxygenation (4,8). It has also been shown that lower-limb compression garments reduce recovery heart rate immediately following exercise, further aiding their potential use as a recovery strategy (17).

Compression garments have also been shown to augment lower-limb "muscle pump" action thereby increasing cardiac venous return in preparation for renal perfusion and blood-borne waste product removal (15). It is thought that compression garments achieve this effect by creating an external pressure gradient, which reduces available space for muscle edema to occur and thereby reduces the secondary inflammatory response (10).

Improvement in these markers of muscle damage could be assumed to herald an increased recovery effect from compression garments; this has been demonstrated in previous studies looking at short-term recovery in cyclists and after intense resistance training (7,9,16). These studies looked at short-term recovery between repeated bouts of exercise separated by 24 hours or less. It would be difficult to extrapolate this to running because of the different biomechanics and muscle fatigue profile between cycling or heavy resistance training and running (18). To date, there have been no studies looking at functional recovery following exhaustive running and the use of compression garments. There has been 1 recent study showing a trend to significance in measures of maximum voluntary isometric contraction, CK, and C-reactive protein levels following marathon running (14).

If compression socks produce beneficial effects on recovery following exhaustive exercise, they could provide a benefit in recovery from both training and competition. This information would aid runners, strength and conditioning specialists, athletic trainers, and coaches to increase the training efficiency of their programs.

The primary aim of this study was to determine if lower-limb compression garments impact on the functional recovery from distance running.

Methods

Experimental Approach to the Problem

This study used a randomized controlled double-blinded design to determine the functional recovery effects of wearing below-knee compression socks compared with placebo noncompressive below-knee socks. Participants were randomized by a computer-generated random number into either the compression sock group or the placebo noncompressive group. The compression socks used were medical grade below-knee Jobst compression socks (BSN Medical Inc., Rutherford College, NC, USA) with a compressive value at the ankle of 30–40 mm Hg and at the calf of 21–28 mm Hg, which is typical of many of the compression socks commercially available to customers (Figure 1). The placebo socks used were minimal-compressive SmartKnit seamless knee-high diabetic socks (Knit-Rite Inc., Kansas City, KS, USA), designed to only give enough compression to stop them falling down. Calf circumference and shoe size data were collected from each participant to ensure correct fit as per the manufacturers instructions.

The premarathon and postmarathon treadmill tests were performed 2 weeks before and 2 weeks after each study participant's respective marathon. Study participants were asked to begin wearing their socks within 1 hour of finishing their marathon and were asked to wear them continuously for 48 hours following this.

The study was multicentered covering the 2012 Melbourne, 2013 Canberra, and 2013 Gold Coast marathons.

Subjects

Twenty-two moderately trained runners competing in the 2012 Melbourne marathon, 17 moderately trained runners competing in the 2013 Canberra marathon, and 20 moderately trained runners competing in the 2013 Gold Coast marathon were randomized in the study. In total, 33 completed the full marathon of 26.2 miles (42.195 km) and

Figure 1. Jobst Activewear compression socks.

TABLE 1. Anthropometric and training characteristics of the study participants.

	All participants (mean ± *SD*)	Compression group (mean ± *SD*)	Placebo group (mean ± *SD*)
Number	*N* = 33	*n* = 16	*n* = 17
Male/female	23/10	12/4	11/6
Age (y)	38.5 ± 7.2	39.0 ± 6.2	38.1 ± 8.2
Height (cm)	174.4 ± 9.7	173.2 ± 8.4	174.4 ± 11.2
Training volume (weekly hours)	6.2 ± 3.2	5.5 ± 1.9	6.9 ± 4.1
Years of running (y)	7.7 ± 7.6	8 ± 8.2	7.5 ± 7.3
Marathon time (hour:min)	3:58 ± 0:26	4:03 ± 0:29	3:54 ± 0:23

attended premarathon and postmarathon treadmills. The runners were recruited by electronic digital messages in the newsletters of each marathon, direct contact with local running clubs, local triathlon clubs, local fitness establishments, and through our Facebook page.

Inclusion criteria were Melbourne, Canberra, or Gold Coast marathon participants older than 18 years. Exclusion criteria were a history of lower-limb ischemia or a previous lower-limb amputation because of peripheral vascular disease and regular use of nonsteroidal anti-inflammatory medications. A questionnaire was completed detailing the participants age, number of years running, and average weekly running distance. We also collected anthropological measurements to ensure correct fitting of the compression socks (Table 1). All study participants gave written informed consent and the study was approved by the Monash University Human Research Ethics Committee (approval number CF12/0348-2012000146), and the trial registered with the Australia and New Zealand Clinical Trial Registry (registration number 12611000468921). Table 1 shows the physical and training characteristics of the 33 study subjects.

