

**This is an electronic reprint of the original article.
This reprint *may differ* from the original in pagination and typographic detail.**

Author(s): Vesterinen, Ville; Nummela, Ari; Laine, Tanja; Hynynen, Esa; Mikkola, Jussi; Häkkinen, Keijo

Title: A Submaximal Running Test With Post-Exercise Cardiac Autonomic And Neuromuscular Function In Monitoring Endurance Training Adaptation

Year: 2017

Version:

Please cite the original version:

Vesterinen, V., Nummela, A., Laine, T., Hynynen, E., Mikkola, J., & Häkkinen, K. (2017). A Submaximal Running Test With Post-Exercise Cardiac Autonomic And Neuromuscular Function In Monitoring Endurance Training Adaptation. *Journal of Strength and Conditioning Research*, 31(1), 233-243.
<https://doi.org/10.1519/JSC.0000000000001458>

All material supplied via JYX is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

TITLE PAGE

A SUBMAXIMAL RUNNING TEST WITH POST-EXERCISE CARDIAC AUTONOMIC AND NEUROMUSCULAR FUNCTION IN MONITORING ENDURANCE TRAINING ADAPTATION

Ville Vesterinen¹, Ari Nummela¹, Tanja Laine¹, Esa Hynynen¹, Jussi Mikkola¹, Keijo Häkkinen²

¹KIHU – Research Institute for Olympic Sports, Jyväskylä, Finland

²Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland

Corresponding author:

Ville Vesterinen

KIHU - Research Institute for Olympic Sports

Address: Rautpohjankatu 6, 40700 Jyväskylä, Finland

Telephone: +358 40 543 1273

Fax: +358 20 781 1501

E-mail: ville.vesterinen@kihu.fi

Running head: Monitoring Endurance Training Adaptation

1 **ABSTRACT**

2

3 The aim of this study was to investigate whether a submaximal running test (SRT) with post-
4 exercise heart rate recovery, heart rate variability and countermovement jump measurements
5 could be used to monitor endurance training adaptation. Thirty-five endurance trained men
6 and women completed an 18-week endurance training program. Maximal endurance
7 performance and maximal oxygen uptake were measured every eight weeks. In addition, SRT
8 with post-exercise heart rate recovery, heart rate variability and countermovement jump
9 measurements were performed every four weeks. SRT consisted of two 6-minute stages at
10 70% and 80% of HR_{max} and a 3-minute stage at 90% HR_{max} , followed by a 2-minute recovery
11 stage for measuring post-exercise heart rate recovery, heart rate variability and
12 countermovement jump test. The highest responders according to the change of maximal
13 endurance performance showed significant improvement in running speeds during stages 2
14 and 3 in SRT, while no changes were observed in the lowest responders. The strongest
15 correlation was found between the change of maximal endurance performance and running
16 speed during stage 3, while no significant relationships were found between the change of
17 maximal endurance performance and the changes of post exercise heart rate recovery, heart
18 rate variability and countermovement jump. Running speed at 90% HR_{max} intensity was the
19 most sensitive variable to monitor adaptation to endurance training. The present submaximal
20 test showed potential to monitor endurance training adaptation. Furthermore, it may serve a
21 practical tool for athletes and coaches to evaluate weekly the effectiveness of training
22 program without interfering normal training habits.

23

24 **Key Words:** running, training, performance, heart rate recovery, heart rate variability,
25 countermovement jump

26

27 **INTRODUCTION**

28

29 An optimal regulation of training load and recovery plays a major role in successful training.
30 Failure in this regulation may lead to non-optimal adaptation to training, marked as decreased
31 endurance performance, especially in the case of accumulated fatigue or overtraining (31,
32 40). Monitoring changes in performance during training may serve essential information for
33 coaches and athletes in optimizing training load and recovery. Maximal laboratory tests are
34 usually used in order to evaluate training adaptation. However, the tests are usually
35 performed two to three times per year due to impracticality, expensiveness and
36 exhaustiveness (25). Therefore, the maximal tests are not optimal methods for regular
37 monitoring of training adaptation. The information should be found out non-invasively and
38 quickly e.g. from standardized warm-up for providing a practical tool for athletes and
39 coaches to monitor training adaptation.

40

41 Exercise HR is probably the most frequently used method to quantify the training intensity
42 and internal training load in running. In addition, exercise HR at a certain submaximal level
43 may reflect training induced changes in endurance performance. Decreased HR at
44 submaximal exercise has been observed to be a sign of positive training adaptation (2, 3, 38).
45 Lamberts et al. (25) developed a submaximal cycling test, which has been observed to be able
46 to predict maximal cycling performance from submaximal power at standardized submaximal
47 HR levels and post-exercise heart rate recovery (HRR) (24, 25). Recently, a cross-sectional
48 study by Otter et al. (35) showed the potential of the same submaximal protocol to predict
49 endurance performance also in rowing. Less is known about the usefulness of the
50 submaximal protocol in monitoring changes in endurance running performance in

51 longitudinal training studies. In our previous study, we observed that HR / running speed
52 (RS) – index, calculated from all constant speed running exercises, serves a potential tool for
53 daily monitoring of training adaptation (41). However, different durations and intensities of
54 training sessions, may cause fluctuation in exercise HR, and thus, may disturb the
55 relationship between HR and RS (1, 21). Recently, we observed that the changes in RS at 80
56 and 90 % of HR_{max} in a three-staged submaximal running test in field conditions were related
57 with the change in maximal endurance performance during the 18-week endurance training
58 program (43). However, environmental factors such as wind, temperature and terrain may
59 impair the usefulness of the submaximal running test in monitoring of training adaptation in
60 spite of the standardizing of exercise duration and intensity. Treadmill running is growing
61 more popular and it serves more standardized conditions compared with running in outdoor
62 field conditions.

63
64 In addition, cardiac autonomic activity is likely to have an important role in endurance
65 training adaptation (2, 3, 15, 23, 24). Faster cardiorespiratory recovery after exercise has been
66 shown to be related to a greater vagal activity and aerobic capacity (8, 13, 39, 43). In
67 addition, the measurement of post-exercise HRR and heart rate variability (HRV) have been
68 proposed to have potential for monitoring fatigue and predicting changes in endurance
69 performance parameters (3, 20, 23, 24, 45), and would be easy and quickly to perform in
70 practical training situation. However, previous studies are partly conflicting, and thus, more
71 research is needed to investigate the ability of post-exercise HRR and HRV to monitor
72 training adaptation.

73

74 Previous studies have also shown that neuromuscular factors are important determinants of
75 endurance running performance (34, 36). Countermovement jump (CMJ) has been used in

76 several sports to assess muscle power of the lower extremities often correlating with running
77 performance(9, 16). In addition, it has been observed that reduced CMJ performance is
78 related to neuromuscular fatigue (7, 12, 30), which could be essential information in
79 monitoring endurance training adaptation. Measures of neuromuscular function with various
80 jumping tests (e.g. CMJ, squat jump) have become popular in training monitoring, especially
81 in team-sports, due to the simplicity and the minimal amount of additional training load (7,
82 12, 30). However, to our best knowledge there are no previously published studies about a
83 possible relationship between changes in CMJ and endurance training adaptation.

84

85 The aim of this study was to investigate whether a submaximal running test (SRT) combined
86 with the post-exercise HRR, HRV and CMJ measurements conducted in the laboratory
87 conditions could be used in monitoring changes in endurance performance during an 18-week
88 training period. We hypothesized that 1) increased running speeds at standardized
89 submaximal HR levels and post-exercise cardiac vagal activity would be related to enhanced
90 endurance performance (3, 38, 43, 45), and 2) decreased neuromuscular function would be
91 related to negative endurance training adaptation (7, 9, 16).

