

# ARCHIVIO ISTITUZIONALE DELLA RICERCA

# Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca

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

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Piras, A., Gatta, G. (2017). Evaluation of the Effectiveness of Compression Garments on Autonomic Nervous System Recovery After Exercise. JOURNAL OF STRENGTH AND CONDITIONING RESEARCH, 31(6), 1636-1643 [10.1519/JSC.000000000001621].

Availability:

This version is available at: https://hdl.handle.net/11585/598530 since: 2017-06-13

Published:

DOI: http://doi.org/10.1519/JSC.000000000001621

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (https://cris.unibo.it/). When citing, please refer to the published version.

(Article begins on next page)

Journal of Strength and Conditioning Research Publish Ahead of Print DOI: 10.1519/JSC.000000000001621

Submitted to *Journal of Strength & Conditioning Research* Editors-in-Chief: William J. Kraemer, PhD.

# Title: Evaluation of the effectiveness of compression garments on autonomic

# nervous system recovery following exercise

#### **Authors:**

 Alessandro Piras, Department of Biomedical and Neuromotor Sciences University of Bologna;
 Giorgio Gatta, Department for Life Quality Studies University of Bologna;

## Author's correspondence:

Alessandro Piras, Department of Biomedical and Neuromotor Sciences University of Bologna Piazza di Porta S. Donato, 2 40126 Bologna – Italy Phone: (0039) 051 - 2091774 Fax: (0039) 051 - 2091737 E-mail: <u>alessandro.piras3@unibo.it</u>

# 1 Abstract

2 The aim of this investigation was to evaluate the recovery pattern of a whole body compression 3 garment on hemodynamic parameters and on ANS activity following a swimming performance. Ten 4 young male athletes were recruited and tested in two different days, with and without wearing the 5 garment during the recovery phase. After a warm-up of 15 minutes, athletes were instructed to 6 perform a maximal 400m freestyle swimming event, and then time series of beat-to-beat intervals for 7 heart rate variability (HRV), baroreflex sensitivity (BRS), and hemodynamic parameters were 8 recorded for 90 minutes of recovery. The vagally mediated HF power of R-R intervals, NN50, and 9 pNN50 showed a faster recovery due to the costume, meanwhile, the LFRR index of sympathetic 10 modulation of the heart, as well as LF:HF ratio and BRS alpha index (aLF) were augmented in control 11 than in garment condition. When athletes wore the swimsuit, cardiac output was increased and the 12 returning of the blood to the heart, investigated as stroke volume, was kept constant due to the 13 reduction of the total peripheral resistances. During control condition, HR was restored back to 14 baseline value 20 minutes later with respect to garment condition, confirming that the swimsuit 15 recover faster. The effectiveness of the swimsuit on ANS activity after a maximal aerobic performance 16 has been shown with a greater recovery in terms of HRV and hemodynamic parameters. BRS was 17 reduced in both conditions, maybe due to prolonged vasodilatation that may have also influenced the 18 post-exercise hypotension.

19

Copyright © 2016 National Strength and Conditioning Association

- 22
- 23
- 24
- 25
- 26
- 27

<sup>20</sup> Keywords: heart rate variability, baroreflex sensitivity, compression garments, recovery, swimming
21 Running head: Autonomic nervous system recovery in swimmers

### 28 INTRODUCTION

29 The day of the competition, swimmers are subjected to several races that require maximum effort. 30 Performance may be affected because muscles, cardiorespiratory parameters and blood homeostasis 31 could be dramatically reduced race after race. During local or qualifying trial competitions, swimmers 32 take part in successive events, and when the recovery time is short, a subsequent effort cannot be 33 effectively applied unless an adequate restoration of homeostasis occurs (32). Therefore, there is the 34 need to find a way that speeds up the recovery time, helping swimmers to perform better in a 35 subsequent event. Thus, it is important to have information on the most effective recovery time that 36 may improve performance during the next event (14).

