Evaluation of the Effectiveness of Compression Garments on Autonomic Nervous System Recovery After Exercise

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Title: Evaluation of the effectiveness of compression garments on autonomic nervous system recovery following exercise

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Abstract

The aim of this investigation was to evaluate the recovery pattern of a whole body compression garment on hemodynamic parameters and on ANS activity following a swimming performance. Ten young male athletes were recruited and tested in two different days, with and without wearing the garment during the recovery phase. After a warm-up of 15 minutes, athletes were instructed to perform a maximal 400m freestyle swimming event, and then time series of beat-to-beat intervals for heart rate variability (HRV), baroreflex sensitivity (BRS), and hemodynamic parameters were recorded for 90 minutes of recovery. The vagally mediated HF power of R–R intervals, NN50, and pNN50 showed a faster recovery due to the costume, meanwhile, the LFRR index of sympathetic modulation of the heart, as well as LF:HF ratio and BRS alpha index (αLF) were augmented in control than in garment condition. When athletes wore the swimsuit, cardiac output was increased and the returning of the blood to the heart, investigated as stroke volume, was kept constant due to the reduction of the total peripheral resistances. During control condition, HR was restored back to baseline value 20 minutes later with respect to garment condition, confirming that the swimsuit recover faster. The effectiveness of the swimsuit on ANS activity after a maximal aerobic performance has been shown with a greater recovery in terms of HRV and hemodynamic parameters. BRS was reduced in both conditions, maybe due to prolonged vasodilatation that may have also influenced the post-exercise hypotension.

Keywords: heart rate variability, baroreflex sensitivity, compression garments, recovery, swimming

Running head: Autonomic nervous system recovery in swimmers

INTRODUCTION

The day of the competition, swimmers are subjected to several races that require maximum effort. Performance may be affected because muscles, cardiorespiratory parameters and blood homeostasis could be dramatically reduced race after race. During local or qualifying trial competitions, swimmers take part in successive events, and when the recovery time is short, a subsequent effort cannot be effectively applied unless an adequate restoration of homeostasis occurs (32). Therefore, there is the need to find a way that speeds up the recovery time, helping swimmers to perform better in a subsequent event. Thus, it is important to have information on the most effective recovery time that may improve performance during the next event (14).

Different studies have investigated the effect of compression garment (CG) on recovery, and most of them did it during and/or after exercise (11,29). Applying compression exclusively during continuous exercise did not show any benefits for recovery 24 hours after exercise (2). Therefore, it seems essential to wear compression clothing for at least 12 to 24 hours after exercise to improve recovery (29). Although such improvement has been investigated mostly on sprinting ability, vertical jumping exercise, and muscle damage markers (29), few researchers have focused their studies on the effects of clothing skin pressure exerted by compression garments on the autonomic nervous system (ANS) activity and hemodynamic parameters. Indeed, data directly demonstrating influences on venous return, cardiac output or stroke volume appear to be sparse (33), and none were identified for athletes (24). Cardiovascular modification has been assessed using heart rate, and findings indicate little effect of CGs during exercise, so that cardiovascular influences of CGs in exercise (11) and during recovery (29) remain largely unclear.

To our knowledge, no studies have investigated the effect of wearing CG on hemodynamic parameters and on ANS activity at rest, following a single bout of aerobic exercise. Heart rate variability (HRV), a non-invasive assessment of autonomic regulation of heart frequency, and baroreflex sensitivity (BRS), a reflex that modify heart period in response to variations in systolic blood pressure (SBP), have been used to evaluate the different body responses to physical exercise (21,23) and during recovery times (18,30). Autonomic recovery following an acute bout of exercise is specific to the mode and intensity of effort. One hour following mild exercise showed elevated values of HRV and BRS (24) but depressed after 2 hours of supine recovery from multiple high intensity interval exercise (30). Niemela et al. (18) found that high and low frequency (HF and LF) power of HRV, as well as blood pressure oscillations returned to the control level after 30 min of aerobic exercise. In earlier studies, BRS has been shown to exceed the pre-exercise values at 60 min after aerobic exercise (15), but this finding has not been reported by all (31). Somers et al (28) reported that BRS is decreased only for 20 min, but others have shown the recovery period to be longer (9,31). BRS is reduced after both aerobic and resistance exercise compared with baseline values (7), allowing increases in BP and HR (10,27).

Thus, it would be of interest to explore a possible connection between compression garment, swimming performance, and the reliable physiological parameter such as the autonomic nervous system recovery. We hypothesized that a compression garment worn following a maximal 400-m freestyle event would enhance the autonomic recovery process (8,13). Thus, the aim of this investigation was to evaluate the recovery pattern of a whole body compression garment after a swimming performance on hemodynamic parameters and on ANS activity on subsequent 90 minutes of recovery. We measured HRV and BRS activity by analysing the simultaneous spontaneous variations of heart rate and systolic blood pressure, in order to determine autonomic nervous system activity in a non-invasive manner (20). Therefore, RR interval and SBP variability were investigated on both frequency and time domain with short-term analysis. In the past, this methodology has furnished measurable indicators of vagal and sympathetic activity of heart rate and (19) of vasomotor tone (25).