Procedures

The end point–time to exhaustion on a graded maximal treadmill test–was measured using a stepwise speed and gradient treadmill test to voluntary maximum duration. Participants had a 5-minute warm-up at a 4% gradient and 4 $km \cdot h^{-1}$. Following the warm-up, the treadmill speed was increased to 6 $km \cdot h^{-1}$ for the next stage and then by 1 $km \cdot h^{-1}$ every 3 minutes until a speed of 13 $km \cdot h^{-1}$ was reached. The treadmill gradient was then increased by 2% every 3 minutes until a maximum gradient of 12% was reached. To ensure safety of the participants, rate of perceived exertion was recorded 2 minutes into each stage using the Borg rate of perceived exertion visual analog scale. Heart rate was recorded 2 minutes into each stage and was continuously monitored throughout the trial using a Polar RS300x heart rate monitor (Polar Electro Oy, Kempele, Finland) to capture maximum heart rate, which was used as a marker of appropriate effort. The participants were asked to continue on with the treadmill protocol until voluntary exhaustion and the treadmill was terminated at that time. The total treadmill running time, maximum heart rate, and rate of perceived exertion were recorded. Participants (1 in total) were excluded if their postmarathon treadmill maximum heart rate achieved was not within 95% of their premarathon treadmill maximum. This cutoff level was used to ensure an appropriate level of effort was achieved by each participant during the follow-up treadmills. Temperature in the exercise room for all treadmills was 18–21° C with a relative humidity of 48–52% during the premarathon and postmarathon treadmills. The motorized treadmills used at each venue were the Tempo T3200 treadmill (Horizon Fitness Australia, Morwell, Australia) in Melbourne and Life Fitness T3 treadmills (Life Fitness, Rosemont, IL, USA) in both Canberra and the Brisbane testing sites. The venues used were the physiology department at Melbourne University Monash Campus in Melbourne, the Australian Institute of Sport facility gymnasium in Canberra, and the YMCA, Brunswick Street in Brisbane.

To control for circadian variability, an identical treadmill time slot was used for the premarathon and postmarathon treadmill tests. During the treadmill, plain water was available for hydration and participants were asked to drink to thirst. No treadmill familiarization protocol was used.

Below-knee compression socks (Jobst ActiveWear 30–40 mm Hg Firm Support Unisex Athletic Knee Highs) were used in the compression group. The correct size was determined according to the manufacturer's instructions using self measurement of calf diameter and shoe size by each participant. Correctly fitted, they are designed to have a maximal compression at the ankle of 30–40 mm Hg (European class 3 compression) with a graduated decrease in compression proximally to achieve a compression value of 70% of maximum at the calf. They are composed of 58% polyester, 20% nylon, 10% cotton, and 12% spandex. The socks produce a circular compression on the lower leg. They were provided free of charge by Jobst Australia.

The placebo group were provided with a noncompressive SmartKnit seamless knee-high diabetic sock. They are designed to be seam free and only provide the minimum compression value to stop them falling down. These were purchased from SmartKnit Australia.

Statistical Analyses

Data were analyzed using the SPSS statistical software package (version 17.0; SPSS Inc., Chicago, IL, USA).