92

93 **METHODS**

94

95 **Experimental Approach to the Problem**

96 The three-staged submaximal running test (SRT) was modified from the Lamberts and
97 Lambert Submaximal Cycle Test (25). In addition to determining submaximal running speed
98 at 70%, 80% and 90% of HR_{max} intensities, post-exercise HRR, HRV and CMJ
99 measurements were performed. Recreational endurance runners performed SRT four times in
100 laboratory conditions during the 18-week endurance training period. Changes in SRT were

101 compared to changes in maximal endurance performance and maximal oxygen consumption
102 in all subjects pooled and retrospectively divided quartiles according to the improvement of
103 maximal endurance performance.

104

105 **Subjects**

106 Forty recreational endurance runners (20 women, 20 men), 22-50 years of age volunteered to
107 participate in the study. The subjects were healthy and had been training at least three times
108 per week during the previous 6 months. They did not have any diseases or use regular
109 medication. Age, pre-training $\text{VO}_{2\text{max}}$, regular training background, weekly training times and
110 weekly running kilometers (during the previous two months) were 35 ± 10 years, 47 ± 5
111 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, 14 ± 8 years, 5.6 ± 1.7 times, 38 ± 19 km for women and 35 ± 6 years, 53 ± 5
112 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, 14 ± 8 years, 4.4 ± 2.0 times, 27 ± 15 km for men. After being fully informed
113 about the study design and the possible risks, all subjects completed an informed consent
114 document. The study was approved by the Ethics Committee of the University of Jyväskylä,
115 Finland and conducted according to the provisions of the most recent Declaration of Helsinki.

116

117 **Study design**

118 The subjects took part in an 18-week training program. The training program was divided
119 into an 8-week low intensity endurance training period and an 8-week intensive training
120 period with increased training volume or intensity. A maximal incremental treadmill running
121 test was performed before and after both training periods (at weeks 0, 9 and 18) and
122 submaximal running test (SRT) at weeks 0, 4, 9, 13 and 18. The maximal treadmill test and
123 SRT were separated by at least two easy training days during the testing weeks. All testing
124 was performed at about the same time of day (within 2 hours) with stable laboratory
125 conditions.

126

127 **Maximal incremental treadmill running test**

128 The subjects were asked not to do any vigorous physical activity two days prior to the
129 maximal treadmill running test. The subjects performed the running test for determination of
130 maximal oxygen uptake (VO_{2max}), the peak treadmill running speed (RS_{peak}), LT2 and LT1 as
131 described in the study of Vesterinen et al. (42). The test started at $7 \text{ km}\cdot\text{h}^{-1}$ for women $8 \text{ km}\cdot\text{h}^{-1}$
132 ¹ for men and followed by an increase of $1 \text{ km}\cdot\text{h}^{-1}$ every third minute until volitional
133 exhaustion. The incline was kept at 0.5 degrees during the whole test. HR was recorded
134 continuously using a heart rate monitor (Suunto t6, Suunto Ltd, Vantaa, Finland). Blood
135 samples ($20 \mu\text{L}$) were taken from the fingertip at the end of each stage to analyze blood
136 lactate concentrations (La) (Biosen S_line Lab+ lactate analyzer, EKF Diagnostic,
137 Magdeburg, Germany). Oxygen consumption was measured breath-by-breath throughout the
138 test using a portable gas analyzer (Oxycon Mobile, Viasys Health Care, Würzburg,
139 Germany). The highest 60-s VO_2 value during the treadmill test was considered as VO_{2max} .
140 The maximal endurance performance was determined as the treadmill running speed (RS_{peak})
141 at exhaustion, which has been observed to be highly reliable with intraclass correlation
142 coefficients of 0.99 ± 0.01 and the coefficient of variation of 1.2% measured in the
143 incremental treadmill running test (10). If the subject could not complete the whole 3 min of
144 the last speed, RS_{peak} was calculated as follows: speed of the last completed stage ($\text{km}\cdot\text{h}^{-1}$) +
145 (running time (s) of the speed at exhaustion – 30 s) / (180-30 s) * $1 \text{ km}\cdot\text{h}^{-1}$. The determination
146 of lactate thresholds was based on the rise and change in the inclination of the blood lactate
147 curve during the test (11). LT1 was set at $0.3 \text{ mmol}\cdot\text{L}^{-1}$ above the lowest lactate value. LT2
148 was set at intersection point between 1) a linear model between LT1 and the next lactate point
149 and 2) a linear model for the lactate points with La increase of at least $0.8 \text{ mmol}\cdot\text{L}^{-1}$.

150

151 Submaximal running test (SRT)

152 The present submaximal running test (SRT) was modified from the Lamberts and Lambert
153 Submaximal Cycle Test (25). SRT was designed to be as a standardized warm-up protocol.
154 The 17-minutes SRT consisted of three stages (Fig 1). The speed of the treadmill was set by
155 heart rate corresponding to 70%, 80% and 90% of a subject's maximum heart rate (HR_{max})
156 for 6, 6 and 3 minutes, respectively. The target HRs were calculated based on HR_{max} in the
157 maximal incremental treadmill test at week 0. HR was recorded throughout the test using a
158 HR monitor (Suunto t6, Suunto Ltd, Vantaa, Finland) but the data of the first minute of each
159 stage was excluded from analyses due to the setting of running speed (RS) to reach the target
160 HR. Therefore, average RS and HR were calculated over a five-minute period (1:00-6:00 and
161 7:00-12:00) for stage 1 and 2, and for a two-minute period (13:00-15:00) for stage 3. Mean
162 power of all three stages has been observed to be highly repeatable with intraclass correlation
163 coefficients of 0.91, 0.92 and 0.90 in rowing (35), and 0.91, 0.98 and 1.00 in cycling (25).
164 RPE was recorded in the final minute of each stage. After completing the running test, the
165 subjects were asked to stand without moving and talking for 2 minutes for determining post-
166 exercise HRR and HRV. They were asked to breathe normally, without control of the
167 respiratory rate. HRR was calculated by subtracting heart rate after 60 s recovery from HR at
168 the end of third stage. A vagal-related HRV index, the natural logarithm of the square root of
169 the mean squared differences of successive R-R intervals (lnRMSSD), was calculated over
170 the second recovery minute (16:00-17:00) for achieving more stable HR compared the first
171 recovery minute. Kaikkonen et al. (19) observed that the first 2-min recovery after exercise
172 may give enough information on HRV recovery for evaluating training load. lnRMSSD has
173 been suggested to provide the most reliable and practically applicable HRV variable for
174 regular monitoring (39). R-R interval (RRI) data was analyzed using the Firstbeat Sports
175 software (version 4.0.0.5, Firstbeat Technologies Ltd, Jyväskylä, Finland). RRIs were

176 checked and edited by an artifact detection filter of the Firstbeat Sports (37) software and all
177 falsely detected, missed, and premature heart beats were excluded before calculation of HRR
178 and lnRMSSD.