37 Different studies have investigated the effect of compression garment (CG) on recovery, and 38 most of them did it during and/or after exercise (11,29). Applying compression exclusively during 39 continuous exercise did not show any benefits for recovery 24 hours after exercise (2). Therefore, it 40 seems essential to wear compression clothing for at least 12 to 24 hours after exercise to improve 41 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 42 43 effects of clothing skin pressure exerted by compression garments on the autonomic nervous system 44 (ANS) activity and hemodynamic parameters. Indeed, data directly demonstrating influences on 45 venous return, cardiac output or stroke volume appear to be sparse (33), and none were identified for 46 athletes (24). Cardiovascular modification has been assessed using heart rate, and findings indicate 47 little effect of CGs during exercise, so that cardiovascular influences of CGs in exercise (11) and 48 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 55 specific to the mode and intensity of effort. One hour following mild exercise showed elevated values 56 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 57 58 HRV, as well as blood pressure oscillations returned to the control level after 30 min of aerobic 59 exercise. In earlier studies, BRS has been shown to exceed the pre-exercise values at 60 min after 60 aerobic exercise (15), but this finding has not been reported by all (31). Somers et al (28) reported that 61 BRS is decreased only for 20 min, but others have shown the recovery period to be longer (9,31). BRS 62 is reduced after both aerobic and resistance exercise compared with baseline values (7), allowing 63 increases in BP and HR (10,27).

64 Thus, it would be of interest to explore a possible connection between compression garment, 65 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 66 freestyle event would enhance the autonomic recovery process (8,13). Thus, the aim of this 67 investigation was to evaluate the recovery pattern of a whole body compression garment after a 68 69 swimming performance on hemodynamic parameters and on ANS activity on subsequent 90 minutes 70 of recovery. We measured HRV and BRS activity by analysing the simultaneous spontaneous 71 variations of heart rate and systolic blood pressure, in order to determine autonomic nervous system 72 activity in a non-invasive manner (20). Therefore, RR interval and SBP variability were investigated 73 on both frequency and time domain with short-term analysis. In the past, this methodology has 74 furnished measurable indicators of vagal and sympathetic activity of heart rate and (19) of vasomotor 75 tone (25).

76

## 77 **METHODS**

#### 78 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

85 Elettronica, Padova, Italy), were ~13mmHg on the forearms, ~10mmHg on the upper arms, ~6mmHg

86 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\*\*\*

90

# 91 Subjects

92 Ten male athletes [age  $21.60\pm1.58$  yr., height of  $179\pm0.05$  cm, and BMI of  $23.17\pm1.33$  kg/m2] 93 responded to volunteer and subsequently participated in the study. All subjects competed at the 94 national level and trained at least 14 hours per week. Given that all participants were athletes, they 95 were healthy, non-smokers, and they did not take any medication during the study. Moreover, they 96 were advised to avoid training and any stimulant (e.g. coffee, energy drink) 24 hours before the test. 97 This study was approved by Bioethics Committee of the University of Bologna and all participants 98 were informed of the benefits and risks of the investigation prior to signing an institutionally approved 99 informed consent document to participate in the study.

100

#### 101 **Procedure**

102 On two separate occasions, same athletes were tested with (GAR) and without (CON) wearing the 103 compression costume only during the recovery phase following a swimming performance. All 104 swimmers underwent non-invasive continuous blood pressure monitoring using the servo-controlled 105 infrared finger plethysmography (Portapres device; TNO/BMI) for analysis of HRV and BRS. Tests 106 were done under a standardized procedure at the same time of the day (9:00-12:00) to avoid circadian 107 influence. In both occasions, each swimmer was first tested in a supine position, in a room quiet and 108 with a comfortable temperature (22-25°C), for 10 minutes (baseline). They were instructed to stand 109 still and be quiet, with a respiratory frequency of 12-15 breaths/min. After a warm-up of 15 minutes, 110 they were instructed to perform a maximal 400-m freestyle as in competition, during which total and 111 intermediate time were recorded at each length (25 m). The day of the GAR test, the compression 112 garment was dressed only during the recovery phase, not during the swimming performance. During 113 the recovery phase, signals were measured 20-30, 40-50, 60-70, and 80-90 minutes after the cessation 114 of the swimming performance. For the final analysis of autonomic function, the last 5 min of every 115 recovery phase were used for calculations, as recommended by guidelines for HRV analysis during 116 short term recording (4).

