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ORIGINAL ARTICLE: TRAINING AND TESTING

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Heart rate variability: response following a single bout of interval training

Running title: Heart rate variability following exercise

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25 **Abstract**

26 We investigated the effect of exercise on heart rate variability by analysing the heart rate power
27 spectrum prior to, and 1 and 72 h following, an interval training session. Subjects initially
28 performed a graded test to exhaustion to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and the
29 running speed at which $\dot{V}O_{2max}$ was first attained ($v\dot{V}O_{2max}$). The training session was
30 completed on a separate day and comprised six 800 m runs at $1 \text{ km}\cdot\text{h}^{-1}$ below $v\dot{V}O_{2max}$. Prior to
31 the training session (pre), 1 h following the training session (+1 h), and 72 h following the
32 training session (+72 h), subjects sat quietly in the laboratory for 20 min whilst breathing
33 frequency was maintained at $12 \text{ breath}\cdot\text{min}^{-1}$. Cardiac cycle R-R interval data were collected
34 over the final 5 min of each 20 min period and analysed by means of autoregressive power
35 spectral analysis to determine the high frequency (HF) and low frequency (LF) components of
36 heart rate variability. Heart rate was higher, and the standard deviation of the R-R intervals was
37 lower, at +1 h than for pre or +72 h ($P<0.05$). The HF and the LF components of heart rate
38 variability were also lower ($P<0.05$) for +1 h than for pre or +72 h when the data were expressed
39 in ms^2 . However, no changes in the LF:HF ratio were observed, and the changes in the HF and
40 LF components disappeared when the data were expressed as a fraction of the total power.
41 Whilst these findings illustrate the importance of controlling the timing of exercise prior to the
42 determination of heart rate variability, the time course of the post-exercise heart rate variability
43 response remains to be quantified.

44

45 **Key words**

46 Overload - autonomic nervous system - respiratory sinus arrhythmia

47

48 **Introduction**

49 The examination of heart rate variability (HRV) in the frequency domain is a non-invasive
50 technique that has been used to assess autonomic nervous system influences on the heart [(13)].
51 Recently HRV has been studied in athletes, both during normal training and detraining [(3)] and
52 during a period of overtraining [(14)]. It is likely that the assessment of the autonomic nervous
53 system in athletes will increase over the next few years, since the autonomic nervous system is
54 known to be important in the aetiology of the overtraining syndrome [(10); (8)].

55

56 It is generally assumed that recovery following a single bout of running exercise is normally
57 complete after 72 h of recovery, and previous studies suggest that this is the case [e.g.,(6)].
58 However, performance has rarely been assessed during the days of recovery following a single
59 bout of running exercise, with the exception of a marathon run [(12); (11)]. Not surprisingly
60 after such an extreme running overload, these studies demonstrated prolonged fatigue that
61 extended beyond 72 h. Physiological changes that would be expected to decrease performance
62 capability have been demonstrated to recover within 72 h following a more 'moderate' single
63 bout of exercise. These physiological changes include muscle glycogen [(1)] and plasma volume
64 [(9)]. These studies provide a solid basis for the approach taken in the present study, which
65 attempted to characterise the response of heart rate variability following a single bout of interval
66 training at a point of definite fatigue and recovery [(6)].

67

68 Very few studies have examined the response of HRV following a single bout of exercise.
69 Furlan and colleagues [(3)] studied untrained subjects 1, 24 and 48 h after a 30 min bout of high
70 intensity exercise, whereas Bernardi and colleagues [(2)] studied trained runners 0.5, 24 and 48 h
71 after a 46 km trail run. Both groups found that the power of the LF and HF components of the
72 HRV power spectrum and the LF:HF ratio were elevated in the hour following exercise but had
73 returned to pre-exercise levels 24 h after the exercise bout. There was, however, an important

74 methodological difference between the two studies: whereas Furlan accounted for changes in the
75 total spectral power in their analysis by expressing the LF and HF powers relative to this total
76 power as well as in absolute units (ms^2) and analysing changes in both relative and absolute
77 powers, Bernardi made no attempt to account for changes in total power.

