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1 *Individual variability in cardiac biomarker release after 30 min high intensity rowing in*
2 *elite and amateur athletes*

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31 **Abstract**

32 This study had two specific objectives; 1) to examine the individual variation in the pattern of
33 cardiac troponin I (cTnI) and N-terminal pro-brain natriuretic peptide (NT-proBNP) response
34 to high intensity rowing exercise, and 2) to establish if individual heterogeneity in biomarker
35 appearance was influenced by athletic status (elite vs. amateur). We examined cTnI and NT-
36 proBNP in 18 elite and 14 amateur rowers before and 5 min, 1, 3, 6, 12, and 24 h after a 30
37 min maximal rowing test. Peak post-exercise cTnI (pre: 0.014 ± 0.030 , peak post: $0.058 \pm$
38 $0.091 \mu\text{g.L}^{-1}$, $p = 0.000$) and NT-proBNP (pre: 15 ± 11 , peak post: $31 \pm 19 \text{ ng.L}^{-1}$, $p = 0.000$)
39 were elevated. Substantial individual heterogeneity in peak and time course data noted for
40 cTnI. Peak cTnI exceeded the upper reference limit (URL) in 9 elite and 3 amateur rowers.
41 No rower exceeding the URL for NT-proBNP. Elite rowers had higher baseline ($0.019 \pm$
42 0.038 vs. $0.008 \pm 0.015 \mu\text{g.L}^{-1}$; $p = 0.003$) and peak post-exercise cTnI (0.080 ± 0.115 vs.
43 $0.030 \pm 0.029 \mu\text{g.L}^{-1}$; $p = 0.022$) than amateur rowers but the change with exercise was
44 similar between groups. There were no significant differences in baseline and peak post-
45 exercise NT-proBNP between groups. In summary, marked individuality in cTnI response
46 was noted to a short but high intensity rowing bout. Athlete status did not seem to mediate
47 the change in cardiac biomarkers to high intensity exercise.

48

49 **Keywords:** exercise; cTnI; NT-proBNP; athletic status; rowing, elite athletes, amateur athlete

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56 ***Introduction***

57 An increasing number of studies have described the elevation of cardiac troponin I (cTnI), a
58 biomarker of cardiac cell necrosis, and N-terminal pro-brain natriuretic peptide (NT-proBNP),
59 a biomarker of cardiac dysfunction, after prolonged and strenuous exercise (Scharhag et al.
60 2008; Shave et al. 2010a). The cardiac biomarker response to short-duration, high-intensity
61 exercise is largely unknown although some have suggested that within the endurance exercise
62 domain cTnI increased with exercise intensity (Legaz-Arrese et al. 2011; Serrano-Ostáriz et
63 al. 2011). Shave et al. (2010b) are one of the few groups to have studied the cTnI response to
64 shorter, high-intensity bouts of exercise. In spite of the limited volume of exercise (30 min
65 all-out treadmill run) cTnI was elevated during recovery in 75% of athletes (Shave et al.
66 2010b).

67 Importantly Shave et al. (2010b) observed that the cTnI appearance during recovery was
68 markedly heterogeneous and confirmed similar individuality of response noted in field based
69 studies of prolonged exercise (Shave et al. 2010a) as well as an observation from a meta-
70 analysis (Shave et al. 2007). The percentage of individuals with post-exercise cTnI or cTnT
71 levels above the upper reference limit (URL) has varied from 0% (Roth et al. 2007) to 100%
72 (Middleton et al. 2008) in individual studies but this may partially represent the “lottery” of a
73 single post-exercise blood test. It is important that in on-going cardiac biomarker research
74 that multiple post-exercise blood draws occur to fully understand any heterogeneity in cTnI
75 or NTpro-BNP peak concentrations as well as recovery kinetics (Middleton et al. 2008).

76 The influence of exercise intensity on NT-proBNP release is less well known. Within the
77 endurance exercise domain data suggests that NT-proBNP increase may be more influenced
78 by exercise duration (Serrano-Ostáriz et al. 2009) but studies involving shorter bouts of high
79 intensity exercise in well-trained athletes are limited.