METHODS

Experimental Approach to the Problem

This study was developed in order to determine the recovery pattern of wearing compression garment compared with control condition. Athletes were tested in two occasions, with and without wearing the swimsuit during the recovery phase, separated by one week each other. The compression garment chosen for the experiment was manufactured of 65% polyamide, 34% elastane, and 1% of carbon fiber on the periphery. The central body part was composed by 58% polyamide and 42% elastane. The pressure generated by the whole body compression garment, measured by PicoPress M-700 (Microlab Elettronica, Padova, Italy), were ~13mmHg on the forearms, ~10mmHg on the upper arms, ~6mmHg on the chest, ~15mmHg on the medial calf, ~8mmHg on the mid front thighs and ~5mmHg on the mid hip. The swimsuit (Powerskin Recovery Compression, Arena, Macerata, Italy) (Figure 1) was made in order to ensure the maximum compression at the level of peripheral limbs. In these areas, the compression has a measure of about 25-30% smaller than the circumference of the specific area.

Figure 1 about here

Subjects

Ten male athletes [age 21.60±1.58 yr., height of 179±0.05 cm, and BMI of 23.17±1.33 kg/m2] responded to volunteer and subsequently participated in the study. All subjects competed at the national level and trained at least 14 hours per week. Given that all participants were athletes, they were healthy, non-smokers, and they did not take any medication during the study. Moreover, they were advised to avoid training and any stimulant (e.g. coffee, energy drink) 24 hours before the test. This study was approved by Bioethics Committee of the University of Bologna and all participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Procedure

On two separate occasions, same athletes were tested with (GAR) and without (CON) wearing the compression costume only during the recovery phase following a swimming performance. All swimmers underwent non-invasive continuous blood pressure monitoring using the servo-controlled infrared finger plethysmography (Portapres device; TNO/BMI) for analysis of HRV and BRS. Tests were done under a standardized procedure at the same time of the day (9:00-12:00) to avoid circadian influence. In both occasions, each swimmer was first tested in a supine position, in a room quiet and with a comfortable temperature (22-25°C), for 10 minutes (baseline). They were instructed to stand still and be quiet, with a respiratory frequency of 12-15 breaths/min. After a warm-up of 15 minutes, they were instructed to perform a maximal 400-m freestyle as in competition, during which total and intermediate time were recorded at each length (25 m). The day of the GAR test, the compression garment was dressed only during the recovery phase, not during the swimming performance. During the recovery phase, signals were measured 20-30, 40-50, 60-70, and 80-90 minutes after the cessation of the swimming performance. For the final analysis of autonomic function, the last 5 min of every recovery phase were used for calculations, as recommended by guidelines for HRV analysis during short term recording (4).

HRV analysis. The Portapres recordings were used to extract time series of R-R intervals and systolic as well as diastolic pressures, to analyze HRV and BRS. Data were analysed with Kubios HRV software (v. 2.0, 2008, Biosignal Analysis and Medical Imaging Group, University of Kuopio, Finland), in which all time series were filtered to exclude artefacts. All measure were analysed in according to conditions by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (4). Time domain indices for HRV analysis were: the number of interval differences of successive R-R intervals greater than 50 ms (NN50), and the proportion derived by dividing NN50 by the total number of R-R intervals NN50 (pNN50). Furthermore, we analysed two main frequency components of HRV: low frequency (LF) ranging from 0.04 to 0.15 Hz, and high frequency (HF) centered at the breathing frequency (4). It has been shown that the HF spectral component of HR variability (HFRR) is an index of the vagal tone, whereas both sympathetic and vagal activities contributed to the LF (LFRR) spectral component of HRV (6). Given that LFRR does not provide an index of sympathetic modulation when measured in absolute units, we expressed the power in both absolute and normalized units (19). Such normalized units are obtained by dividing the power of each component by total variance from which the very-low-frequency component had been subtracted, and multiplying this value by 100 (16,19). Therefore, low and high frequency (LFRR and HFRR) spectral components measured in normalized units, or as LF/HF ratio, provide quantitative markers of cardiac sympathetic and vagal modulation respectively (19).

BRS analysis. Baroreflex sensitivity was computed from RR intervals and SBP sequence subtracted from the finger arterial pressure waveform. These data were then utilised to define the oscillations in both heart rate and systolic arterial pressure measures. Beatscope version 1.1a (TNO/BMI, Amsterdam, The Netherlands) was used to evaluate spontaneous BRS, with a BRS add-on module that computes the time-domain cross correlation BRS. This technique is based on the computer identification in the time domain of 4 or more spontaneous sequences of consecutive beats, distinguished by either a progressive increase in SBP and R-R interval (+RR /+SBP sequences) or by a progressive reduction of the same variables (-RR/-SBP sequences). The incline of the regression line between SBP and RR interval fluctuations is taken as an index of the arterial baroreflex sensitivity of the heart, same as the laboratory method based on i.v. injection of vasoactive drugs. This technique for BRS identification has lower within-patient variance than other methods, and provides more values per minute than the standard time-domain based method (34). Moreover, a blood pressure spectral analysis has been used. Low-Frequency (LF-SBP) spectral component of SBP variability return the sympathetic activity of the vascular α-adrenergic receptors, while high-frequency (HF-SBP) reflect the influence of breathing on systolic blood pressure (19). Then, to obtain information about the effect of sympathovagal modulation on sinoatrial node spontaneous activity (19), we calculated the BRS alpha index from the low-frequency band (αLF). It was computed as square root of the ratio between the RR power and the corresponding SAP spectral component (20). This analysis was also confirmed by Robbe et al. (26), who showed that the middle frequency band (0.07-0.14 Hz) between SBP and RR interval time gives equivalent results to those obtained using the phenylephrine method.