117

HRV analysis. The Portapres recordings were used to extract time series of R-R intervals and 118 119 systolic as well as diastolic pressures, to analyze HRV and BRS. Data were analysed with 120 Kubios HRV software (v. 2.0, 2008, Biosignal Analysis and Medical Imaging Group, University of 121 Kuopio, Finland), in which all time series were filtered to exclude artefacts. All measure were 122 analysed in according to conditions by the Task Force of the European Society of Cardiology and the 123 North American Society of Pacing and Electrophysiology (4). Time domain indices for HRV analysis 124 were: the number of interval differences of successive R-R intervals greater than 50 ms (NN50), and 125 the proportion derived by dividing NN50 by the total number of R-R intervals NN50 (pNN50). 126 Furthermore, we analysed two main frequency components of HRV: low frequency (LF) ranging from 127 0.04 to 0.15 Hz, and high frequency (HF) centered at the breathing frequency (4). It has been shown 128 that the HF spectral component of HR variability (HFRR) is an index of the vagal tone, whereas both

129 sympathetic and vagal activities contributed to the LF (LFRR) spectral component of HRV (6). Given 130 that LFRR does not provide an index of sympathetic modulation when measured in absolute units, we 131 expressed the power in both absolute and normalized units (19). Such normalized units are obtained by 132 dividing the power of each component by total variance from which the very-low-frequency 133 component had been subtracted, and multiplying this value by 100 (16,19). Therefore, low and high 134 frequency (LFRR and HFRR) spectral components measured in normalized units, or as LF/HF ratio, 135 provide quantitative markers of cardiac sympathetic and vagal modulation respectively (19).

136

137 BRS analysis. Baroreflex sensitivity was computed from RR intervals and SBP sequence subtracted 138 from the finger arterial pressure waveform. These data were then utilised to define the oscillations in 139 both heart rate and systolic arterial pressure measures. Beatscope version 1.1a (TNO/BMI, 140 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 141 142 identification in the time domain of 4 or more spontaneous sequences of consecutive beats, 143 distinguished by either a progressive increase in SBP and R-R interval (+RR /+SBP sequences) or by a 144 progressive reduction of the same variables (-RR/-SBP sequences). The incline of the regression line 145 between SBP and RR interval fluctuations is taken as an index of the arterial baroreflex sensitivity of 146 the heart, same as the laboratory method based on i.v. injection of vasoactive drugs. This technique for 147 BRS identification has lower within-patient variance than other methods, and provides more values 148 per minute than the standard time-domain based method (34). Moreover, a blood pressure spectral 149 analysis has been used. Low-Frequency (LF-SBP) spectral component of SBP variability return the 150 sympathetic activity of the vascular  $\alpha$ -adrenergic receptors, while high-frequency (HF-SBP) reflect the 151 influence of breathing on systolic blood pressure (19). Then, to obtain information about the effect of 152 sympathovagal modulation on sinoatrial node spontaneous activity (19), we calculated the BRS alpha 153 index from the low-frequency band ( $\alpha$ LF). It was computed as square root of the ratio between the RR 154 power and the corresponding SAP spectral component (20). This analysis was also confirmed by 155 Robbe et al. (26), who showed that the middle frequency band (0.07-0.14 Hz) between SBP and RR 156 interval time gives equivalent results to those obtained using the phenylephrine method.

158 *Hemodynamic parameters*. From the blood pressure waveform, stroke volume (SV), cardiac output 159 (CO), and total peripheral vascular resistance (TPR) were estimated by the pulse contour method of 160 Wesseling (the Modelflow method - software TNO/BMI, Amsterdam, The Netherlands) that has been 161 validated extensively (3,12).

162

#### 163 Statistical Analysis

164 Shapiro-Wilk test was used to check the normal distribution of data. Measures with skewed 165 distribution were log transformed (Ln) before analysis. The ICC was used to assess the reliability of 166 time between the test and retest of 400m freestyle event. A 5 x 2 repeated measures ANOVA was 167 performed separately to analyse all investigated variables. Time (Baseline; R20-30; R40-50; R60-70; 168 and R80-90) was the within-subjects factor and condition (GAR; CON) the between-subjects factor. 169 To examine changes between recovery phases (R20-30; R40-50; R60-70; and R80-90) and baseline 170 values on each condition, a paired sample t-test was used. Data were analysed with SPSS v20.0 (SPSS, 171 Chicago, IL, USA). Means were considered significantly different at p< 0.05. Effect sizes were 172 calculated using partial eta squared ( $\eta p2$ ).