179

180 ***Figure 1 about here***

181

182 **Countermovement jump (CMJ) test**

183 CMJ test was performed 3 min after the end of SRT on a commercially available force plate
184 (Accupower, Advanced Mechanical Technology, Watertown, USA) to measure CMJ height
185 (CMJ_h) from the force time curve. The subjects performed three trials with hands held on the
186 hips throughout the entire movement, separated by 60 s recovery between the trials. They
187 were instructed to jump as high as possible. Countermovement depth was self-selected by the
188 subject but no less than 90°. Force data were collected and analyzed by using custom-
189 designed software (Research Institute for Olympic Sports, Jyväskylä, Finland), which used
190 the equation $h = I^2 \cdot 2gm^{-2}$ to calculate jump height from impulse, where I is the impulse, g is
191 the gravity, and m is the mass of subject. Jump height was determined as an average of the
192 two best jumps.

193

194 **Training**

195 The subjects were asked to train at low-intensity (below or at lactate threshold 1, LT1) and
196 maintain the same training frequency (mean: 5.2 ± 1.9 times per week) as before the study
197 during the 8-week preparation period. Thereafter, running training volume and intensity was
198 progressively increased during the following eight weeks. The training was periodized so that
199 three weeks of intense training was followed by an easy training week. The subjects
200 completed 1-3 moderate (30-40 min, intensity between LT1 and LT2) or high intensity

201 interval (4x4 min with 4 min of recovery or 6x2 min with 2 min of recovery) or constant
202 speed (20 min) training sessions with the intensity above LT2 during intense week.
203 Endurance training consisted primarily of running but occasionally included also cycling,
204 Nordic walking and/or cross-country skiing. Furthermore, the subjects were asked to
205 complete 1 muscle endurance circuit training session per week. The subjects controlled their
206 training intensity by measuring HR during all exercises with Garmin FR 610 heart rate
207 monitor with GPS (Garmin Ltd, Schaffhausen, Switzerland). In addition, the moderate and
208 high intensity training sessions were supervised by experienced members of the research
209 group.

210

211 **Statistical analysis**

212 The results are expressed as means \pm standard deviations (SD). Normality of the data was
213 assessed by Shapiro–Wilk goodness-of-fit test and homogeneity of variance was assessed by
214 Levene's variance test. The subjects were retrospectively divided into quartiles (the 1st
215 quartile, Q1, the highest response ($n = 9$); the 2nd quartile, Q2, moderate response ($n = 9$); the
216 3rd quartile, Q3, low response ($n = 9$), the 4th quartile, Q4, the lowest response ($n = 8$)) of
217 percentage change in RS_{peak} from week 0 to week 18. Differences between the quartiles were
218 analyzed using a one-way analysis of variance (One-way ANOVA) and changes in maximal
219 running test, SRT and CMJ_h (group-by-training interaction) were analyzed using repeated
220 measures of ANOVA, followed by Bonferroni as a post hoc test. In addition, standardized
221 effects sizes (ES) were calculated using the partial eta square with following threshold
222 values: < 0.2 (trivial), $0.2 - 0.5$ (small), $0.5 - 0.8$ (moderate) and > 0.8 (large) (6). Pearson
223 product moment correlation coefficient was used to determine relationships between absolute
224 values of SRT and CMJ_h , and endurance performance variables at week 9. In addition,
225 relationships were analyzed between changes in SRT, CMJ_h , and RS_{peak} for all the subjects

226 and for women and men separately. In addition to measures of statistical significance, the
227 following criteria were adopted to interpret the magnitude of the correlation between
228 measurement variables: <0.1 (trivial), 0.1 – 0.3 (small), 0.3 – 0.5 (moderate), 0.5 – 0.7
229 (large), 0.7 – 0.9 (very large) and 0.9 – 1.0 (almost perfect) (18). Statistical significance was
230 accepted as $p < 0.05$. Statistical analyses were carried out using SPSS software (IBM SPSS
231 Statistics 20, IBM, New York, USA).

232

233 **RESULTS**

234

235 **Training data**

236 A total of 35 subjects completed the whole 18-week training program. Four subjects dropped
237 out from the program due to injuries and one with lack of motivation. Training volume
238 remained similar during both training periods (7.1 ± 2.6 h \cdot week⁻¹ vs. 6.4 ± 2.0 h \cdot week⁻¹), as
239 well as training frequency (5.9 ± 2.1 sessions \cdot week⁻¹ vs. 6.0 ± 2.1 sessions \cdot week⁻¹). Running
240 volume increased from 33 ± 17 km \cdot week⁻¹ to 41 ± 16 km \cdot week⁻¹ ($p < 0.001$) in the second
241 training period. In addition, the percentage amount of high intensity training increased from 1
242 $\pm 2\%$ to $4 \pm 3\%$ ($p < 0.001$), when as amount of low ($86 \pm 9\%$ vs. $84 \pm 9\%$) and moderate
243 intensity ($13 \pm 8\%$ vs. $12 \pm 9\%$) training remained unaltered between the training periods.

244

245 **Submaximal running test**

246 The speed of the treadmill was successfully set for the target HR levels (70%, 80% and 90%
247 of HR_{max}) in SRT (Table 1), with no changes between the five testing sessions. Individual
248 ranges in HR were 67 – 74% during the first, 79 – 82% during the second and 88 – 93% of
249 HR_{max} during the third stage. RPE, post-exercise HRR and lnRMSSD remained constant

250 during the whole training period but a constant increase was observed in RS of all stages
 251 during the second half of the training period ($p < 0.01$).

252

253 ***Table 1 about here***

254

255 **Predictors of endurance training**

256 RS of all stages in SRT were well correlated with RS_{peak} (stage 1: $r = 0.71$, stage 2: $r = 0.77$,
 257 stage 3: $r = 0.85$, all $p < 0.001$, very large) and with $VO_{2\text{max}}$ (stage 1: $r = 0.68$, large; stage 2: r
 258 $= 0.74$, very large; stage 3: $r = 0.75$, very large; all $p < 0.001$). Post exercise HRR and
 259 $\ln\text{RMSSD}$ correlated moderately with $VO_{2\text{max}}$ ($r = 0.44$ and $r = 0.39$, both $p < 0.05$), but not
 260 with RS_{peak} . Similar correlations were observed in women and men, except HRR, which
 261 correlated with both $VO_{2\text{max}}$ and RS_{peak} in women after SRT ($r = 0.62$ and $r = 0.64$, both $p <$
 262 0.01 , large), but not in men. A similar trend was found between HRR and $VO_{2\text{max}}$ ($r = 0.48$, p
 263 $= 0.098$, moderate) in men. In addition, CMJ_h correlated with RS_{peak} ($r = 0.57$, $p < 0.001$,
 264 large), when all pooled, and the correlation separated for women and men were $r = 0.44$ ($p =$
 265 0.052 , moderate) and $r = -0.23$ ($p = 0.418$, small).

266

267 **Training effects**

268 $VO_{2\text{max}}$ and RS_{peak} improved by $2.2 \pm 6.2\%$ ($p = 0.043$) and $3.2 \pm 4.0\%$ ($p < 0.001$) during the
 269 18-week training period. $VO_{2\text{max}}$ increased moderately in Q1 ($p = 0.004$), whereas small or
 270 trivial changes ($p > 0.05$) were observed in other quartiles (Table 2). Large improvement of
 271 RS_{peak} were observed in Q1, Q2 and Q3 (all $p < 0.001$), but not in Q4 ($p = 0.066$). The change
 272 in RS_{peak} was greater ($p < 0.001$) in Q1 compared with other quartiles. HR_{max} decreased (183
 273 ± 10 vs. 180 ± 8 ; $ES = 0.58$, moderate; $p = 0.017$) in Q4, but remained unaltered in other
 274 quartiles. A large increase of RS 3 ($p < 0.001$) was observed in Q1, whereas small or

275 moderate changes ($p < 0.01$) were observed in other quartiles. Moderate or small increases (p
276 < 0.05) were observed in SRT RS 1 and RS 2 in all quartiles, except in Q4 ($p > 0.05$). Post
277 exercise HRR, RMSSD and CMJ_h, showed trivial changes in all quartiles ($p > 0.05$), except
278 CMJ_h in Q2 (moderate, $p < 0.05$).