80 Individual variability in biomarker response in the extant literature has been speculated to be,
81 at least partially, related to training or “athletic” status. It has been suggested that highly-
82 trained individuals have lower post-exercise cTnI and NT-proBNP release (Mehta et al. 2012;
83 Neilan et al. 2006). Indeed, the only two previous studies on elite athletes reported normal
84 post-exercise cardiac biomarker levels (Bonetti et al. 1996; König et al. 2003). Contrary, we
85 have recently observed in untrained subjects that a controlled endurance training intervention
86 resulted in higher pre- and post-exercise values of cTn with no changes in NT-proBNP
87 (Legaz-Arrese et al., 2015). Currently, the influence of training level on cardiac biomarker
88 release has not yet been evaluated in a controlled study with disparate groups in terms of
89 training or athletic status completing a similar (relative) high intensity exercise bout. Finally,
90 it has been postulated that increases in both biomarkers may be dependent on their respective
91 resting values (Legaz Arrese et al. 2005; Serrano-Ostáriz et al. 2011) although this construct
92 has not been studied in different athlete groups.

93 Consequently, the purpose of the present study was to determine the cardiac biomarker
94 response to a short duration, high intensity bout of rowing with specific emphasis on detailing
95 individual responses across multiple assessment points during a 24 hr recovery period. A
96 secondary purpose was to determine the influence of athlete status on cTnI and NT-proBNP
97 release by comparing two cohorts; amateur and elite rowers.

98

99 ***Material and Methods***

100

101 *Participants*

102 Thirty-two male rowers were recruited from a large Rowing Club in Spain through an open
103 invitation to all of its members. Volunteers included elite rowers ($n = 18$) who had at least 3
104 yr of competitive history at the national or international level (1 world champion, 1 under-23

105 world champion, 1 Olympic competitor, 2 Spanish champions, and 3 Spanish sub-
106 champions) and were training ≥ 5 days per week and non-competitive amateur rowers ($n =$
107 14) who trained ≤ 3 days per week. All rowers provided informed written consent. The study
108 followed the ethical guidelines of the Declaration of Helsinki and was approved by the
109 Research Ethics Committee of the Government of Aragón (CEICA; Spain).

110

111 *Research Design and Protocols*

112 All rowers attended a preliminary testing session 1 week before the main study was
113 performed. At this initial testing body height was measured to the nearest 0.1 cm (SECA 225
114 SECA, Hamburg, Germany). Body mass was determined to the nearest 0.05 kg (SECA 861,
115 SECA, Hamburg, Germany). A questionnaire was completed to obtain personal data,
116 performance level, training history, and history of any cardiac symptoms. Exclusion criteria
117 were a significant personal or early family history of cardiovascular disease and/or abnormal
118 ECG at baseline examination.

119 The rowers then performed a progressive incremental test to exhaustion on a Concept II
120 rowing ergometer (Model C, Morrisville, VT, USA) to determine the maximal heart rate
121 (HR) (Polar Electro Oy, Kempele, Finland). Prior to the test, the rowers completed a self-
122 paced 5-min warm-up ($HR < 130 \text{ beats} \cdot \text{min}^{-1}$). The test began at a workload of 150 W (elite
123 rowers) or 75 W (amateur rowers) with workload increments of 50 W every 3 min until
124 exhaustion. Strong verbal encouragement was provided to all participants.

125 On Saturday, 7 days after the progressive incremental test, all participants returned to the
126 laboratory to complete the 30 min rowing test. All participants were fully habituated to the 30
127 min all-out rowing test protocol and were asked to abstain from strength training and
128 strenuous exercise for 48 h before testing. Therefore, the last high intensity training session
129 was made on Wednesday. All high-intensity testing sessions occurred at 11:00 am in a sports

130 hall at a temperature of 18-21 °C and a relative humidity of 50-60%. The rowers completed a
131 self-paced 5-min warm-up (HR <130 beats.min⁻¹) followed by a 30-min “all-out” rowing test.
132 Pairs of rowers competed side-by-side to mimic a regular competition and again strong verbal
133 encouragement was provided. During the test HR was recorded continuously via a Polar HR
134 monitor (Polar Electro Oy, Kempele, Finland) and downloaded using Polar Precision
135 Performance software (v. 3.0). The mean power output (W) and distance covered were
136 recorded every 5 min from the rowing ergometer screen. Immediately after the test was
137 completed, the participants rated the test for perceived exertion (RPE) (Borg and Kaijser
138 2006). Venous blood samples were taken before, immediately after (5 min), as well as 1, 3, 6,
139 12, and 24 h after exercise to assess serum cardiac-specific biomarkers.