Hemodynamic parameters. From the blood pressure waveform, stroke volume (SV), cardiac output (CO), and total peripheral vascular resistance (TPR) were estimated by the pulse contour method of Wesseling (the Modelflow method - software TNO/BMI, Amsterdam, The Netherlands) that has been validated extensively (3,12).

Statistical Analysis

Shapiro-Wilk test was used to check the normal distribution of data. Measures with skewed distribution were log transformed (Ln) before analysis. The ICC was used to assess the reliability of time between the test and retest of 400m freestyle event. A 5 x 2 repeated measures ANOVA was performed separately to analyse all investigated variables. Time (Baseline; R20-30; R40-50; R60-70; and R80-90) was the within-subjects factor and condition (GAR; CON) the between-subjects factor. To examine changes between recovery phases (R20-30; R40-50; R60-70; and R80-90) and baseline values on each condition, a paired sample t-test was used. Data were analysed with SPSS v20.0 (SPSS, Chicago, IL, USA). Means were considered significantly different at p< 0.05. Effect sizes were calculated using partial eta squared (ηp2).

RESULTS

No significant difference was observed between the two swimming test (p > 0.05) in which the time to complete 400-m was 269.9±13.1 sec in the first occasion, and 269.6±13.0 sec for the second one. The data from the swimming test and re-test days were analysed using intra-class correlation coefficient. A high degree of reliability was found between measurements, in which the average measure ICC was 0.979 with a 95% confidence interval from 0.920 to 0.995 ($F_{9,\ 9}$ = 86.74, p<.001). No significant difference was also observed between the two baseline values (GAR vs. CON) (p > 0.05) for all variables investigated. Analysis on main effect showed a significant difference for time (p < 0.05), which means that during the recovery period, all parameters, regardless of the type of condition (GAR, CON), changed significantly with respect to the baseline value. Paired sample t-test allowed us to see, for each condition in each recovery time, which variables differed from baseline.

Baroreflex sensitivity

After a maximal 400-m freestyle event, BRS mean of both conditions was reduced for 50 min compared to baseline (F4,72 = 13.90, $p < 0.001$, ηp2 = 0.44, Figure 2A). However, αLF showed a significant reduction after 20-30 min only when athletes wore the garment [t(9) = 2,19; p = 0.046, Figure 2B]. Blood pressure remain almost stable when subjects wore the garment, changing after the effort only during the control condition, with a reduction for 70 min of SBP [t(9) = 2,38; p = 0.042, Figure 2C], and for 50 min of DBP [t(9) = 2,62; p = 0.028, Figure 2D], showing a post-exercise hypotension.

Figure 2 about here

Heart rate variability indices

HRV value showed a clear effect influenced by the garment (Figure 3). HFRR, NN50, and pNN50 demonstrated, in both conditions, a lower value 40-50 min after the effort (*F*4,72 = 18.06, $p < 0.001$, ηp2 = 0.50 for NN50; *F*4,72 = 21.73, $p < 0.001$, ηp2 = 0.55 for pNN50; and *F*4,72 = 7.83, $p = 0.005$, ηp2 = 0.30 for HFRR). The same variables exhibited a prolonged reduction (60-70 min) only in CON condition [t(9) = 3,03; $p = 0.014$, t(9) = 2,54; $p = 0.031$, and t(9) = 2,66; $p = 0.026$, respectively]. Figure 3B shows the LFRR value unchanged in GAR, while returns to baseline value after 30 min in CON [t(9) = 2,79; $p = 0.021$]. This is confirmed also by LF:HF ratio [t(9) = 2,34; $p = 0.040$, Figure 3C], with a conclusion that, wearing the swimsuit during the post-exercise speeds up recovery after performance.

Figure 3 about here

Hemodynamic parameters

Analysis of hemodynamic parameter showed that, wearing the garment during the post-exercise, athletes exhibited higher value of CO for 20-30 min [t(9) = 3,46; $p = 0.007$, Figure 4A]. This result happens due to the stable value of SV that remains at the baseline level during the post exercise with respect to CON condition, in which it was reduced for 50 min [t(9) = 2,61; *p* = 0.028, Figure 4B]. HR significantly increased in both conditions for 50 min (*F*4,72 = 57.96, *p* < 0.001, ηp2 = 0.76), while maintaining higher value for 70 min only during CON condition [t(9) = 2,41; *p* = 0.039], confirming that when subjects wore the garment they showed a faster recovery (Figure 4C). TPR significantly decreases in both conditions for 30 min (*F*4,72 = 15.72, *p* < 0.001, ηp2 = 0.47), showing a significant prolonged reduction for 50 min during GAR [t(9) = 2,84; *p* = 0.019, Figure 4D].