78

79 The HRV response following a single bout of exercise may differ between trained and untrained
80 subjects. However, the exercise bout studied by Bernardi et al. [(2)] differs from that which
81 individuals would routinely perform in training due to its length (few athletes would routinely
82 perform a 46 km run) and the fact that it was completed at an altitude of 2500 m. In the present
83 study we investigated the HRV response of trained individuals following a single bout of interval
84 exercise similar to that which many athletes might routinely perform in training. To evaluate the
85 impact of changes in total power on this response we performed our analyses with and without
86 correcting for changes in the total spectral power.

87

88

89 **Materials and Methods**

90 Eight trained male sports students (mean (SD): age 22 (2) years; height 1.81 (0.08) m; body mass
91 79.1 (8.1) kg; $\dot{V}\text{O}_{2\text{max}}$ 53.6 (4.4) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) volunteered to take part in the study after being
92 informed of the nature of the study and the potential risks. In accordance with the requirements
93 of the Institution's ethics committee, all subjects gave written informed consent and completed a
94 medical history and health questionnaire. Subjects were involved in training for a variety of
95 sports but they all included interval training sessions similar to the one they performed in this
96 study as part of their regular training.

97

98 Each subject visited the laboratory on three occasions. Visits 1 and 2 were separated by 7 days
99 and visits 2 and 3 were separated by 3 days (exactly 72 h). On their first visit subjects completed
100 a graded running test to exhaustion. The second visit included 20 min of quiet sitting, followed
101 by an interval training session (TS), an hour of recovery and rehydration, and a further 20 min of
102 quiet sitting. On their final visit subjects completed only the 20 min of quiet sitting. Subjects
103 were requested not to eat or drink anything other than water in the final 4 h before each visit and
104 to perform no exercise, beyond normal lifestyle activities, between the second and third visits to
105 the laboratory (see figure 1). In the final hour prior to each visit to the laboratory, subjects were
106 instructed to abstain from consuming any fluid.

107

108 INSERT FIGURE 1 ABOUT HERE

109

110 Both the graded test and the TS were performed on a motorised treadmill (Ergo ELG 70,
111 Woodway, Weil am Rhein, Germany) with the gradient set at 0%. The starting speed for the
112 graded test was selected to ensure that exhaustion was reached in ~10 min with speed being
113 increased by $0.75 \text{ km}\cdot\text{h}^{-1}$ every 45 s. This test was used to determine $\dot{V}\text{O}_{2\text{max}}$, the speed at which
114 $\dot{V}\text{O}_{2\text{max}}$ was first attained ($v \dot{V}\text{O}_{2\text{max}}$), and maximum HR (HR_{max}). Expired air was collected
115 continuously over ~45 s periods and the highest $\dot{V}\text{O}_2$ attained was taken as $\dot{V}\text{O}_{2\text{max}}$.

116

117 The TS comprised six 800 m runs at $1 \text{ km}\cdot\text{h}^{-1}$ below $v \dot{V}\text{O}_{2\text{max}}$ separated by 3 min recovery
118 periods. Each subject was weighed before and after the TS and the change in body mass was
119 calculated. The equivalent fluid volume was then determined and the subject was required to
120 consume this fluid immediately on completion of the TS. This rehydration strategy has been
121 used in previous studies and has been shown to be effective at restoring plasma volume [(4)].

122

123 Throughout the graded test and the TS subjects wore a chest strap and heart rate (HR) was
124 measured by short range telemetry (Vantage NV, Polar Electro Oy, Kempele, Finland).
125 Throughout the graded test subjects wore a nose clip and breathed through a large, broad flanged
126 rubber mouthpiece (Hans Rudolf, Kansas, USA) fitted to a low-resistance (inspired <3 cmH₂O
127 and expired <1 cmH₂O at 350 L.min⁻¹) breathing valve (Cranlea, Birmingham, UK) of negligible
128 volume (90 ml). A 150 L Douglas bag was connected to the expired side of this valve via a 1.5
129 m length of light weight Falconia tubing (3.5 cm internal diameter) (Cranlea, Birmingham, UK).
130 A whole number of breaths were collected and the collection was timed using a digital
131 stopwatch.