140

141 *Blood Sampling and Analysis*

142 Blood samples were drawn by repetitive venipuncture from an antecubital vein and quickly
143 centrifuged. The serum and plasma were drawn off and stored at -80 °C for later analysis.
144 cTnI was analyzed from samples of EDTA (ethylenediaminetetraacetic acid) plasma with the
145 Access AccuTnI assay (Beckman Coulter, Fullerton, CA, USA). The imprecision profile of
146 839 duplicate samples showed 10% and 20% coefficients of variation values of 0.014 and
147 0.008 µg.L⁻¹, respectively. The URL for cTnI, defined as the 99th percentile of healthy
148 participants, was 0.04 µg.L⁻¹ (Eggers et al. 2007). NT-proBNP was analyzed in the serum
149 with an Elecsys proBNP electrochemiluminescent immunoassay on the Roche Elecsys 1010
150 (Roche Diagnostics, Lewes, United Kingdom) with an analytical range of 5–35,000 ng.L⁻¹
151 and intra- and interassay imprecisions of 0.7–1.6% and 5.3–6.6%, respectively. The URL for
152 NT-proBNP was considered to be 125 ng.L⁻¹ (Silver et al. 2004).

153

154 *Statistical analysis*

155 Statistical analyses were performed using the IBM Statistical Package for the Social Sciences
156 (IBM SPSS Statistics, v. 20.0 for WINDOWS). Cohort data are presented as the mean \pm
157 standard deviation unless otherwise stated. Kolmogorov-Smirnov tests were used to check for
158 normal distribution and data for cTnI and NT-proBNP were log-transformed prior to
159 statistical testing. To measure the impact of sampling time during recovery (pre, 5 min, 1, 3,
160 6, 12, and 24 h post-exercise) as well as athletes status (elite and amateur) upon cTnI and NT-
161 proBNP mixed model 2-way ANOVAs were performed with post-hoc Bonferroni tests
162 employed when appropriate. Differences between groups in the relative increase of cTnI and
163 NT-proBNP were assessed by independent t-test. A stepwise regression analysis was carried
164 out to analyze the relationships between post-exercise values of cTnI and NT-proBNP and
165 several potential predictors (e.g., baseline cTnI and NT-proBNP concentration, mean and
166 max exercise HR, rowing performance, RPE). The values were considered to be significant if
167 $p < 0.05$.

168

169 **Results**

170 The characteristics of the elite and amateur rowers are shown in Table 1. The elite rowers had
171 more years of training, greater weekly training frequency, and higher weekly training volume
172 (all $p < 0.05$). Performance during the graded rowing test was greater in the elite rowers (294
173 ± 18 W vs. 211 ± 44 W; $p = 0.000$), but maximum HR (elite: 196 ± 7 beats.min⁻¹; amateur:
174 193 ± 9 beats.min⁻¹; $p = 0.372$) and exercise duration (elite: $11:38 \pm 1:40$ min; amateur: $11:09$
175 $\pm 2:38$ min; $p = 0.544$) showed not significant statistical differences between groups.

176

177 *Maximal 30-min rowing test*

178 All of the subjects completed the maximal 30-min rowing test and every blood draw.
179 Performance during the 30 min all out test was substantially greater in the elite athlete (Table

180 2). Whilst mean HR was higher in the elite (180 ± 7 beats.min⁻¹) compared to the amateur
181 rowers (171 ± 12 beats.min⁻¹; $p = 0.023$) there was no difference in the maximum HR (elite
182 rowers: 195 ± 7 beats.min⁻¹, amateur rowers: 188 ± 11 beats.min⁻¹; $p = 0.061$) or RPE (elite
183 rowers: 8.7 ± 0.5 , amateur rowers: 8.6 ± 0.5 ; $p = 0.536$).

184

185 *cTnI release*

186 A significant main effect of sampling time was observed for cTnI with an elevation at 3-, 6-,
187 and 12-h post-exercise compared to baseline ($p = 0.000$) (Table 3). All participants presented
188 with an increase in cTnI post-exercise with the URL for cTnI exceeded by 2 rowers at all
189 measurements points and another 10 rowers (8 elite and 2 amateur) having sporadic data
190 points above the URL during recovery (Fig. 1). The maximum post-exercise cTnI was
191 observed at 3 h in 11 individuals, 6 h in 19 individuals, and 12 h of recovery in 2 individuals.