Figure 4 about here

DISCUSSION

The aim of this investigation was to evaluate the recovery pattern of a whole body compression garment on hemodynamic parameters and on ANS activity following a maximal 400-m freestyle event. We measured HRV and BRS activity by analysing the simultaneous spontaneous variations of heart rate and systolic blood pressure. The principal finding of the present study is that compression garments had an effect on the pattern of autonomic function recovery. Primarily, the vagally mediated HF power of R–R intervals, NN50, and pNN50 showed a faster recovery due to the costume, meanwhile, the LFRR index of sympathetic modulation of the heart, as well as LF:HF ratio were augmented in control than in garment condition. This finding indicates that the costume has a positive influence on the ANS activity, which is predominantly related to the significant fast recovery of parasympathetic nervous system after the effort. Next, the LF power of BRS, which reflects sympathetic tone, was not affected by the effect of exercise during the recovery phase when the athletes wore the costume. Graduated compression implies that the applied pressures are highest distally, and decrease proximally, deriving from medical applications that relate primarily to circulatory roles such as the reduction of venous pooling and augmentation of venous blood flow return. In fact, cardiac output was increased, avoiding post-exercise hypotension, and the returning of the blood to the heart, investigated as stroke volume, was keep constant due to the reduction of the peripheral resistances. Findings from our study could have relevance for post-exercise recovery, since

HR was restored back to the baseline level at 60 min of recovery during GAR condition and 80 min of recovery during CON condition.

Swimming at high intensities, such as during racing and tough sets, can cause metabolites like inorganic phosphate, ADP, hydrogen ions, and of course, lactate, to accumulate in the muscles (14). A build-up of these metabolites is associated with conditions that can compromise the next swimming performance. The rate of recovery of the accumulated fatigue agents may differ during passive and active recovery using short or long duration and this may affect performance (32). Active recovery facilitates the removal/utilization of lactate after a race or tough set. The intensity of the active recovery influences how quickly this removal/utilization of lactate occurs. Too high an intensity may produce additional lactate, while too low an intensity may not create enough circulation to remove/utilize the lactate faster than passive recovery (32). For this reason in recent years it is increased the need to find methods necessary to improve the recovery time. The increasing attractiveness of compression garments in different sports is likely due to accumulating evidence of enhanced performance and recovery (29). To our knowledge, no research has documented the effect of compression clothing on indicators of recovery performance such as HRV, BRS and hemodynamic parameters.

During recovery from moderate and heavy exercise heart rate remains elevated above the pre-exercise level for a relatively long period of time (up to 60 min) (5). Niemela et al. (18) found HR elevated at 60 min after aerobic and heavy resistance exercise and at 30 min after light resistance exercise compared with the control level. Our test can be catalogued among aerobic performances because, even if we did not measure any metabolic parameter, subjects did the 400-m with a great time, under 270 sec, in which the estimated contribution of anaerobic metabolism represented 20% of total energy output (14). In our study, HR was restored to the baseline level after 60 min, compared to control condition in which subject recovered after 80 min. Furthermore, HF power of RR intervals, as well as time domain indices like NN50 and pNN50, recognized as a marker of vagal activity (4), were restored back after 50 min. Previous studies have shown these indices reduced until 30 min after aerobic exercise (9,18) compared to baseline level. Likewise, LFRR, that represents an index of sympathetic modulation if analysed in normalized units, as well as LF:HF ratio, were presumably back to the baseline level before the first recovery period investigated (20-30 min). Overall, the effect of compression garment on the neural control of the autonomic nervous system results in a recovery back to the baseline level 60 min after the performance.

Different studies showed that, immediately after the end of aerobic exercise, BRS is significantly reduced (18,27,31). Our results are in agreement with Stuckey et al. (30) in which baroreflex does not have as great role in maintaining BP in acute recovery from exercise as it does under prolonged resting conditions. As it was found in other studies (7,18,31), BRS value was reduced significantly at 40-50 min after exercise, and it gradually increases back to the baseline level after 60-70 min in both conditions. BRS alpha index (αLF) had a significant reduction until 30 min only during wearing garment, returning to baseline value at 40-50 min. Moreover, in both conditions, this value tended to rise above the baseline level 80-90 min after the cessation of the effort, as it was also reported by Niemela et al. (18) after both aerobic and light resistance exercise.

After an acute bout of exercise blood pressure falls, sometimes for several hours. This hypotensive effect can be affected by the exercise, and it persists if the subject maintains supine position (28), as it happens in our control condition. In normotensive subjects, a reduction in systemic vascular resistance after maximal exercise is counterbalanced by the increase of cardiac output, avoiding a clinically significant blood pressure reduction. Therefore, we can hypothesize that post-exercise hypotension could be due not to an overall decrease in sympathetic tone but to persisting vasodilatation (22). The decrease in total peripheral resistance (Figure 4D) is associated with a double reflex response: sympathetic activation (Figure 3B) and depressed vagal tone (Figures 3A, 3D, 3E), which may be responsible for the concomitant increases in heart rate (Figure 4C) and cardiac output (Figure 4A). They are associated even with or caused by a reduction in baroreflex sensitivity (Figure 2A). This could also be attributed to the garment condition even if the reduction of arterial pressure was not significantly different from baseline value. Moreover, data directly demonstrating influences on venous return, cardiac output or stroke volume appear to be sparse (33), and none were identified for people engaged in exercise or during recovery period. Possible mechanisms for flow augmentation have been discussed (17) and include a myogenic vasodilatory response. The myogenic response of the vessels leads to vasodilatation and favours arterial inflow to the muscle, hence increasing local blood inflow. Improved venous hemodynamic has been suggested to result in increased end-diastolic filling of the heart, increasing stroke volume and cardiac output (1). Since stroke volume is a limiting factor for performance, the application of compression clothing could serve as an ergogenic aid.