132

133 Expired fractions of O₂ and CO₂ were measured using a paramagnetic O₂ analyser and an
134 infrared CO₂ analyser (1440 series, Servomex, Crowborough, UK). Bottled nitrogen was used to
135 set the zero for both analysers, fresh (outside) air was used to set the span for the O₂ analyser,
136 and a gravimetrically prepared mixture (4% CO₂, 16% O₂, balance N₂; Cryoserve, Worcester,
137 UK) was used both to set the span for the CO₂ analyser and to check the linearity of the O₂
138 analyser. All gas mixtures were first saturated (Nafian tubing (Omnifit, Cambridge, UK) in
139 water) and then cooled to 5 °C (Bühler PKE3, Paterson Instruments, Leighton Buzzard, UK)
140 before they entered the gas analysers. Gas volume was measured using a dry gas meter (Harvard
141 Apparatus Ltd., Edenbridge, UK), which was calibrated and checked for linearity throughout the
142 typical collection volume range using a 3 L calibration syringe (Hans Rudolf, Kansas, USA).

143

144 During the tests at 1 hour prior to the TS (T1), 1 hour following the TS (T2) and 72 hours
145 following the TS (T3), subjects sat quietly for 20 min and controlled their breathing frequency
146 (BF). BF was set at 0.20 Hz (12 breath.min⁻¹), with each breath comprising 2 s of inspiration and
147 3 s of expiration. Subjects wore a chest strap consisting of two electrodes and a transmitter

148 (Polar Electro Oy, Kempele, Finland) and the data were transmitted directly to a PC via an
149 interface (Advantage, Polar Electro Oy, Kempele, Finland). R-R interval data were collected
150 over the final 5 min of the 20 min period and stored for subsequent analysis (Precision
151 Performance 2.1, Polar Electro Oy, Kempele, Finland). The data were initially filtered using
152 median and moving average based methods to minimise artifacts in the ECG signal. (Normally
153 such artifacts are a result of the wireless transmission system which may be influenced by an
154 external electromagnetic field.) The mean and standard deviation of the R-R intervals were then
155 calculated and a power spectrum analysis was undertaken (using autoregressive modelling with a
156 fixed model order of 18).

157

158 The HRV power spectrum can be divided into three frequency bands: high frequency (HF), low
159 frequency (LF) and very low frequency (VLF) ((3); (13)). For the HF component, which is
160 synchronous with respiration, a frequency band of 0.16 to 0.24 Hz was selected (BF was
161 controlled at 0.20 Hz). For the LF component, which typically ranges between 0.03 and 0.15 Hz
162 and is normally observed at ~0.1 Hz, a frequency band of 0.04 to 0.16 Hz was selected. Finally,
163 for the VLF component, a frequency band of 0.00 to 0.04 Hz was selected. For the HF and LF
164 components power was expressed both in ms^2 and in normalised units. The normalisation
165 procedure involves dividing the HF or LF power (ms^2) by the total spectral power minus the VLF
166 component (also in ms^2) and the result is therefore a dimensionless ratio. The use of normalised
167 units is thought to minimise the influence of changes in total power on the HF and LF powers
168 [(13)].

169

170 Differences between T1, T2 and T3 were evaluated using repeated measures analysis of variance
171 and Newman-Keuls post hoc tests at the 0.05 alpha level. As the data for the spectral parameters
172 were positively skewed (prior to normalisation), these data were transformed via a natural
173 logarithmic function prior to analysis. This is consistent with the approach of Bernardi and

174 colleagues [(2)] who, having found that the data for the spectral parameters were skewed,
175 transformed the data with a log transformation. Data for T1, T2 and T3 are presented as mean
176 (68% confidence interval) as it is not possible to 'back-transform' a log transformed standard
177 deviation into the original measurement units. The presentation of data as mean (68%
178 confidence interval) is consistent with the normal convention of presenting data as mean (one
179 standard deviation).