192 A significant main effect for athlete status was observed with cTnI data higher in elite rowers
193 including pre-exercise values (amateur: 0.008 ± 0.015 $\mu\text{g.L}^{-1}$; elite: 0.019 ± 0.038 $\mu\text{g.L}^{-1}$; $p =$
194 0.003). There was no significant interaction of test time and athlete status with respect to
195 cTnI ($p = 0.311$). In support of this, the maximal increase in cTnI (peak-baseline) did not
196 show significant differences between groups either in absolute terms (elite: 0.062 ± 0.083
197 $\mu\text{g.L}^{-1}$; amateur: 0.023 ± 0.021 $\mu\text{g.L}^{-1}$; $p = 0.145$) or relative terms (elite: $440 \pm 382\%$;
198 amateur: $1252 \pm 1817\%$; $p = 0.398$). In both groups was observed a similar variability (CV)
199 in pre-exercise (elite: 200%; amateur: 188%) and peak post-exercise (elite: 144%; amateur:
200 98%) cTnI values. The stepwise regression analysis using maximum post-exercise cTnI
201 values as dependent variable, and basal cTnI and mean exercise HR as independent variables
202 yielded an $R^2 = 0.810$ ($p = 0.000$). Basal cTnI value was identified as the best post-exercise
203 cTnI predictor ($R^2 = 0.781$, $p = 0.000$).

204

205 *NT-proBNP release*

206 There was a main effect of time with an increase in NT-proBNP from pre-exercise at 5 min,
207 1-, 3-, 6-, 12-, and 24-h post-exercise ($p = 0.001$; Table 3). There was a rise in NT-proBNP
208 post exercise in all subjects but the URL was not exceeded by any subject (Fig. 2). The
209 maximum post-exercise NT-proBNP values were observed at 5 min in 10 individuals, 1 h for
210 4 individuals, 6 h for 7 individuals, 12 h for 4 individuals, and 24 h for 11 individuals. There
211 was no significant main effect of athlete status on NT-proBNP data and there was no time by
212 athlete status interaction effect. In support of this latter point there was no difference between
213 the elite and amateur rowers with respect to the peak NT-proBNP increase in absolute terms
214 (14 ± 11 vs. 18 ± 13 ng.L⁻¹, respectively; $p = 0.470$) or relative terms ($115 \pm 71\%$ vs. $165 \pm$
215 213% , respectively; $p = 0.536$). After the stepwise regression analysis the only variable
216 significantly associated with the logarithm of maximum post-exercise NT-proBNP values
217 was the logarithm of basal NT-proBNP values ($R^2 = 0.697$, $p = 0.000$). There was no
218 correlation between change in NT-proBNP and cTnI data.

219

220 ***Discussion***

221 The main findings of this study were; (1) a single 30-min bout of “all-out” rowing exercise
222 resulted in a significant increase in the cTnI and NT-proBNP in both elite and amateur
223 rowers, (2) significant individual heterogeneity in peak cTnI during recovery was noted with
224 the URL for cTnI exceeded in 12/32, (3) less individual variability was apparent in peak NT-
225 proBNP response with no data point exceeded the URL, (4) baseline and post-exercise cTnI
226 data were higher in elite rowers, but (5) the rowing-induced changes in cTnI and NT-proBNP
227 were independent of athlete status.

228

229 *Post-exercise cTnI peak and kinetics in elite and amateur rowers*

230 Our results in rowers extend the findings of Shave et al. (2010b) who employed a 30 min
231 high intensity run and demonstrate that cTnI is elevated following short-duration, high-
232 intensity exercise in non-elite athletes. An elevation in cTnI occurred in all participants
233 despite the relatively short duration and limited exercise volume. In prolonged exercise there
234 is some evidence to suggest that cTnI release is positively associated with exercise intensity
235 (Fu et al. 2009; Serrano-Ostáriz et al. 2011; Shave et al. 2007). Whilst the current study does
236 not compare exercise intensities it adds to the extant data that different types and intensities
237 of exercise can stimulate an increase in circulating cTnI. According to the results of Shave et
238 al. (2010b) cTnI release following short-duration intense exercise may be as common as
239 when prolonged exercise trials are studied and the current study supports this contention.
240 This also underscores the necessity to complete blood draws during recovery (Middleton et
241 al. 2008).