PRATICAL APPLICATIONS

In conclusion, there were evident changes in autonomic regulation after exercise when subjects wore the compression garment than during the control condition. The use of the compression garments, allowed only during the recovery period, could provide a functional recovery following a swimming performance. First, HR was restored to the baseline level 60 min following exercise, cardiac output augmented, stroke volume unchanged and total peripheral resistance decreased. Secondly, vagal outflow was significantly reduced during the control condition compared with the compression garment, as documented by the changes in the HF power of R–R interval fluctuation, NN50 and pNN50 time domain indices. Thirdly, sympathovagal balance, assessed by LF:HF ratio, and the sympathetic modulation of the heart, evaluated by LFRR, were unchanged during the recovery period only when subject wore the swimsuit. After these conclusions, we recommend to all athletes to use the compression garment when they are involved in several races close together, both during training period and in competition, in order to obtain a faster recovery. Furthermore, we suggested further investigations with the intention to see if the compression garments are able to reduce the recovery time also in other type of swimming performance.

REFERENCES

1. Ali, A, Caine, MP, and Snow, BG. Graduated compression stockings: physiological and perceptual responses during and after exercise. *J Sports Sci* 25: 413–419, 2007.

2. Ali, A, Creasy, RH, and Edge, JA. Physiological effects of wearing graduated compression stockings during running. *Eur J Appl Physiol* 109: 1017–1025, 2010.

3. Bos, WJ, van Goudoever, J, van Montfrans, GA, van den Meiracker, AH, and Wesseling, KH. Reconstruction of brachial artery pressure from noninvasive finger pressure measurements.

Circulation 94: 1870–5, 1996.

4. Camm, A, Malik, M, Bigger, J, and Günter, B. Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. *Circulation* 93: 1043–1065, 1996.

5. Carter, R, Watenpaugh, DE, Wasmund, WL, Wasmund, SL, and Smith, ML. Muscle pump and central command during recovery from exercise in humans. *J Appl Physiol* 87: 1463–9, 1999.

6. Casadei, B, Moon, J, Johnston, J, Caiazza, A, and Sleight, P. Is respiratory sinus arrhythmia a good index of cardiac vagal tone in exercise? *J Appl Physiol* 81: 556–564, 1996.

7. Collier, SR, Kelly, EE, Jae, SY, Fernhall, B, Capes, IC, Universidade, U, et al. Arterial Stiffness and Baroreflex Sensitivity Following. *Int J Sport Med* 28: 197–203, 2007.

8. Davies, V, and Thompson, KG. The Effects of Compression Garments on Recovery. *J Strength Cond Res* 23(6): 1786–1794, 2009.

9. Heffernan, KS, Kelly, EE, Collier, SR, and Fernhall, B. Cardiac autonomic modulation during recovery from acute endurance versus resistance exercise. *Eur J Cardiovasc Prev Rehabil* 13: 80–86, 2006.

10. Iellamo, F, Legramante, JM, Raimondi, G, and Peruzzi, G. Baroreflex control of sinus node during dynamic exercise in humans: effects of central command and muscle reflexes. *Am J Physiol* 272: H1157–64, 1997.

11. Iverson, A. Compression Garments and Exercise. *Sport Med* 41: 815–843, 1990.

12. Jellema, WT, Wesseling, KH, Groeneveld, AB, Stoutenbeek, CP, Thijs, LG, and van Lieshout, JJ. Continuous cardiac output in septic shock by simulating a model of the aortic input impedance: a comparison with bolus injection thermodilution. *Anesthesiology* 90: 1317–1328, 1999.

13. Kraemer, WJ, Flanagan, SD, Comstock, BA, Fragala, MS, Earp, JE, Dunn-Lewis, C, et al. 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.

14. Laffite, LP, Vilas-boas, JP, Demarle, A, Fernandes, R, and Billat, L. Changes in Physiological and Stroke Parameters During a Maximal 400-m Free Swimming Test in Elite Swimmers. *Changes* 29: S17–S31, 2004.

15. Legramante, JM, Galante, A, Massaro, M, Attanasio, A, Raimondi, G, Pigozzi, F, et al. Hemodynamic and autonomic correlates of postexercise hypotension in patients with mild hypertension. *Am J Physiol Regul Integr Comp Physiol* 282: R1037–R1043, 2002.

16. Malliani, A, Pagani, M, Lombardi, F, and Cerutti, S. Cardiovascular neural regulation explored in the frequency domain. *Circulation* 84: 482–492, 1991.

17. Mayrovitz, HN and Larsen, PB. Effects of compression bandaging on leg pulsatile blood flow. *Clin Physiol* 17: 105–117, 1997.

18. Niemelä, TH, Kiviniemi, AM, Hautala, AJ, Salmi, JA, Linnamo, V, and Tulppo, MP. Recovery pattern of baroreflex sensitivity after exercise. *Med Sci Sports Exerc* 40: 864–870, 2008.

19. Pagani, M, Lombardi, F, Guzzetti, S, Rimoldi, O, Furlan, R, Pizzinelli, P, et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circ Res* 59: 178–193, 1986.

20. Pagani, M, Somers, V, Furlan, R, Dell'Orto, S, Conway, J, Baselli, G, et al. Changes in autonomic regulation induced by physical training in mild hypertension. *Hypertension* 12: 600–610, 1988.

21. Perini, R, and Veicsteinas, A. Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. *Eur J Appl Physiol* 90: 317–325, 2003.

22. Piepoli, M, Coats, AJ, Adamopoulos, S, Bernardi, L, Feng, YH, Conway, J, et al. Persistent peripheral vasodilation and sympathetic activity in hypotension after maximal exercise. *J Appl Physiol* 75: 1807–1814, 1993.