173

## 174 **RESULTS**

175 No significant difference was observed between the two swimming test (p > 0.05) in which the time to 176 complete 400-m was 269.9±13.1 sec in the first occasion, and 269.6±13.0 sec for the second one. The 177 data from the swimming test and re-test days were analysed using intra-class correlation coefficient. A 178 high degree of reliability was found between measurements, in which the average measure ICC was 179 0.979 with a 95% confidence interval from 0.920 to 0.995 ( $F_{9,9} = 86.74$ , p<.001). No significant 180 difference was also observed between the two baseline values (GAR vs. CON) (p > 0.05) for all 181 variables investigated. Analysis on main effect showed a significant difference for time (p < 0.05), 182 which means that during the recovery period, all parameters, regardless of the type of condition (GAR,

183 CON), changed significantly with respect to the baseline value. Paired sample t-test allowed us to see,184 for each condition in each recovery time, which variables differed from baseline.

185

#### 186 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,  $\eta p2 = 0.44$ , Figure 2A ). However,  $\alpha LF$  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\*\*\*

#### 195 Heart rate variability indices

196 HRV value showed a clear effect influenced by the garment (Figure 3). HFRR, NN50, and pNN50 197 demonstrated, in both conditions, a lower value 40-50 min after the effort (F4,72 = 18.06, p < 0.001, 198  $\eta p 2 = 0.50$  for NN50; F4,72 = 21.73, p < 0.001,  $\eta p 2 = 0.55$  for pNN50; and F4,72 = 7.83, p = 0.005, 199  $\eta p2 = 0.30$  for HFRR). The same variables exhibited a prolonged reduction (60-70 min) only in CON 200 condition [t(9) = 3,03; p = 0.014, t(9) = 2,54; p = 0.031, and t(9) = 2,66; p = 0.026, respectively].201 Figure 3B shows the LFRR value unchanged in GAR, while returns to baseline value after 30 min in 202 CON [t(9) = 2,79; p = 0.021]. This is confirmed also by LF:HF ratio [t(9) = 2,34; p = 0.040, Figure203 3C], with a conclusion that, wearing the swimsuit during the post-exercise speeds up recovery after 204 performance.

205

206 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 (F4,72 = 57.96, p < 0.001,  $\eta p 2 = 0.76$ ), 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 (F4,72 = 15.72, p < 0.001,  $\eta p 2 = 0.47$ ), showing a significant prolonged reduction for 50 min during GAR [t(9) = 2,84; p = 0.019, Figure 4D].

216

\*\*\*Figure 4 about here\*\*\*

## 217 **DISCUSSION**

218 The aim of this investigation was to evaluate the recovery pattern of a whole body compression 219 garment on hemodynamic parameters and on ANS activity following a maximal 400-m freestyle 220 event. We measured HRV and BRS activity by analysing the simultaneous spontaneous variations of 221 heart rate and systolic blood pressure. The principal finding of the present study is that compression 222 garments had an effect on the pattern of autonomic function recovery. Primarily, the vagally mediated 223 HF power of R-R intervals, NN50, and pNN50 showed a faster recovery due to the costume, 224 meanwhile, the LFRR index of sympathetic modulation of the heart, as well as LF:HF ratio were 225 augmented in control than in garment condition. This finding indicates that the costume has a positive 226 influence on the ANS activity, which is predominantly related to the significant fast recovery of 227 parasympathetic nervous system after the effort. Next, the LF power of BRS, which reflects 228 sympathetic tone, was not affected by the effect of exercise during the recovery phase when the 229 athletes wore the costume. Graduated compression implies that the applied pressures are highest 230 distally, and decrease proximally, deriving from medical applications that relate primarily to 231 circulatory roles such as the reduction of venous pooling and augmentation of venous blood flow 232 return. In fact, cardiac output was increased, avoiding post-exercise hypotension, and the returning of 233 the blood to the heart, investigated as stroke volume, was keep constant due to the reduction of the 234 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 ofrecovery during CON condition.