279

280 ***Table 2 about here***

281

282 Relationships between the changes of RS in SRT, and the changes of VO_{2max} and RS_{peak} after
283 18 weeks of training are shown in Fig 2. The changes in RS 2 and RS 3 showed large or
284 moderate correlations with the change of both VO_{2max} and RS_{peak}. No significant relationships
285 were found between the changes of VO_{2max} and RS_{peak}, and the changes of post exercise
286 lnRMSSD ($r = 0.06$, $r = -0.02$, both trivial), HRR ($r = 0.01$, $r = -0.09$, both trivial) and CMJ_h
287 ($r = 0.21$, small, $r = 0.15$, trivial). No sex differences were observed in the correlations.

288

289 ***Figure 2 about here***

290

291 The changes of the variables in SRT in the highest (Q1) and the lowest (Q4) responders at
292 weeks 4, 9, 13 and 18 are presented in Fig 3. A significant training effect (test of within-
293 subjects effect) between the measurement weeks was observed in RS of all stages in Q1 ($p <$
294 0.005 , all), but only in RS 3 ($p = 0.036$) in Q4. No changes were observed in either quartile in
295 RPE, HRR, lnRMSSD and CMJ_h. Significant differences between Q1 and Q4 were observed
296 in the change of RS 3 at week 13 ($p = 0.021$) and 18 ($p = 0.008$). In addition, the change of
297 RS 2 tended to be greater in Q1 than Q4 at week 13 ($p = 0.076$) and 18 ($p = 0.136$).

298

299 ***Figure 3 about here***

300

301 **DISCUSSION**

302

303 The first main finding of the present study showed the significant relationship between the
304 changes in RS 2 and RS 3, and the changes in RS_{peak} and $VO_{2\text{max}}$. In addition, the RS change
305 in SRT of the highest responders (Q1) differed significantly from the RS of the lowest
306 responders (Q4) after the 13th training week, when the running volume and intensity were
307 progressively increased. Secondly, contrary to our hypotheses, the changes in post-exercise
308 cardiac vagal activity and neuromuscular function were not related to endurance training
309 adaptation.

310

311 The speed of the treadmill was set successfully for the target heart rate levels of the stages in
312 SRT by the exercise physiologist. Individual range of HR was the smallest during the third
313 stage (90% of HR_{max}), which expresses that the intensity around LT2 seems to be reasonable
314 for accurate regulation of HR. These findings are in line with the previous study related to
315 submaximal running test (22). Unfortunately, no measurements of reliability were conducted
316 in the present study. However, Otter et al. (35) observed almost perfect intra-class correlation
317 coefficients in power of all three stages in rowing and Lamberts et al. (35) in cycling in the
318 same kind of submaximal protocol than performed by running in the present study. High
319 reliability has also been reported in running performance at 80% of HR_{max} intensity in a
320 submaximal running test on treadmill (44). Heart rates (70%, 80%, 90%) and RPEs (2, 3, 5)
321 of the stages showed that the SRT protocol was truly submaximal and did not cause
322 remarkable training load. Thus, SRT seems to be a useful method for regular monitoring
323 without interfering normal training.

324

325 **Running speed during submaximal test in predicting endurance performance and**
326 **monitoring training adaptation**

327 The present results in the cross-sectional analysis showed the relationships between RS of all
328 stages in SRT and maximal endurance performance ($r = 0.71 - 0.85$), and maximal aerobic
329 capacity ($r = 0.68 - 0.75$). The strongest predictor for RS_{peak} and VO_{2max} was RS at 90% of
330 HR_{max} , which is in line with our previous study (43) and the studies of Lamberts et al. (25)
331 and Otter et al. (35). Recently, we observed the similar significant relationships between RS
332 at 70-90% of HR_{max} in SRT performed in outdoor field conditions and maximal endurance
333 performance ($r = 0.74-0.83$) and aerobic capacity ($r = 0.58-0.75$) (43). It seems that more
334 standardized laboratory conditions in the present study did not enhance the relationships.
335 Lamberts et al. (25) found the largest correlation between power corresponding the intensity
336 of 90% of HR_{max} in the submaximal cycling test, and peak cycling performance ($r = 0.94$).
337 Otter et al. (35) similarly observed that power at 90% of HR_{max} in a submaximal rowing test
338 was the best predictor ($r = -0.93$) of 2000 m maximal rowing time. In addition, the previous
339 studies reported high reliability of variables measured during the stages of 80% and 90% of
340 HR_{max} (25, 35). Slightly smaller correlations between RS at submaximal intensities and
341 maximal running performance in the present study may be explained by more challenging
342 and rougher regulation of power (= running speed) compared to exercises with the ergometer,
343 like cycling or rowing.

344

345 The previous findings support that power or RS at certain submaximal HR levels predicts
346 endurance performance in the cross-sectional setup. However, less is known whether
347 submaximal performance tracks sensitively enough the changes of endurance performance
348 during longitudinal training studies. The present results showed that the changes in RS at
349 80% and RS 90% of HR_{max} intensities were related to the changes in both endurance

350 performance and VO_{2max} . This is in line with the previous findings about the relationship
351 between decreased exercise HR and improvements in endurance performance (2, 3, 38, 43).
352 Regardless of the non-significant relationship between the change in RS at 70% of HR_{max} and
353 the change in endurance performance, the first 6 min stage is needed for adequate warming-
354 up for the subsequent stages and main training session. Recently, we observed the strongest
355 relationships between changes in RS at 90% of HR_{max} intensity in SRT performed in field
356 conditions and changes in both endurance performance ($r = 0.79$) and VO_{2max} ($r=0.62$) (43).
357 In addition, RS at 90% HR_{max} was the most sensitive variable to separate the highest and the
358 lowest responders during the training period (43). Unexpectedly, the correlations were lower
359 in the present study in spite of the standardized laboratory conditions. It seems that the
360 standardized laboratory condition may not be necessary for using SRT in monitoring training
361 adaptation. The highest (Q1) and the lowest responders (Q4) were separated by the changes
362 of RS 3 after 13 and 18 weeks of training. According to these findings, an intensity of 80-
363 90% of HR_{max} is needed for monitoring training adaptation. A time point when it was
364 possible to identify the highest and lowest responders for the first time was at week 13 based
365 on the data of RS 3 in SRT and at week 18 based on the data of the maximal test. From the
366 practical point of view, obtaining that kind of information about the adaptation 5 weeks
367 earlier, would allow the possibility for athletes and coaches to change their training program
368 earlier for achieving desirable training adaptation.

369

370 Regardless of relatively clear observations about the relationship between performance at
371 certain submaximal HR and endurance performance in the present and in previous studies (2,
372 3, 38, 41, 43), decreased exercise HR and HR_{max} have been observed to be related also to
373 negative training adaptation in the case of short-term overreaching or overtraining (17, 27). In
374 the present study, only trivial changes were observed in HR_{max} , except among the lowest

375 responders who showed moderate decreases in HR_{max} , which together with the poor
376 improvement in endurance performance could be a sign of overreaching. However, RPE
377 remained relatively unaltered at submaximal levels. In the case of overreaching or
378 overtraining, RPE would increase at submaximal levels because one should work harder for
379 achieving the same HR level due to higher relative intensity, if HR_{max} is reduced (26).
380 Therefore, RPE together with the data of RS give reasonable information about training
381 adaptation. Furthermore, no signs of fatigue or overreaching were observed in the injured
382 subjects among dropouts who performed the repeated testing at least twice before the
383 termination of the study. It seems that fatigue or overreaching was not a reason for the
384 injuries or more frequent monitoring might be needed for identifying risks for injuries.