23. Piras, A, Persiani, M, Damiani, N, Perazzolo, M, and Raffi, M. Peripheral heart action (PHA) training as a valid substitute to high intensity interval training to improve resting cardiovascular

changes and autonomic adaptation. *Eur J Appl Physiol* 115: 763–773, 2015.

24. Raczak, G, Pinna, GD, La Rovere, MT, Maestri, R, Nilowicz-Szymanowicz, L, Ratkowski, W, et al. Cardiovagal response to acute mild exercise in young healthy subjects. *CircJ* 69: 976–980, 2005.

25. Rimoldi, O, Pierini, S, Ferrari, A, Cerutti, S, Pagani, M, and Malliani, A. Analysis of short-term oscillations of R-R and arterial pressure in conscious dogs. *Am J Physiol* 258: H967–H976, 1990.

26. Robbe, HW, Mulder, LJ, Ruddel, H, Langewitz, WA, Veldman, JB, and Mulder, G. Assessment of baroreceptor reflex sensitivity by means of spectral analysis. *Hypertension* 10: 538–543, 1987.

27. Sala-Mercado, JA, Ichinose, M, Hammond, RL, Ichinose, T, Pallante, M, Stephenson, LW, et al. Muscle metaboreflex attenuates spontaneous heart rate baroreflex sensitivity during dynamic exercise. *Am J Physiol Heart Circ Physiol* 292: H2867–H2873, 2007.

28. Somers, VK, Conway, J, Coats, A, Isea, J, Sleight, P. Postexercise Hypotension Is Not Sustained in Normal and Hypertensive Humans. *Hypertension* 18: 211–215, 1991.

29. Sperlich, B, Born, D, Sperlich, B, and Holmberg, H. Bringing Light Into the Dark□: Effects of Compression Clothing on Performance and Recovery Bringing Light Into the Dark□: Effects of Compression Clothing on Performance and Recovery. *Int J Sports Physiol Perform* 8: 4–18, 2013.

30. Stuckey, MI, Tordi, N, Mourot, L, Gurr, LJ, Rakobowchuk, M, Millar, PJ, et al. Autonomic recovery following sprint interval exercise. *Scand J Med Sci Sport* 22: 756–763, 2012.

31. Studinger, P, Lénárd, Z, Kováts, Z, Kocsis, L, and Kollai, M. Static and dynamic changes in carotid artery diameter in humans during and after strenuous exercise. *J Physiol* 550: 575–583, 2003.

32. Toubekis, AG, Tsolaki, A, Smillos, I, Douda, HT, Kourtesis, T, and Tokmakidis, SP. Swimming performance after passive and active recovery of various durations. *Int J Sports*

Physiol Perform 3: 375–386, 2008.

33. Watanuki, S, and Murata, H. Effects of Wearing Compression Stockings on Cardiovascular Responses. *Ann Physiol Anthropol* 13: 121–127, 1994.

34. Westerhof, BE, Gisolf, J, Karemaker, JM, Wesseling, KH, Secher, NH, and van Lieshout, JJ. Time course analysis of baroreflex sensitivity during postural stress. *Am J Physiol Heart Circ Physiol* 291: H2864–H2874, 2006.

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FIGURE LEGENDS

Figure 1. Compression garment.

Athlete, in a supine position, is wearing the compression garment during the recovery period. An infrared plethysmography is inserted in his finger for non-invasive continuous blood pressure monitoring.

Figure 2. Baroreflex and blood pressure data.

Baroreflex sensitivity (**A**), BRS low-frequency spectral band (**B**), systolic (**C**) and diastolic blood pressure (**D**) indices at baseline level and during recovery time in garment (GAR, *black line with square*) and control (CON, *gray line with triangles*) condition.

* Differences of both conditions with respect to baseline

† Differences of CON with respect to baseline

‡ Differences of GAR with respect to baseline

Figure 3. Heart rate variability data.

HRV high- and low-frequency spectral band (**A**, **B**), HRV time domain indices (**D**, **E**), and sympathovagal balance (**C**) at baseline level and during recovery time in garment (GAR, *black line with square*) and control (CON, *gray line with triangles*) condition.