180

181 **Results**

182 The TS was a heavy overload for the subjects, as shown by their heart rate response (Figure 2).
183 The mean (SD) heart rate at the end of each bout increased from 177 (5) to 193 (5) beats.min⁻¹
184 over the course of the six 800 m bouts. These figures should be compared with the maximum
185 HR of 198 (5) beats.min⁻¹ obtained during the graded test. The TS elicited heart rates of between
186 87 % and 98 % of maximum.

187

188 INSERT FIGURE 2 ABOUT HERE

189

190 Data for resting HR, the standard deviation of R-R intervals (RRSD), and spectral parameters of
191 HRV are presented in Table 1. No differences were observed between T1 and T3 for any of the
192 variables ($p>0.05$). However, some changes were observed between T1 and T2 that were then
193 reversed between T2 and T3. Resting HR increased by 8 beats.min⁻¹ between T1 and T2 and
194 decreased by 12 beats.min⁻¹ between T2 and T3. The RRSD showed an opposite pattern,
195 decreasing by 18 ms between T1 and T2 and increasing by 26 ms between T2 and T3. Both LF
196 and HF power decreased (by 1679 and 695 ms² respectively) between T1 and T2 and increased
197 (by 2878 and 444 ms² respectively) between T2 and T3. Since total power also decreased
198 between T1 and T2 and increased between T2 and T3 (by 2617 and 3969 ms² respectively), when

199 the LF and HF powers were expressed in normalised units no changes were observed ($p > 0.05$).
200 The LF:HF ratio was not significantly altered at T2 relative to T1 and T3 ($p > 0.05$).

201

202 INSERT TABLE 1 ABOUT HERE

203

204 **Discussion**

205 The TS used in the present study provides a tolerable but heavy overload [(4)] and results in
206 impaired performance 1 h following exercise [(6)] despite rehydration, normalised core
207 temperature, and normalised blood lactate concentration ($[La^-]_B$) at rest [(5)] in similarly trained
208 subjects. It is also thought to be a realistic TS - one that athletes would regularly undertake as
209 part of their training programme.

210

211 The finding of increased HR 1 h following the TS is consistent with previous studies [(3);(4)].
212 Analysis of HRV in the time domain through the standard deviation of R-R intervals showed a
213 decrease in HRV 1 h following the TS. Whilst this change in HRV is suggestive of a change in
214 autonomic activity, it is impossible to attribute the change to parasympathetic or sympathetic
215 influence. For example, the fact that a smaller variability was found in conjunction with a higher
216 heart rate is likely to be partly a consequence of the reduced baroreflex influence on heart rate
217 adjustment within a heart beat as the RR interval decreases. By examining HRV in the frequency
218 domain it is possible to partition the effect of the parasympathetic and sympathetic nervous
219 system. The HF component of the HRV power spectrum is centred at the BF and has been used
220 as a non-invasive, indirect measure of cardiac parasympathetic tone [(7)]. In contrast, the low
221 frequency component is thought to reflect slow oscillations of the arterial pressure variability
222 signals (at ~ 0.1 Hz) and has been used as an indirect measure of cardiac sympathetic tone [(3)].
223 To ensure no overlap between the two components it is necessary to keep BF quite high. If BF is
224 uncontrolled, or controlled at a low rate, overlap can occur between the HF and LF components

225 of the power spectrum making it difficult to reliably determine the power of each component
226 [(13)]. Our use of a controlled BF of 0.20 Hz (12 breath.min⁻¹) in the present study is consistent
227 with the findings of Strano and colleagues [(13)] which suggest that BF should be maintained at
228 between 12 and 15 breath.min⁻¹ (0.20 and 0.25 Hz).