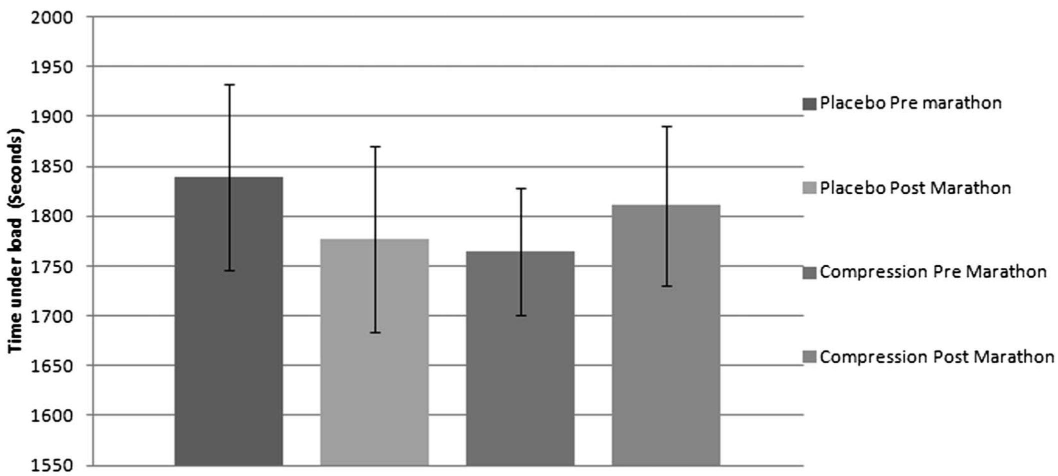

Figure 2. Time under load stepwise treadmill test up to a voluntary maximum: compressive vs. placebo group.

The χ^2 test was used to check for normal distribution of the data. The 2-tailed Student's t-test was used to assess the statistical significance of our results. A p-value of less than 0.05 was considered significant.

The Student's t-test was used as this is a valid method to analyze the difference in treadmill times in 2 independent groups. Our p value was 0.0091 and we considered this a significant result.

Results

The results of the stepwise treadmill test to voluntary maximum demonstrated that running performance in the compression group improved by 52.4 ± 103.3 seconds, whereas it decreased by 61.7 ± 129.6 seconds in the placebo as shown in Figure 2. There was a statistically significant difference with compression socks showing an increase in treadmill time to exhaustion with a p-value of 0.0091. Compared with the placebo group the compression group had a 5.9% improvement in their run time to exhaustion.

Table 2 shows the maximum heart rate, rate of perceived exertion of the study participants, and treadmill time to exhaustion. There was no statistical difference in maximal heart rate, maximal rate of perceived exertion, or baseline treadmill time to exhaustion between the 2 groups.

Fifty-nine participants consented to take part in the study. Thirty-three participants completed the study fully with before and after treadmill data provided for analysis. Of the 26 participants who failed to complete the study, 15 participants failed to attend the initial treadmill test, 13 runners failed to complete their marathon, 1 runner failed to wear the compression socks for the full 48 hours because of muscle soreness, 5 runners were unable to attend the postmarathon treadmill 2 weeks after the marathon, 1 participant was unable to complete the treadmill test because of dizziness, and 1 participant failed to achieve 95% of their baseline treadmill test in their follow-up test and was subsequently excluded.

Table 2. Mean maximal heart rate, rate of perceived exertion, and treadmill time to exhaustion.*

Treadmill	Placebo first treadmill (mean ± *SD*)	Placebo second treadmill (mean ± *SD*)	Compression first treadmill (mean ± *SD*)	Compression second treadmill (mean ± *SD*)
Maximum HR ($b \cdot min^{-1}$)	179 ± 10.7	181 ± 9.0	183 ± 10.7	182 ± 10.9
Maximum RPE (VAS)	8.7 ± 1.5	8.3 ± 1.9	7.9 ± 1.4	8.8 ± 1.1
Time to exhaustion (s)	1,839 ± 382	1,777 ± 386	1,765 ± 254	1,811 ± 319

*RPE = rate of perceived exertion; VAS = visual analogue scale.

The baseline characteristics of the compression and placebo groups were not statistically different. One study participant was unable to wear the compression socks for the full 48 hours following the Melbourne marathon. This was due to subjective discomfort from the compressive effect. The participant was in the compression group. Their symptoms resolved within 30 minutes of removing the socks and no long-term consequences were reported. It is difficult to determine whether their symptoms were directly related to the compressive effects of the compression garments or muscle damage from the marathon. No other participants in either group reported any other adverse events.

Discussion

We aimed to answer the question of whether below-knee compression garments worn for 48 hours following marathon running confer a functional recovery benefit. Our results confirmed our hypothesis showing that there was a significant improvement in run time to exhaustion in the compression group compared with the placebo group.

Analysis of the data showed on average a 3.4% decline in postmarathon treadmill tests in the placebo group and a 2.6% improvement in postmarathon treadmill test times in the compression group. This would indicate that the compression group had recovered fully from the marathon and the actual marathon, or enforced rest following the event, had improved their fitness capabilities. The placebo group had failed to fully recover from the marathon at their follow-up treadmill.