385

386 **Post-exercise heart rate recovery and heart rate variability after submaximal exercise in**
387 **predicting endurance performance and monitoring training adaptation**

388 Faster cardiorespiratory recovery after exercise as measured by post-exercise HRR and HRV
389 have been shown to be related to a greater VO_{2max} and/or endurance performance (8, 39, 43).
390 In the cross-sectional analysis of the present study, HRR and HRV correlated with VO_{2max} ,
391 but not with endurance performance, except in women ($r = 0.64$). In our previous study, we
392 observed the similar correlation between HRR after SRT in field conditions and VO_{2max} ($r =$
393 0.49) (43). When the correlations were analyzed separately by sexes, the stronger correlations
394 between HRR and VO_{2max} were observed in women ($r = 0.62$) compared with men ($r = 0.48$).
395 However, no sex differences were observed in the significances of the correlations, which is
396 in line with previous studies (28, 29). A limitation of the present study was a relatively small
397 number of subjects and a larger sample size would give more statistical power in comparison
398 between sexes. The present results support that the higher post-exercise cardiovascular

399 autonomic activity measured by HRR and HRV is related with the higher aerobic capacity,
400 but not with endurance performance.

401

402 Changes in post-exercise HRR and HRV have been proposed as markers of changes in
403 cardiac autonomic regulation and training adaptation. An increased HRR has been shown to
404 be related with the improved VO_{2max} or endurance performance (8, 23, 24). Lamberts et al.
405 (23) observed positive relationships between the changes of HRR after the 40 km cycling
406 time trial and peak power output ($r = 0.73$) and 40 km time trial time ($r = 0.95$) after 4 weeks
407 of high intensity training. In the present study, HRR and $\ln RMSSD$ remained unaltered
408 during the training period. Furthermore, contrary to our hypothesis no relationships were
409 observed between the individual change of post-exercise HRR and HRV with the change of
410 RS_{peak} or VO_{2max} , like in our previous study (43) and the study by Buchheit et al. (4) in team-
411 sports. The absence of the relationships between post-exercise HRR and HRV, and endurance
412 performance may be explained by the relatively homogeneous group of the subjects. The
413 relationship seems to be weaker in homogeneous groups (33, 35), which may be due to the
414 relation between genetic polymorphism in acetylcholine receptor M2 and post-exercise HRR
415 (14). Thus, it may be possible that post-exercise HRR may indicate overall aerobic fitness but
416 the change in HRR is not sensitive enough to track changes in endurance performance and
417 aerobic capacity, especially in homogeneous groups. The discrepancies between studies can
418 also be explained with different protocols in the measurements. The mode, duration and
419 intensity of exercise may affect post-exercise HRR and HRV (8). Exercise intensity has been
420 proposed to have a graded effect on post-exercise HRV during the initial minutes of recovery,
421 with a greater preceding intensity resulting in a lower HRV (32). It has been suggested that
422 exercise intensity below $LT1$ should be used for assessing the actual post-exercise cardiac
423 autonomic regulation by HRV measures (5). The greater relative exercise intensity causes the

424 greater blood acidosis and metaboreflex stimulation, and post-exercise HRV is very largely
425 related to exercise intensity rather than cardiac autonomic regulation (5, 39). Therefore, the
426 relatively high exercise intensity (90% of $HR_{max} \sim LT2$) in the present study, may explain the
427 non-significant findings between the changes in post-exercise HRV and the training
428 adaptation.

429

430 **CMJ in predicting and monitoring endurance performance**

431 In addition to cardiorespiratory and metabolic factors, neuromuscular factors have an
432 important role in endurance performance. We found a large correlation ($r = 0.57$) between
433 CMJ_h and RS_{peak} (all pooled). The finding supports that muscle power of the lower
434 extremities is related with running performance (9, 16). However, the relationship was found
435 only in women, but not in men, when sexes were analysed separately. It needs to be
436 emphasized that the present subjects performed one muscle endurance training session per
437 week, but no explosive strength training of any kind. As it was hypothesized, no remarkable
438 changes in CMJ occurred during the training period. The individual changes of CMJ_h were
439 not related to changes of RS_{peak} during the present training period neither in women, men or
440 in the whole group. It has been proposed that reduced CMJ_h performance could be an
441 indicator of neuromuscular fatigue (7, 12, 30), which could also be observed in impairment of
442 endurance performance. The declining trend could be observed in CMJ_h during weeks 4 – 18
443 in the lowest responders (Fig. 3.G), but the change was not statistically significant. It is
444 possible that it may be an early signal of neuromuscular fatigue, but there were no indicators
445 of that at the group mean level. In addition, it is possible that other variables than jumping
446 height would be more sensitive for detecting neuromuscular fatigue (12) in endurance
447 running performance. However, these results cannot endorse the use of CMJ_h as a valid
448 method for monitoring endurance training adaptation.

449

450 **PRACTICAL APPLICATIONS**

451

452 Nowadays, the measurements of running speed, HRR, HRV and CMJ can be easily
453 performed by mobile applications and heart rate monitors with GPS and accelerometers,
454 without expensive and solid measurement methods. However, the data is commonly used for
455 determining training intensity, volume and load, but the data is not often fully utilized for
456 systematic monitoring of training adaptation and training prescription. The present results
457 support that the non-invasive and practical running speed and post-exercise measurements
458 can be used to track changes in endurance performance. Changes in running speeds at 80-
459 90% of HR_{max} in the SRT may provide the most valuable information about the training
460 adaptation for athletes and coaches. An increment in the submaximal running speed may
461 reflect the positive change in maximal endurance performance and a decrement may suggest
462 declined maximal endurance performance. Thus, SRT may inform if training has led to
463 undesirable outcomes and if a training program should be changed. In addition, the present
464 results suggest that the submaximal running test could be performed regularly, e.g. once per
465 week, as a standardized warm-up without interfering normal training habits. Post-exercise
466 cardiac vagal activity reflects aerobic capacity, but may not be sensitive enough for
467 monitoring individual training adaptation. Similarly, the individual changes of neuromuscular
468 function did not correlate with endurance training adaptation, but CMJ performance was
469 related to maximal running performance in the present subject population. Furthermore, SRT
470 together with HRR, HRV and CMJ measurements may serve a useful tool for athletes and
471 coaches to evaluate individual adaptation to endurance training on a weekly basis and,
472 therefore, could be used in training prescription.