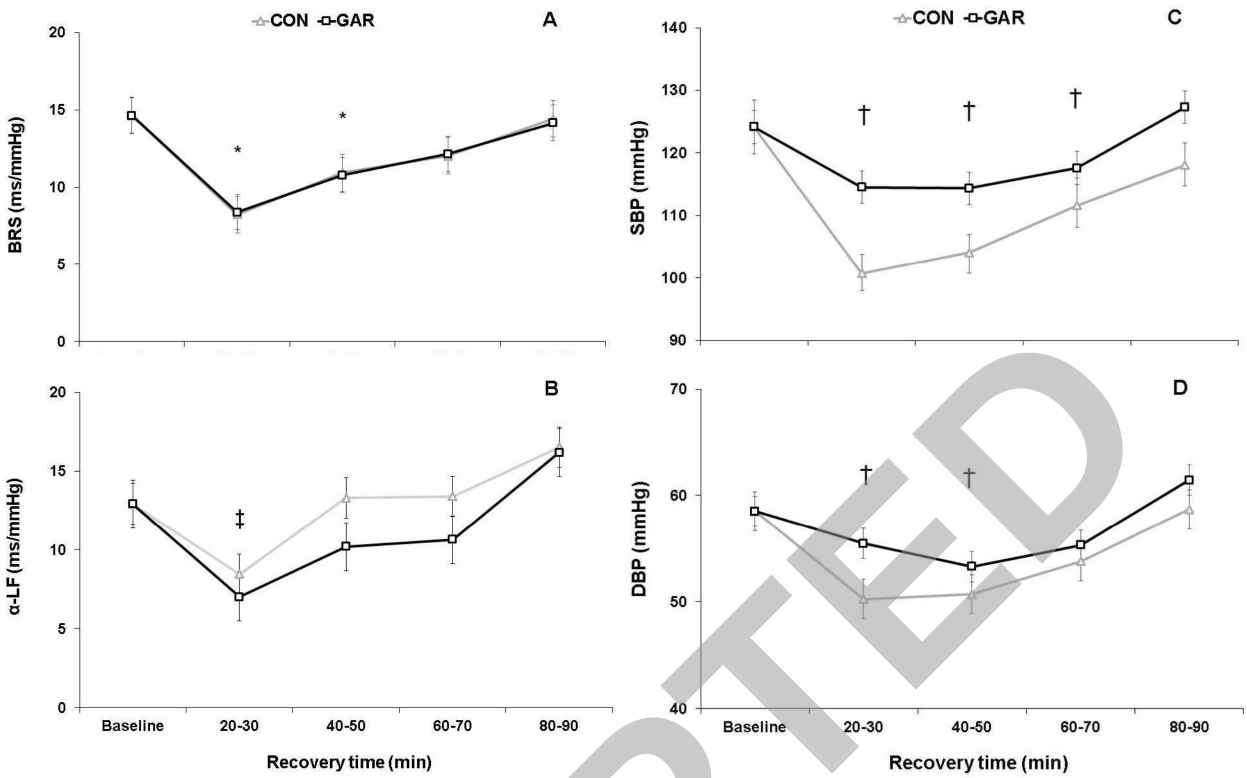
(*, †, ‡) Conventions as in Figure 2.

Figure 4. Hemodynamic data.

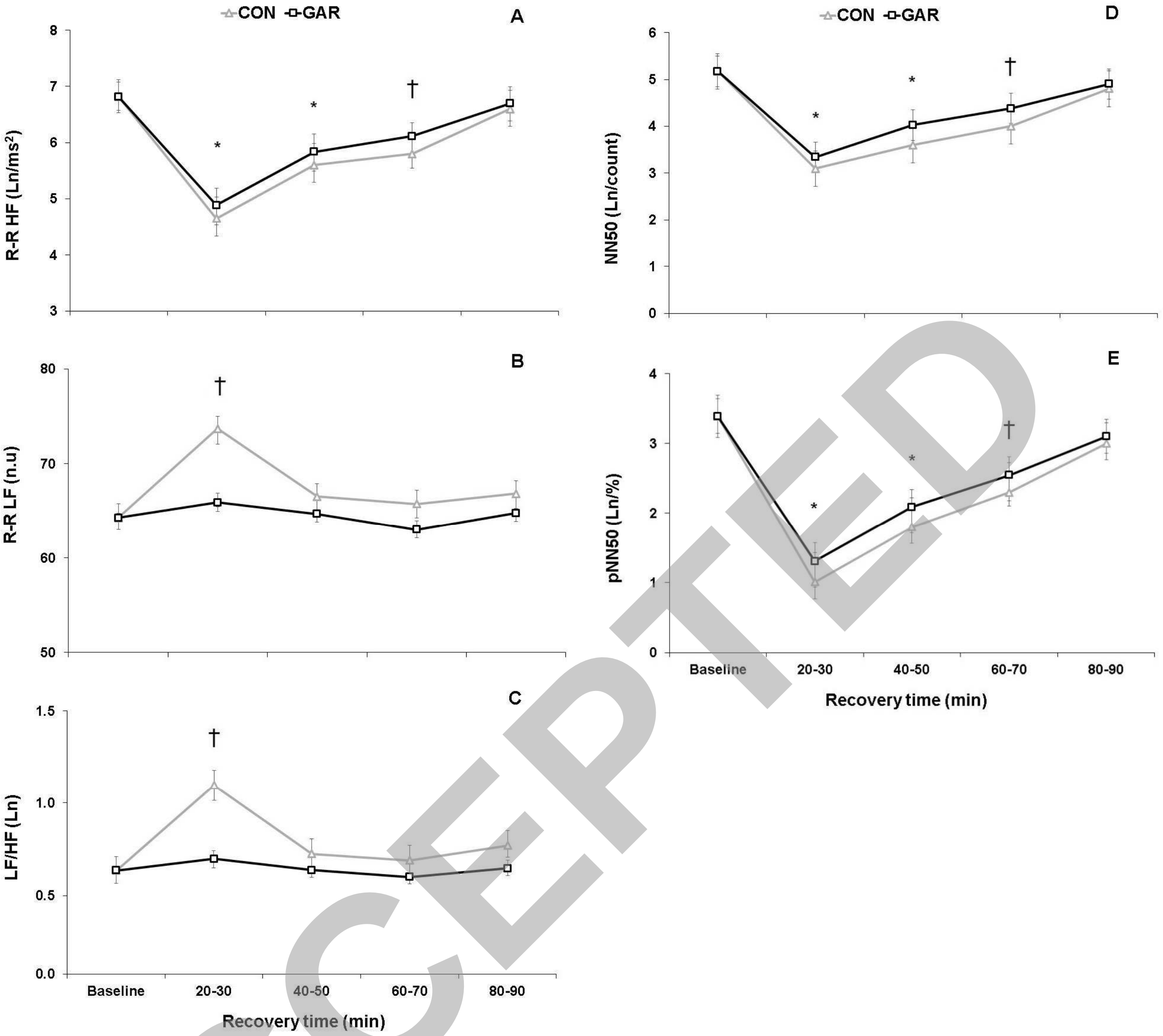
Cardiac output (**A**), stroke volume (**B**), heart rate (**C**), and total peripheral resistance (**D**) at baseline level and during recovery time in garment (GAR, *black line with square*) and control (CON, *gray line with triangles*) condition.