When compared with previous studies, these results would be consistent with decreases in ultrastructural muscle damage and decreased levels of biochemical markers of muscle damage observed (13,25). It is also consistent with previous findings in cyclists of a beneficial effect of compression garments on short-term recovery (7). Our result confirms the physiological benefits of compression garments as demonstrated in previous studies are translated into functional benefits and aid physical recovery from exhaustive exercise.

We chose a graduated treadmill run to exhaustion as a direct measurement of functional recovery. This tool is valid for measuring recovery as it is specific to running fitness measurement and is easily reproducible with minimal variability from external factors (22). We elected not to measure $\dot{V}O_2$max as it has been shown to be a less accurate predictor of overall running performance (19).

The main limitation of this study was the small number of participants recruited. Despite this, we were able to achieve a statistically significant result. A further limitation of the study is in blinding. The study was double blinded, but it is conceivable that participants could develop insight into which group they were in because of the compressive effect of the socks and the fact that they felt "tight." The investigators tried to minimize the risk of group disclosure by providing supporting information to both groups that the effect was hypothesized to be through the wearing of the socks not the degree of compression. We chose a diabetic sock to use as the placebo as it is similar in manufacture and look to a compression sock. Diabetic socks are also designed to have a low compressive value because of the high risk of peripheral vascular disease in diabetics.

We attempted to minimize independent variables such as temperature, humidity, and wind speed by holding the treadmill tests in climactically controlled locations. We also minimized circadian variability by repeating the treadmill tests at a similar time of day for each individual. We did not control for nutritional variability in the 48 hours before each treadmill or other recovery methods used after the marathon. We also did not control for training volume in the 48 hours before each treadmill, which may introduce some bias into our results.

For compression socks, we used a medical grade below-knee compression. We chose below knee to increase compliance with wearing of the sock. Above-knee compression socks have a poor user compliance rate because of increased heat retention and discomfort. Validation of the sock's compressive value was not possible in all participants because of funding limitations. As we used an off-the-shelf product with sizes guided by participants self measurement, there would have been inherent inconsistencies in the actual compressive values obtained. For some of the Canberra participants who were also involved in a side trial with the recovery team at the Australian Institute of Sport, it was possible to measure the compressive value of the socks 24 hours after the marathon. They calculated an average compression value of 20 mm Hg at the calf with a stated value of 21–28 mm Hg compression at this point by the manufacturers.

Future directions for this field of research could include repeating the study with differing degrees of compressive value to find an optimum compression. There is also the possibility of an enhanced effect with the use of full leg compression rather than the below-knee socks we used. It could be hypothesized that a stronger effect would be seen 1 week after marathon running rather than the 2-week recovery we analyzed. We chose 2 weeks as an appropriate time as research has shown incomplete recovery in muscle function 1 week after marathon running (22) and runners anecdotally take at least 2 weeks of rest before restarting run training. It would also be beneficial to control each subject's nutritional intake and training 48 hours before each treadmill and any other recovery strategies used.

Practical Applications

The use of graduated compression socks for 48 hours following exhaustive exercise does aid functional recovery in runners. Below-knee compression socks are a valid, safe, and relatively inexpensive recovery method. This study indicates all runners would benefit from the use of compression socks for 48 hours following exercise and they should see a 6% improvement in their recovery parameters.

Acknowledgments

The assistance of the staff in the recovery department and gymnasium of the Australian Institute of Sport and the assistance of the YMCA in Brisbane during data collection is gratefully acknowledged. We also thank the athletes for their involvement in the study. Compression socks were provided free of charge by Jobst. Otherwise, the study was funded by the principle investigator.

The authors declare no conflicts of interest. The results of the present study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.