237 Swimming at high intensities, such as during racing and tough sets, can cause metabolites like 238 inorganic phosphate, ADP, hydrogen ions, and of course, lactate, to accumulate in the muscles (14). A 239 build-up of these metabolites is associated with conditions that can compromise the next swimming 240 performance. The rate of recovery of the accumulated fatigue agents may differ during passive and 241 active recovery using short or long duration and this may affect performance (32). Active recovery 242 facilitates the removal/utilization of lactate after a race or tough set. The intensity of the active 243 recovery influences how quickly this removal/utilization of lactate occurs. Too high an intensity may 244 produce additional lactate, while too low an intensity may not create enough circulation to 245 remove/utilize the lactate faster than passive recovery (32). For this reason in recent years it is 246 increased the need to find methods necessary to improve the recovery time. The increasing 247 attractiveness of compression garments in different sports is likely due to accumulating evidence of 248 enhanced performance and recovery (29). To our knowledge, no research has documented the effect of 249 compression clothing on indicators of recovery performance such as HRV, BRS and hemodynamic 250 parameters.

251 During recovery from moderate and heavy exercise heart rate remains elevated above the pre-252 exercise level for a relatively long period of time (up to 60 min) (5). Niemela et al. (18) found HR 253 elevated at 60 min after aerobic and heavy resistance exercise and at 30 min after light resistance 254 exercise compared with the control level. Our test can be catalogued among aerobic performances 255 because, even if we did not measure any metabolic parameter, subjects did the 400-m with a great 256 time, under 270 sec, in which the estimated contribution of anaerobic metabolism represented 20% of 257 total energy output (14). In our study, HR was restored to the baseline level after 60 min, compared to 258 control condition in which subject recovered after 80 min. Furthermore, HF power of RR intervals, as 259 well as time domain indices like NN50 and pNN50, recognized as a marker of vagal activity (4), were 260 restored back after 50 min. Previous studies have shown these indices reduced until 30 min after 261 aerobic exercise (9,18) compared to baseline level. Likewise, LFRR, that represents an index of 262 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.

266 Different studies showed that, immediately after the end of aerobic exercise, BRS is 267 significantly reduced (18,27,31). Our results are in agreement with Stuckey et al. (30) in which 268 baroreflex does not have as great role in maintaining BP in acute recovery from exercise as it does 269 under prolonged resting conditions. As it was found in other studies (7,18,31), BRS value was reduced 270 significantly at 40-50 min after exercise, and it gradually increases back to the baseline level after 60-271 70 min in both conditions. BRS alpha index (aLF) had a significant reduction until 30 min only during 272 wearing garment, returning to baseline value at 40-50 min. Moreover, in both conditions, this value 273 tended to rise above the baseline level 80-90 min after the cessation of the effort, as it was also 274 reported by Niemela et al. (18) after both aerobic and light resistance exercise.

275 After an acute bout of exercise blood pressure falls, sometimes for several hours. This 276 hypotensive effect can be affected by the exercise, and it persists if the subject maintains supine 277 position (28), as it happens in our control condition. In normotensive subjects, a reduction in systemic 278 vascular resistance after maximal exercise is counterbalanced by the increase of cardiac output, 279 avoiding a clinically significant blood pressure reduction. Therefore, we can hypothesize that post-280 exercise hypotension could be due not to an overall decrease in sympathetic tone but to persisting 281 vasodilatation (22). The decrease in total peripheral resistance (Figure 4D) is associated with a double 282 reflex response: sympathetic activation (Figure 3B) and depressed vagal tone (Figures 3A, 3D, 3E), 283 which may be responsible for the concomitant increases in heart rate (Figure 4C) and cardiac output 284 (Figure 4A). They are associated even with or caused by a reduction in baroreflex sensitivity (Figure 285 2A). This could also be attributed to the garment condition even if the reduction of arterial pressure 286 was not significantly different from baseline value. Moreover, data directly demonstrating influences 287 on venous return, cardiac output or stroke volume appear to be sparse (33), and none were identified 288 for people engaged in exercise or during recovery period. Possible mechanisms for flow augmentation 289 have been discussed (17) and include a myogenic vasodilatory response. The myogenic response of 290 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.