473

474 **REFERENCES**

475

- 476 1. Achten, J, and Jeukendrup, AE. Heart rate monitoring: applications and limitations.
477 *Sports Med.* 33: 517-538, 2003.
- 478 2. Borresen, J, and Lambert, MI. Autonomic control of heart rate during and after exercise :
479 measurements and implications for monitoring training status. *Sports Med.* 38: 633-646,
480 2008.
- 481 3. Buchheit, M, Chivot, A, Parouty, J, Mercier, D, Al Haddad, H, Laursen, PB, and
482 Ahmaidi, S. Monitoring endurance running performance using cardiac parasympathetic
483 function. *Eur. J. Appl. Physiol.* 108: 1153-1167, 2010.
- 484 4. Buchheit, M, Simpson, MB, Al Haddad, H, Bourdon, PC, and Mendez-Villanueva, A.
485 Monitoring changes in physical performance with heart rate measures in young soccer
486 players. *Eur. J. Appl. Physiol.* 112: 711-723, 2012.
- 487 5. Buchheit, M. Monitoring training status with HR measures: do all roads lead to Rome?
488 *Front. Physiol.* 5: 73, 2014.
- 489 6. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* New Jersey; Lawrence
490 Erlbaum, 1988.
- 491 7. Cormack, SJ, Newton, RU, McGuigan, MR, and Cormie, P. Neuromuscular and
492 endocrine responses of elite players during an Australian rules football season. *Int. J.*
493 *Sports Physiol. Perform.* 3: 439-453, 2008.
- 494 8. Daanen, HA, Lamberts, RP, Kallen, VL, Jin, A, and Van Meeteren, NL. A systematic
495 review on heart-rate recovery to monitor changes in training status in athletes. *Int. J.*
496 *Sports Physiol. Perform.* 7: 251-260, 2012.

- 497 9. Dumke, CL, Pfaffenroth, CM, McBride, JM, and McCauley, GO. Relationship between
498 muscle strength, power and stiffness and running economy in trained male runners. *Int.*
499 *J. Sports Physiol. Perform.* 5: 249-261, 2010.
- 500 10. Dupuy, O, Mekary, S, Berryman, N, Bherer, L, Audiffren, M, and Bosquet, L. Reliability
501 of heart rate measures used to assess post-exercise parasympathetic reactivation. *Clin.*
502 *Physiol. Funct. Imaging* 32: 296-304, 2012.
- 503 11. Faude, O, Kindermann, W, and Meyer, T. Lactate threshold concepts: how valid are
504 they? *Sports Med.* 39: 469-490, 2009.
- 505 12. Gathercole, R, Sporer, B, Stellingwerff, T, and Sleivert, G. Alternative
506 countermovement-jump analysis to quantify acute neuromuscular fatigue. *Int. J. Sports*
507 *Physiol. Perform.* 10: 84-92, 2015.
- 508 13. Hautala, A, Tulppo, MP, Makikallio, TH, Laukkanen, R, Nissila, S, and Huikuri, HV.
509 Changes in cardiac autonomic regulation after prolonged maximal exercise. *Clin.*
510 *Physiol.* 21: 238-245, 2001.
- 511 14. Hautala, AJ, Rankinen, T, Kiviniemi, AM, Makikallio, TH, Huikuri, HV, Bouchard, C,
512 and Tulppo, MP. Heart rate recovery after maximal exercise is associated with
513 acetylcholine receptor M2 (CHRM2) gene polymorphism. *Am. J. Physiol. Heart Circ.*
514 *Physiol.* 291: H459-66, 2006.
- 515 15. Hautala, AJ, Kiviniemi, AM, and Tulppo, MP. Individual responses to aerobic exercise:
516 the role of the autonomic nervous system. *Neurosci. Biobehav. Rev.* 33: 107-115, 2009.
- 517 16. Hebert-Losier, K, Jensen, K, and Holmberg, HC. Jumping and hopping in elite and
518 amateur orienteering athletes and correlations to sprinting and running. *Int. J. Sports*
519 *Physiol. Perform.* 9: 993-999, 2014.
- 520 17. Hedelin, R, Wiklund, U, Bjerle, P, and Henriksson-Larsen, K. Cardiac autonomic
521 imbalance in an overtrained athlete. *Med. Sci. Sports Exerc.* 32: 1531-1533, 2000.

- 522 18. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for
523 studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41: 3-13, 2009.
- 524 19. Kaikkonen, P, Hynynen, E, Mann, T, Rusko, H, and Nummela, A. Can HRV be used to
525 evaluate training load in constant load exercises? *Eur. J. Appl. Physiol.* 108: 435-442,
526 2010.
- 527 20. Kaikkonen, P, Hynynen, E, Mann, T, Rusko, H, and Nummela, A. Heart rate variability
528 is related to training load variables in interval running exercises. *Eur. J. Appl. Physiol.*
529 112: 829-838, 2012.
- 530 21. Lambert, MI, Mbambo, ZH, and St Clair Gibson, A. Heart rate during training and
531 competition for long-distance running. *J. Sports Sci.* 16 Suppl: S85-90, 1998.
- 532 22. Lamberts, RP, and Lambert, MI. Day-to-day variation in heart rate at different levels of
533 submaximal exertion: implications for monitoring training. *J. Strength Cond Res.* 23:
534 1005-1010, 2009.
- 535 23. Lamberts, RP, Swart, J, Noakes, TD, and Lambert, MI. Changes in heart rate recovery
536 after high-intensity training in well-trained cyclists. *Eur. J. Appl. Physiol.* 105: 705-713,
537 2009.
- 538 24. Lamberts, RP, Swart, J, Capostagno, B, Noakes, TD, and Lambert, MI. Heart rate
539 recovery as a guide to monitor fatigue and predict changes in performance parameters.
540 *Scand. J. Med. Sci. Sports* 20: 449-457, 2010.
- 541 25. Lamberts, RP, Swart, J, Noakes, TD, and Lambert, MI. A novel submaximal cycle test to
542 monitor fatigue and predict cycling performance. *Br. J. Sports Med.* 45: 797-804, 2011.
- 543 26. Le Meur, Y, Hausswirth, C, Natta, F, Couturier, A, Bignet, F, and Vidal, PP. A
544 multidisciplinary approach to overreaching detection in endurance trained athletes. *J.*
545 *Appl. Physiol. (1985)* 114: 411-420, 2013.

- 546 27. Le Meur, Y, Pichon, A, Schaal, K, Schmitt, L, Louis, J, Gueneron, J, Vidal, PP, and
547 Hausswirth, C. Evidence of parasympathetic hyperactivity in functionally overreached
548 athletes. *Med. Sci. Sports Exerc.* 45: 2061-2071, 2013.
- 549 28. MacMillan, JS, Davis, LL, Durham, CF, and Matteson, ES. Exercise and heart rate
550 recovery. *Heart Lung* 35: 383-390, 2006.
- 551 29. Mahon, AD, Anderson, CS, Hipp, MJ, and Hunt, KA. Heart rate recovery from
552 submaximal exercise in boys and girls. *Med. Sci. Sports Exerc.* 35: 2093-2097, 2003.
- 553 30. McLean, BD, Coutts, AJ, Kelly, V, McGuigan, MR, and Cormack, SJ. Neuromuscular,
554 endocrine, and perceptual fatigue responses during different length between-match
555 microcycles in professional rugby league players. *Int. J. Sports Physiol. Perform.* 5: 367-
556 383, 2010.
- 557 31. Meeusen, R, Duclos, M, Foster, C, Fry, A, Gleeson, M, Nieman, D, Raglin, J, Rietjens,
558 G, Steinacker, J, Urhausen, A, European College of Sport Science, and American
559 College of Sports Medicine. Prevention, diagnosis, and treatment of the overtraining
560 syndrome: joint consensus statement of the European College of Sport Science and the
561 American College of Sports Medicine. *Med. Sci. Sports Exerc.* 45: 186-205, 2013.
- 562 32. Michael, S, Jay, O, Halaki, M, Graham, K, and Davis, G. Submaximal exercise intensity
563 modulates acute post-exercise heart rate variability. *Eur. J. Appl. Physiol.* 2016 Jan 18
564 (Epub ahead of print).
- 565 33. Mouro, L, Fabre, N, Andersson, E, Willis, S, Buchheit, M, and Holmberg, HC. Cross-
566 country skiing and postexercise heart-rate recovery. *Int. J. Sports Physiol. Perform.* 10:
567 11-16, 2015.
- 568 34. Nummela, AT, Paavolainen, LM, Sharwood, KA, Lambert, MI, Noakes, TD, and Rusko,
569 HK. Neuromuscular factors determining 5 km running performance and running
570 economy in well-trained athletes. *Eur. J. Appl. Physiol.* 97: 1-8, 2006.