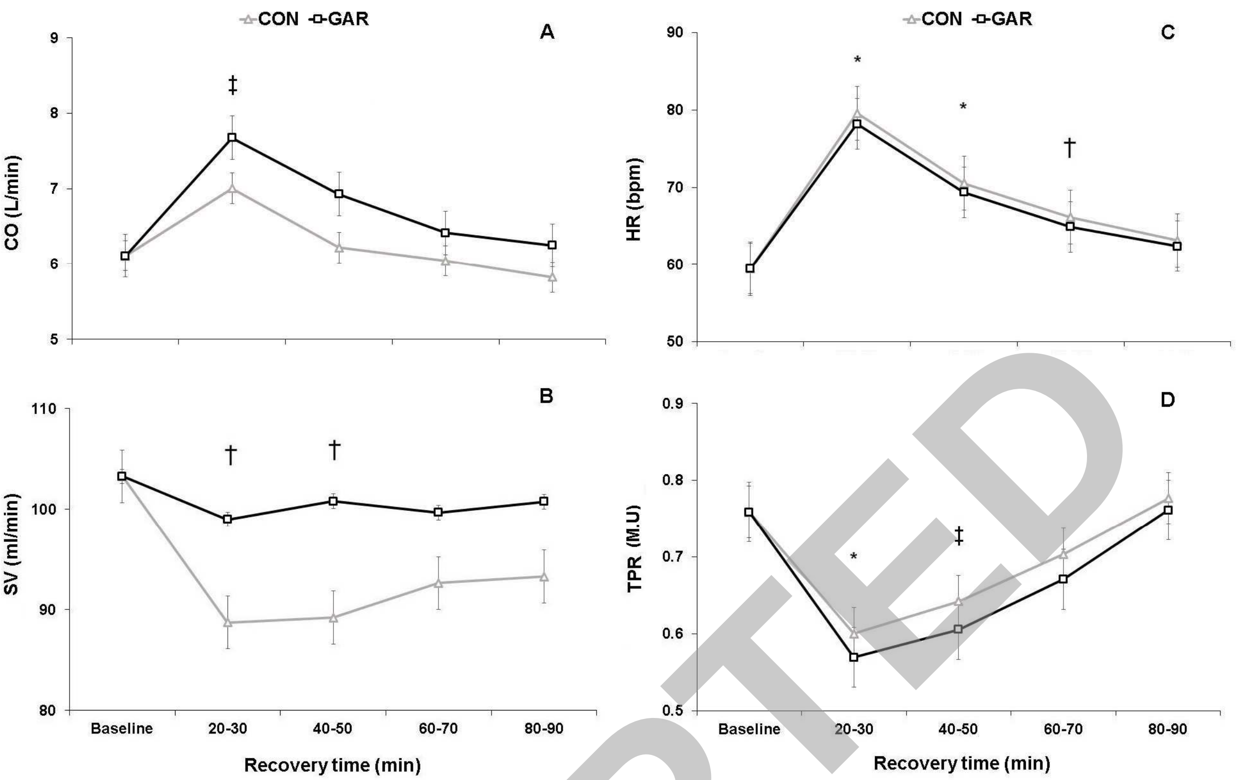
(*, †, ‡) Conventions as in Figure 2.


arena
arena



CON
GAR
A
BRS (ms/mmHg)
0
5
10
15
20
*
*
B
α-LF (ms/mmHg)
0
5
10
15
20
‡
Baseline
20-30
40-50
60-70
80-90
Recovery time (min)
C
SBP (mmHg)
90
100
110
120
130
140
†
†
†
D
DBP (mmHg)
40
50
60
70
†
†
Baseline
20-30
40-50
60-70
80-90
Recovery time (min)


CON GAR
A
R-R HF (Ln/ms^2)
8
7
6
5
4
3
*
*
†
B
R-R LF (n.u)
80
70
60
50
†
C
LF/HF (Ln)
1.5
1.0
0.5
0.0
†
Baseline
20-30
40-50
60-70
80-90
Recovery time (min)
CON GAR
D
NN50 (Ln/count)
6
5
4
3
2
1
0
*
*
†
E
pNN50 (Ln/%)
4
3
2
1
0
*
*
†
Baseline
20-30
40-50
60-70
80-90
Recovery time (min)


CON
GAR
A
CO (L/min)
9
8
7
6
5
‡
C
HR (bpm)
90
80
70
60
50
*
*
†
B
SV (ml/min)
110
100
90
80
†
†
D
TPR (M.U)
0.9
0.8
0.7
0.6
0.5
*
‡
Baseline
20-30
40-50
60-70
80-90
Recovery time (min)