294

# 295 PRATICAL APPLICATIONS

296 In conclusion, there were evident changes in autonomic regulation after exercise when subjects wore 297 the compression garment than during the control condition. The use of the compression garments, 298 allowed only during the recovery period, could provide a functional recovery following a swimming 299 performance. First, HR was restored to the baseline level 60 min following exercise, cardiac output 300 augmented, stroke volume unchanged and total peripheral resistance decreased. Secondly, vagal 301 outflow was significantly reduced during the control condition compared with the compression 302 garment, as documented by the changes in the HF power of R-R interval fluctuation, NN50 and 303 pNN50 time domain indices. Thirdly, sympathovagal balance, assessed by LF:HF ratio, and the 304 sympathetic modulation of the heart, evaluated by LFRR, were unchanged during the recovery period 305 only when subject wore the swimsuit. After these conclusions, we recommend to all athletes to use the 306 compression garment when they are involved in several races close together, both during training 307 period and in competition, in order to obtain a faster recovery. Furthermore, we suggested further 308 investigations with the intention to see if the compression garments are able to reduce the recovery 309 time also in other type of swimming performance.

310

## 311 **REFERENCES**

- 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.
- Ali, A, Creasy, RH, and Edge, JA. Physiological effects of wearing graduated compression
   stockings during running. *Eur J Appl Physiol* 109: 1017–1025, 2010.
- 316 3. Bos, WJ, van Goudoever, J, van Montfrans, GA, van den Meiracker, AH, and Wesseling, KH.
- 317 Reconstruction of brachial artery pressure from noninvasive finger pressure measurements.

- 318 *Circulation* 94: 1870–5, 1996.
- 319 4. Camm, A, Malik, M, Bigger, J, and Günter, B. Task force of the European Society of
  320 Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate
  321 variability: standards of measurement, physiological interpretation and clinical use. *Circulation*322 93: 1043–1065, 1996.
- S. 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.
- 325 6. Casadei, B, Moon, J, Johnston, J, Caiazza, A, and Sleight, P. Is respiratory sinus arrhythmia a
  326 good index of cardiac vagal tone in exercise? *J Appl Physiol* 81: 556–564, 1996.
- 327 7. Collier, SR, Kelly, EE, Jae, SY, Fernhall, B, Capes, IC, Universidade, U, et al. Arterial
  328 Stiffness and Baroreflex Sensitivity Following. *Int J Sport Med* 28: 197–203, 2007.
- B. Davies, V, and Thompson, KG. The Effects of Compression Garments on Recovery. *J Strength Cond Res* 23(6): 1786–1794, 2009.
- 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.
- 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.
- 338 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.
- 342 13. Kraemer, WJ, Flanagan, SD, Comstock, BA, Fragala, MS, Earp, JE, Dunn-Lewis, C, et al.
  343 Effects of a whole body compression garment on markers of recovery after a heavy resistance

- 344 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.
- 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.
- 351 16. Malliani, A, Pagani, M, Lombardi, F, and Cerutti, S. Cardiovascular neural regulation
  352 explored in the frequency domain. *Circulation* 84: 482–492, 1991.
- 353 17. Mayrovitz, HN and Larsen, PB. Effects of compression bandaging on leg pulsatile blood flow.
  354 *Clin Physiol* 17: 105–117, 1997.
- 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.
- 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.
- 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.
- 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.
- 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.