- 571 35. Otter, RT, Brink, MS, Lamberts, RP, and Lemmink, KA. A new Submaximal Rowing
572 Test to predict 2000 meter rowing ergometer performance. *J. Strength Cond Res.* 29:
573 2426-2433, 2015.
- 574 36. Paavolainen, L, Häkkinen, K, Hämmäläinen, I, Nummela, A, and Rusko, H. Explosive-
575 strength training improves 5-km running time by improving running economy and
576 muscle power. *J. Appl. Physiol.* 86: 1527-1533, 1999.
- 577 37. Saalasti, S. Neural networks for heart rate time series analysis. Doctoral thesis,
578 University of Jyväskylä, Jyväskylä, Finland, 2003.
- 579 38. Scharhag-Rosenberger, F, Meyer, T, Walitzek, S, and Kindermann, W. Time course of
580 changes in endurance capacity: a 1-yr training study. *Med. Sci. Sports Exerc.* 41: 1130-
581 1137, 2009.
- 582 39. Stanley, J, Peake, JM, and Buchheit, M. Cardiac parasympathetic reactivation following
583 exercise: implications for training prescription. *Sports Med.* 43: 1259-1277, 2013.
- 584 40. Uusitalo, AL. Overtraining: making a difficult diagnosis and implementing targeted
585 treatment. *Phys. Sportsmed* 29: 35-50, 2001.
- 586 41. Vesterinen, V, Hokka, L, Hynynen, E, Mikkola, J, Häkkinen, K, and Nummela, A. Heart
587 rate-running speed index may be an efficient method of monitoring endurance training
588 adaptation. *J. Strength Cond Res.* 28: 902-908, 2014.
- 589 42. Vesterinen, V, Häkkinen, K, Laine, T, Hynynen, E, Mikkola, J, and Nummela, A.
590 Predictors of individual adaptation to high-volume or high-intensity endurance training
591 in recreational endurance runners. *Scand. J. Med. Sci. Sports.* doi: 10.1111/sms.12530,
592 2015.
- 593 43. Vesterinen, V, Nummela, A, Äyrämo, S, Laine, T, Hynynen, E, Mikkola, J, and
594 Häkkinen, K. Monitoring Training Adaptation With a Submaximal Running Test in Field
595 Conditions. *Int. J. Sports Physiol. Perform.* 2015 Aug 26 (Epub ahead of print).

- 596 44. Wang, SC, Lin, HF, Wu, CF, Lin, BN, Wang, YS, and Huang, YJ. Aerobic power
597 assessment by using a 10 min heart rate control running on treadmill. *J. Sports Med.*
598 *Phys. Fitness* 50: 32-36, 2010.
- 599 45. Yamamoto, K, Miyachi, M, Saitoh, T, Yoshioka, A, and Onodera, S. Effects of
600 endurance training on resting and post-exercise cardiac autonomic control. *Med. Sci.*
601 *Sports Exerc.* 33: 1496-1502, 2001.

602

603 ACKNOWLEDGMENTS

604

605 This study was financially supported by the Finnish Ministry of Education and Culture. The
606 authors wish to thank the subjects for their participation. No conflicts of interest are declared.
607 The results of the present study do not constitute endorsement of the product by the authors
608 or the NCSA.

609 FIGURE LEGENDS

610

611 **Figure 1.** An example of an arbitrary subject' training monitoring test including heart rate and
612 running speed during the submaximal running test (SRT).

613

614 **Figure 2.** Correlations between the changes of maximal oxygen consumption (VO_{2max}) and
615 peak running speed (RS_{peak}), and the changes of running speed during the first (70% HR_{max}),
616 second (80% HR_{max}) and third stage (90% HR_{max}) in the submaximal running test ($n = 33$)
617 after 18 weeks of training.

618

619 **Figure 3.** Changes in running speed (RS) in the first (A), second (B) and third stage (C) of the
620 submaximal running test (SRT), rate of perceived exertion (RPE, D), post exercise heart rate recovery

621 (HRR, E), post-exercise the natural logarithm of the square root of the mean squared differences of
622 successive R-R intervals (lnRMSSD, F) and the countermovement jump height (CMJ_h, G) in the first
623 (high) and fourth (low) quartiles of percentage training adaptation. Circles around symbols denote
624 significant ($p < 0.05$) within-group difference from week 0 and between-groups differences: # $p <$
625 0.05, ## $p < 0.01$ (revealed by Bonferroni post hoc analysis).

626

627

ACCEPTED

TABLES:

Table 1. Physiological and performance variables of the submaximal running test.

	Week 0	Week 4	Week 9	Week 13	Week 18
Stage 1 (70% of HR_{max})					
Running speed (km·h ⁻¹)	8.2 ± 1.4	8.5 ± 1.4	8.9 ± 1.4***	8.8 ± 1.4***	9.0 ± 1.4***
Heart rate (bpm)	131 ± 8	132 ± 7	131 ± 7	132 ± 7	132 ± 7
% HR _{max}	70 ± 2	70 ± 1	70 ± 1	71 ± 1	70 ± 1
RPE (0-10)	2 ± 1	2 ± 1	1 ± 1	1 ± 1	2 ± 1
Stage 2 (80% of HR_{max})					
Running speed (km·h ⁻¹)	10.1 ± 1.5	10.3 ± 1.6	10.6 ± 1.6**	10.6 ± 1.5**	10.8 ± 1.5***
Heart rate (bpm)	150 ± 8	150 ± 8	150 ± 8	150 ± 8	150 ± 8
% HR _{max}	80 ± 1	81 ± 1	80 ± 1	80 ± 1	80 ± 1
RPE (0-10)	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Stage 3 (90% of HR_{max})					
Running speed (km·h ⁻¹)	12.6 ± 1.6	13.0 ± 1.7**	13.3 ± 1.7***	13.4 ± 1.7***	13.7 ± 1.7***
Heart rate (bpm)	168 ± 9	168 ± 8	168 ± 9	167 ± 9	168 ± 9
% HR _{max}	90 ± 1	90 ± 1	90 ± 1	90 ± 1	90 ± 1
RPE (0-10)	6 ± 2	5 ± 2	5 ± 2	5 ± 2	5 ± 1
Recovery period					
HRR (bpm)	42 ± 10	42 ± 9	43 ± 14	43 ± 12	43 ± 10
lnRMSSD (ms)	1.5 ± 0.7	1.6 ± 0.8	1.6 ± 0.8	1.6 ± 0.7	1.6 ± 0.7