229

230 In the present study, LF, HF and total power (ms²) were reduced 1 h following the TS but both
231 had returned to the pre-TS level at 72 h. No changes were observed in the LF:HF component and
232 the changes in LF and HF power disappeared when the data were expressed in normalised units.
233 Furlan and colleagues [(3)], who studied untrained individuals, also found that LF, HF and total
234 power (ms²) were reduced 1 h following an exercise bout. However in these untrained subjects
235 the LF:HF ratio was increased 1 h following exercise and the changes in the HF and LF powers
236 were still present when the data were expressed in normalised units. The changes in HF power
237 were in the same direction regardless of whether the data were expressed in ms² or in normalised
238 units but when the LF power was expressed in normalised units an increase was observed from
239 pre to 1 h post exercise. Whether the different findings relate to the training status of the
240 subjects, the severity of the overload, or some other factor is unclear. Whilst Furlan and
241 colleagues do not give any data regarding the subjects' physiological characteristics, it is likely
242 that they differed somewhat from our subjects who had a $\dot{V}O_{2max}$ of 53.6 ml.kg⁻¹.min⁻¹ and were
243 trained. Importantly, our subjects were used to undertaking training sessions similar to the TS
244 they performed in the present study. Furlan and colleagues do give some information about the
245 exercise bout that was undertaken by their subjects. It comprised a graded test to exhaustion
246 followed by 4-6 repetitions and the total exercise time was ~30 min. No information is presented
247 on these repetitions and the physiological responses are not described. It is difficult, therefore, to
248 determine whether the exercise was more or less severe than the TS that our subjects performed.
249 Although Furlan failed to control breathing frequency it is unlikely that overlap between the LF

250 and HF components would have presented a major problem in their study as the breathing
251 frequency adopted by their subjects, and thus the central frequency for the HF component, was
252 ~0.30 Hz.

253

254 In the study by Bernardi and colleagues [(2)], their well-trained subjects were subjected to a very
255 severe overload at altitude. Their findings, however, were similar to the findings in the present
256 study. Thirty minutes after the overload, the LF and HF components of the power spectrum were
257 both reduced, although the HF component was reduced further than the LF component such that
258 the LF:HF ratio increased. Bernardi and colleagues reported their LF and HF powers in ms^2 .
259 Neither total power nor the power for the VLF component was reported and therefore it is
260 impossible to determine how the LF and HF powers would have changed in response to the
261 overload had they been expressed in normalised units.

262

263 Whilst we can only speculate about the time course of the changes over the 72 h period in the
264 present study, the study by Bernardi et al. [(2)] might shed some light on this issue. At the 24 h
265 time point following the overload, both the LF and HF components of the power spectrum
266 returned to baseline (pre-overload) values. We chose to examine the point of most extreme
267 disturbance (1 h post-TS) in the present study as a preliminary investigation. A further
268 development would be to track the changes between 1 and 72 h post-TS. As the time course of
269 the HRV response following exercise remains to be established the results of studies assessing
270 HRV in exercising populations should be interpreted with caution.

271

272 **Conclusion**

273 The present study has characterised the changes in heart rate variability that occur in trained
274 individuals following an exercise bout that such individuals would regularly undertake as part of

275 their training programme. The findings illustrate the importance of controlling the timing of
276 exercise prior to the determination of heart rate variability. Further studies are required to
277 investigate the time course of the post-exercise heart rate variability response for a given exercise
278 bout. In addition, it would be of interest to investigate the influence of the severity of the
279 exercise overload on the post-exercise response. An understanding of the post-exercise heart rate
280 variability response is necessary if this measure is to be used in the monitoring of athletes in
281 general and the process of overtraining in particular.