References

1. Abraham, WM. Factors in delayed muscle soreness. *Med Sci Sports Exerc* 9: 11–20, 1997.
2. Ali, A, Caine, MP, and Snow, BG. Graduated compression stockings: Physiological and perceptual response during and after exercise. *J Sports Sci* 25: 413–419, 2007.
3. Berry, MJ and McMurray, RG. Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. *Am J Phys Med* 66: 121–132, 1987.
4. Bringard, A, Denis, R, Belluye, N, and 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* 46: 548–554, 2006.
5. Bruunsgaard, H, Galbo, H, Halkjaer-Kristensen, J, Johansen, TL, MacLean, DA, and Pedersen, BK. Exercise-induced increase in serum interleukin-6 in humans is related to muscle damage. *J Physiol* 499: 833–841, 1997.
6. Brynes, WC, Clarkson, PM, White, JS, Hsieh, SS, Frykman, PN, and Maughan, RJ. Delayed onset muscle soreness following repeated bouts of downhill running. *J Appl Physiol* 59: 710–715, 1983.
7. Chatard, JC, Atlaoui, D, Farjanel, J, Louisy, F, Rastel, D, and Guezennec, CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol* 93: 347–352, 2004.
8. Coza, A, Dunn, JF, Anderson, B, and Nigg, BM. Effects of compression on muscle tissue oxygenation at the onset of exercise. *J Strength Cond Res* 26: 1631–1637, 2012.
9. De Glanville, KM and Hamlin, MJ. Positive effects of lower body compression garments on subsequent 40 km cycling time trial performance. *J Strength Cond Res* 26: 480–486, 2012.
10. Driller, MW and Halson, SL. The effects of wearing lower body compression garments during a cycling performance test. *Int J Sports Physiol Perform* 8: 300–306, 2013.
11. Duffield, R, Cannon, J, and King, M. The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *J Sci Med Sport* 13: 136–140, 2010.
12. Halliwill, JR. Mechanisms and clinical implications of post-exercise hypotension in humans. *Exerc Sports Sci Rev* 29: 65–70, 2001.
13. Hikida, RS, Staron, RS, Hagerman, FC, Sherman, WM, and Costill, DL. Muscle fibre necrosis associated with human marathon runners. *J Neurol Sci* 59: 185–203, 1983.
14. Hill, J, Howatson, G, Someren, KV, Walshe, I, and Pedlar, C. The influence of compression garments on recovery following marathon running. *J Strength Cond Res* 28: 2228–2235, August 2014.
15. Kraemer, WJ, Flanagan, SD, Comstock, BA, Fragala, MS, Earp, JE, Dunn-Lewis, C, Ho, J-Y, Thomas, GA, Solomon-Hill, G, Penwell, ZR, Powell, MD, Wolf, MR, Volek, JS, Denegar, CR, and Maresh, CM. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *J Strength Cond Res* 24: 804–814, 2010.
16. Kraemer, WJ, Volek, JS, Bush, JA, Gotshalk, LA, Wagner, PR, Gomez, AL, Zatsiorsky, VM, Duarte, M, Ratamess, NA, Mazzetti, SA, and Selle, BJ. Influence of compression hosiery on physiological responses to standing fatigue in women. *Med Sci Sports Exerc* 32: 1849–1858, 2000.
17. Lovell, DI, Mason, DG, Delphinus, EM, and McLellan, CP. Do compression garments enhance the active recovery process after high-intensity running. *J Strength Cond Res* 25: 3264–3268, 2011.
18. Millet, GY and Lepers, R. Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. *Sports Med* 34: 105–116, 2004.
19. Noakes, TD, Myburgh, KH, and Schall, R. Peak treadmill running velocity during the VO_2 max test predicts running performance. *J Sports Sci* 8: 35–45, 1990.
20. Ostrowski, K, Rohde, T, Asp, S, Schjerling, P, and Pedersen, BK. Pro-and anti-inflammatory cytokine balance in strenuous exercise in humans. *J Physiol (Lond)* 515: 287–291, 1999.
21. Pedersen, BK. Special feature for the Olympics: Effects of exercise on the immune system: Exercise and cytokines. *Immunol Cell Biol* 78: 532–535, 2000.
22. Petersen, K, Hansen, CB, Aagaard, P, and Medsen, K. Muscle mechanical characteristics in fatigue and recovery from a marathon race in highly trained runners. *Eur J Appl Physiol* 101: 385–396, 2007.
23. Rimaund, D, Calmels, P, Roche, F, Mongold, JJ, Trudeau, F, and Devillard, X. Effects of graduated compression stockings on cardiovascular and metabolic response to exercise and exercise recovery in persons with spinal cord injury. *Arch Phys Med Rehabil* 88: 703–709, 2007.
24. Schwane, JA, Johnson, SR, VanDenakker, CB, and Armstrong, RB. Delayed onset muscular soreness and plasma CPK and LDH activities after downhill running. *Med Sci Sports Exerc* 15: 51–56, 1983.
25. Warhol, MJ, Siegel, AJ, Evans, WJ, and Silverman, LM. Skeletal muscle injury and repair in marathon runners after competition. *Am J Pathol* 118: 331–339, 1985.