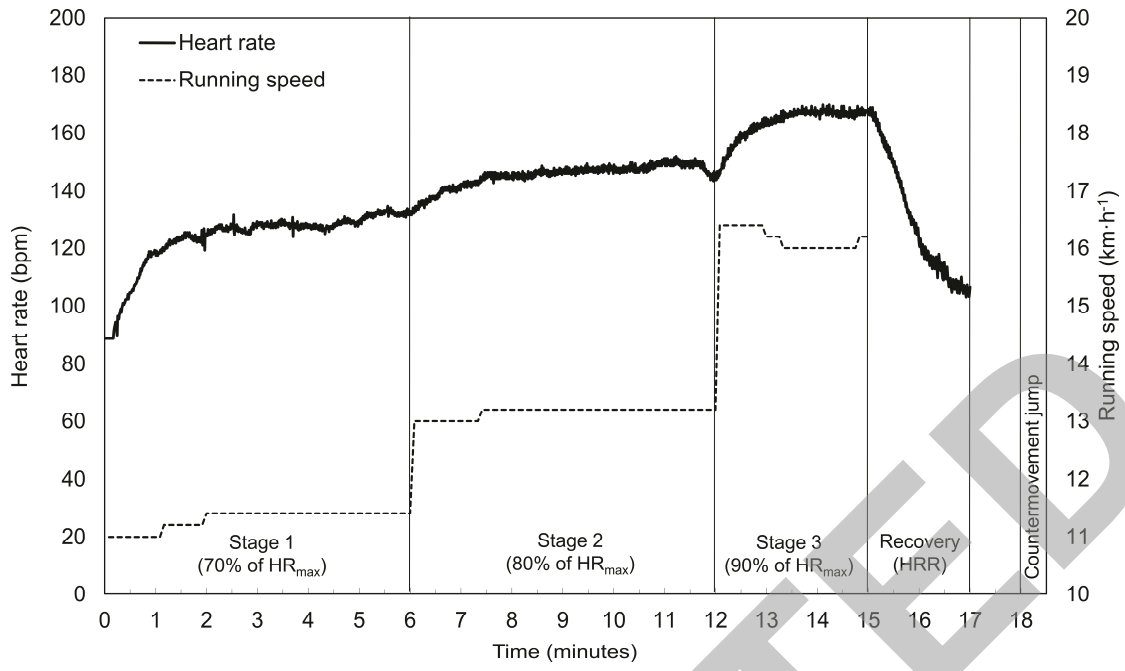
Significant difference from week 0. ** $p < 0.01$, *** $p < 0.001$ (repeated measures of ANOVA). HRR, heart rate recovery during the first minute after the end of the submaximal running test; lnRMSSD, the natural logarithm of the square root of the mean squared differences of successive R-R intervals as calculated during the last minute of the 2-min recovery period after the submaximal running test.

Table 2. Performances before and after the 18-week training period in quartiles of the training adaptation.

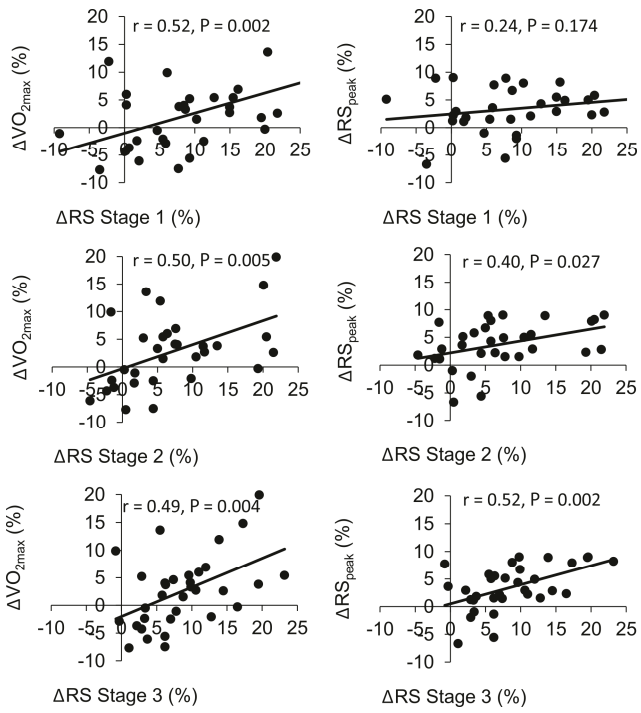
		Percentage change at 18 weeks			
		1st quartile	2nd quartile	3rd quartile	4th quartile
		(n=9)	(n=9)	(n=9)	(n=8)
VO_{2max} (mL·kg⁻¹·min⁻¹)	Pre	48.3 ± 4.5	49.3 ± 4.8	53.4 ± 6.3	48.8 ± 7.8
	Change (%)	8.3 ± 0.8 ^b	2.9 ± 5.4 ^c	0.2 ± 4.3 ^{#,d}	-2.6 ± 4.3 ^{###,c}
RS_{peak} (km·h⁻¹)	Pre	14.8 ± 0.6	14.4 ± 1.1	15.4 ± 1.5	15.0 ± 1.9
	Change (%)	8.3 ± 6.2 ^a	4.4 ± 1.1 ^{###,a}	1.9 ± 0.5 ^{###,a}	-2.2 ± 2.7 ^{###,c}
SRT RS 1 (km·h⁻¹)	Pre	7.7 ± 1.2	7.6 ± 1.1	8.3 ± 1.3	8.6 ± 1.6
	Change (%)	11.4 ± 10.4 ^b	10.8 ± 9.1 ^b	10.7 ± 10.2 ^b	5.1 ± 5.3 ^b
SRT RS 2 (km·h⁻¹)	Pre	9.4 ± 1.3	9.6 ± 1.3	10.3 ± 1.5	10.3 ± 1.9
	Change (%)	10.9 ± 8.4 ^b	5.9 ± 4.7 ^b	7.8 ± 9.2 ^c	1.3 ± 2.3 ^c
SRT RS 3 (km·h⁻¹)	Pre	12.0 ± 1.5	11.9 ± 1.4	12.9 ± 1.6	12.6 ± 2.2
	Change (%)	13.5 ± 7.4 ^a	6.6 ± 3.9 ^b	9.1 ± 4.8 ^b	3.9 ± 2.0 ^{###,b}
SRT HRR (bpm)	Pre	41 ± 9	46 ± 9	47 ± 12	39 ± 11
	Change (%)	8.1 ± 19.5 ^d	8.2 ± 17.9 ^d	4.8 ± 13.6 ^d	11.8 ± 23.0 ^d
SRT RPE	Pre	6 ± 1	6 ± 2	6 ± 2	6 ± 2
	Change (%)	-7.1 ± 13.9 ^c	-5.9 ± 27.4 ^d	12.8 ± 34.0 ^d	-0.4 ± 13.4 ^d
SRT RMSSD (ms)	Pre	1.6 ± 0.6	1.8 ± 0.6	1.6 ± 0.9	1.1 ± 0.3
	Change (%)	15.7 ± 50.0 ^d	-4.2 ± 22.7 ^d	20.1 ± 51.1 ^d	6.2 ± 37.0 ^d
CMJ_h (cm)	Pre	31.1 ± 5.9	23.1 ± 4.6 [#]	29.8 ± 5.9	25.0 ± 4.7
	Change (%)	1.9 ± 5.3 ^d	4.1 ± 4.8 ^b	-2.2 ± 7.3 ^d	-1.2 ± 6.1 ^d

Significant difference to the first quartile. [#] $p < 0.05$, ^{##} $p < 0.01$, ^{###} $p < 0.001$. ^a large effect size, ^b moderate effect size, ^c small effect size, ^d trivial effect size.

VO_{2max}, maximal oxygen consumption; RS_{peak}, peak treadmill running speed; SRT, submaximal running test; RS, running speed; HRR, heart rate recovery; lnRMSSD, the natural logarithm of the square root of the mean squared differences of successive R-R intervals; CMJ_h, the countermovement jump height.



ACCEPTED



ACCEPTED