282

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284

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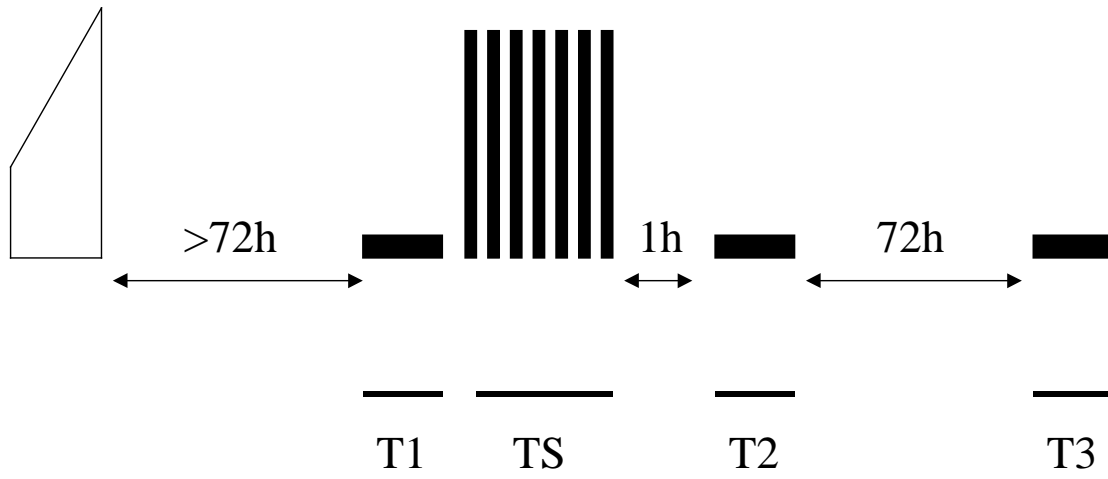
321 **Legend**

322 Figure 1: Schematic of experimental protocol

323

324 Figure 2: Mean heart rate during the final stages of each exercise bout for the interval
325 training session.

326

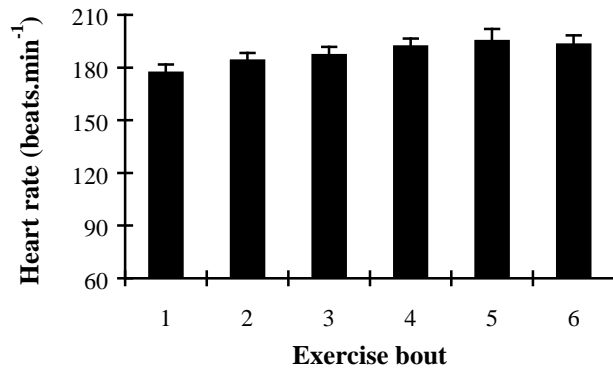


327

328

329 **Figure 2**

330



331

332

333

334 **Table**

335 Table 1. Heart rate and heart rate variability parameters prior to and at 1 and 72 h following
 336 the training session.

	Time point			P value (ANOVA)
	T1	T2	T3	
HR, beats.min ⁻¹	69 (61-77)	77 (64-90)	65 (59-71)	0.002
RRSD, ms	75 (62-88)	57 (33-81)	83 (60-106)	0.011
Total power, ms ²	6257 (4416-8130)	3831 (1162-7322)	7800 (3654-12504)	0.010
LF power, ms ²	3640 (2151-5223)	1961 (621-3621)	4839 (2224-7533)	0.004
HF power, ms ²	886 (145-1580)	191 (20-482)	635 (150-1256)	0.008
LF:HF ratio	14 (2-25)	21 (7-34)	14 (4-25)	0.233
LF power (nu)	0.82 (0.65-0.99)	0.93 (0.89-0.97)	0.88 (0.78-0.97)	0.228
HF power (nu)	0.18 (0.01-0.35)	0.07 (0.03-0.11)	0.12 (0.03-0.22)	0.244

337

338 T1, 1 h prior to the training session; T2, 1 h post; T3, 72 h post; HR, heart rate; RRSD, standard
 339 deviation of R-R intervals; LF, low frequency component of HRV power spectrum; HF high
 340 frequency component; nu, normalised units. Data are presented as mean (68% confidence
 341 interval).