- 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.
- Rimoldi, O, Pierini, S, Ferrari, A, Cerutti, S, Pagani, M, and Malliani, A. Analysis of shortterm oscillations of R-R and arterial pressure in conscious dogs. *Am J Physiol* 258: H967–
  H976, 1990.
- 377 26. Robbe, HW, Mulder, LJ, Ruddel, H, Langewitz, WA, Veldman, JB, and Mulder, G.
  378 Assessment of baroreceptor reflex sensitivity by means of spectral analysis. *Hypertension* 10:
  379 538–543, 1987.
- 380 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.
- 383 28. Somers, VK, Conway, J, Coats, A, Isea, J, Sleight, P. Postexercise Hypotension Is Not
  384 Sustained in Normal and Hypertensive Humans. *Hypertension* 18: 211–215, 1991.
- 385 29. Sperlich, B, Born, D, Sperlich, B, and Holmberg, H. Bringing Light Into the Dark□: Effects of
- 386 Compression Clothing on Performance and Recovery Bringing Light Into the Dark : Effects
- 387 of Compression Clothing on Performance and Recovery. Int J Sports Physiol Perform 8: 4–18,
- 388 2013.
- 389 30. Stuckey, MI, Tordi, N, Mourot, L, Gurr, LJ, Rakobowchuk, M, Millar, PJ, et al. Autonomic
  390 recovery following sprint interval exercise. *Scand J Med Sci Sport* 22: 756–763, 2012.
- 391 31. Studinger, P, Lénárd, Z, Kováts, Z, Kocsis, L, and Kollai, M. Static and dynamic changes in
  392 carotid artery diameter in humans during and after strenuous exercise. *J Physiol* 550: 575–583,
  393 2003.
- 394 32. Toubekis, AG, Tsolaki, A, Smillos, I, Douda, HT, Kourtesis, T, and Tokmakidis, SP.
  395 Swimming performance after passive and active recovery of various durations. *Int J Sports*

- *Physiol Perform* 3: 375–386, 2008.
- 397 33. Watanuki, S, and Murata, H. Effects of Wearing Compression Stockings on Cardiovascular
  398 Responses. *Ann Physiol Anthropol* 13: 121–127, 1994.
- 399 34. Westerhof, BE, Gisolf, J, Karemaker, JM, Wesseling, KH, Secher, NH, and van Lieshout, JJ.
- 400 Time course analysis of baroreflex sensitivity during postural stress. Am J Physiol Heart Circ
- 401 *Physiol* 291: H2864–H2874, 2006.

402

# 403 ACKNOWLEDGMENT:

404 Authors declare no funding received for this work from any of the following organizations: National

- 405 Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).
- 406 Moreover, authors declare no commercial relationship with the Arena Company that produced the
- 407 compression garments investigated in the article.
- 408 No grant support received for this study, and results of the present study do not constitute endorsement409 of the product by the authors or the National Strength and Conditioning Association.
- 410 The authors declare that there is no conflict of interests regarding the publication of this article.
- 411 Authors are grateful to Francesco Campa, Marco Raguzzoni, Stefano Servadei and Andrea Galletti for
- 412 technical assistance in the experiments. Supported by University of Bologna.

413

## 414 **FIGURE LEGENDS**

#### 415 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.

- 419
- 420
- 421
- 422

#### 423 Figure 2. Baroreflex and blood pressure data.

- 424 Baroreflex sensitivity (A), BRS low-frequency spectral band (B), systolic (C) and diastolic blood
- 425 pressure (**D**) indices at baseline level and during recovery time in garment (GAR, *black line with*
- 426 *square*) and control (CON, *gray line with triangles*) condition.
- 427 \* Differences of both conditions with respect to baseline
- 428 † Differences of CON with respect to baseline
- 429 ‡ Differences of GAR with respect to baseline
- 430
- 431 Figure 3. Heart rate variability data.
- 432 HRV high- and low-frequency spectral band (A, B), HRV time domain indices (D, E), and
- 433 sympathovagal balance (C) at baseline level and during recovery time in garment (GAR, black line
- 434 *with square*) and control (CON, *gray line with triangles*) condition.
- 435  $(*, \dagger, \ddagger)$  Conventions as in Figure 2.
- 436

#### 437 Figure 4. Hemodynamic data.

- 438 Cardiac output (A), stroke volume (B), heart rate (C), and total peripheral resistance (D) at baseline
- 439 level and during recovery time in garment (GAR, black line with square) and control (CON, gray line
- 440 *with triangles*) condition.
- 441  $(*, \dagger, \ddagger)$  Conventions as in Figure 2.