242 To our knowledge, this study is the first to demonstrate cTnI release with exercise in elite
243 athletes with values that exceed the URL in some, but not all, participants. Previously, only
244 two studies had evaluated cTnI release in elite athletes. Bonetti et al. (1996) analyzed 25
245 cyclists participating in the Giro d'Italia and reported detectable cTnT values in only 5
246 athletes; moreover, these values were below the cut-offs considered to be indicative of
247 myocardial insult. Similarly, König et al. (König et al. 2003) reported normal post-exercise
248 cTnT levels in 11 professional road cyclists. Both studies were constrained by limited blood
249 sampling (pre- and post-exercise design) and by less-sensitive measurement equipment.

250 Despite the fact that all participants experienced a rise in cTnI post-exercise the magnitude of
251 peak post-exercise levels was variable, which also supports the data from Shave et al.
252 (2010b). Recent studies have also demonstrated “positive” high sensitivity cTnT (hs-cTnT)
253 values after prolonged exercise in most subjects (86-94%) (Mingel et al. 2009; Saravia et al.
254 2010; Scherr et al. 2011; Tian et al. 2012), but with marked heterogeneity in peak hs-cTnT

255 (Scherr et al. 2011; Tian et al. 2012). It is not known what personal, environmental or
256 exercise-related factors mediate the heterogeneity and this requires on-going study. On this
257 point, it should be noted that the baseline cTnI variability is even higher than the observed
258 peak post-exercise variability. Whilst we observed variability in the peak cTnI values
259 recorded 94% of participants recorded their peak cTnI between 3 or 6 h which suggests some
260 consistency in cTnI kinetics and agrees with previous data gathered after a treadmill run
261 (Legaz-Arrese et al. 2015; Tian et al. 2012).

262 As in previous studies (Legaz-Arrese et al. 2011; Serrano-Ostáriz et al. 2011), it is interesting
263 that the main factor that significantly predicted post-exercise values of cTnI was their
264 respective pre-exercise values. In a broad range of pathologies and patient groups baseline
265 cTn values are repeatedly and robustly associated with adverse cardiovascular prognosis and
266 mortality (deFilippi et al. 2010). In healthy population little attention has been focused to the
267 variability of baseline cTn values and whether this variability may have clinical significance.
268 On this matter, our results provide that the athletic status may be one of the factors that
269 determine the heterogeneity in baseline cTnI. Further research into the factors associated with
270 the inter-subject variability in the baseline values of cTn are required.

271 Certain authors suggest that the post-exercise cTnI release is greater in less well-trained
272 individuals (Fortescue et al. 2007; Mehta et al. 2012; Mingels et al. 2009; Neilan et al. 2006).
273 However, other studies did not observe any relationship between training level and cTnI
274 release (Eijsvogels et al. 2015; Hubble et al. 2009; Jassal et al. 2009; Scherr et al. 2011;
275 Serrano-Ostáriz et al. 2009). Our results demonstrated greater pre- and post-exercise values
276 of cTn in elite rowers than in amateur rowers. These data are consistent with our recent
277 controlled endurance training intervention (Legaz-Arrese et al. 2015) and a field based study
278 with marathoners (Saravia et al. 2010). Contradiction with previous studies may relate to

279 differences in exercise regime, training status as well as the limited by the number of blood
280 samples taken during the recovery period, in past work.

281 There has been some descriptive association between peak post-exercise cTnI and mean
282 exercise HR (Fu et al. 2009; Legaz-Arrese et al. 2011; Serrano-Ostáriz et al. 2009).
283 Conversely, the higher absolute and relative work performed by the elite rowers in the 30 min
284 exercise bout did not result in a greater change in cTnI during recovery when compared to
285 amateur rowers. This is in agreement with our recent results in a controlled endurance
286 training intervention (Legaz-Arrese et al. 2015). Globally, current knowledge suggest that
287 increased cTnI with exercise is associated with the relative exercise intensity but not with the
288 absolute intensity or exercise performance.

289 We do not know the reasons behind the higher cTnI baseline levels in elite vs. amateur
290 rowers. A previous study also showed that runners with detectable hs-cTnT were
291 significantly better trained than runners in whom hs-cTnT was non-detectable (Saravia et al.
292 2010). Also, we observed that a controlled endurance training intervention resulted in higher
293 pre-exercise values of hs-cTnT (Legaz-Arrese et al. 2015). One hypothesis is that this effect
294 is due to the successive training sessions with limited recuperation time for elite athletes.
295 However, this seems unlikely to be a factor in this study because subjects were required to
296 abstain from vigorous athletic activity for 48 h before each exercise test. Furthermore, if the
297 greater baseline cTnI values were a consequence of incomplete recuperation, they ought to
298 have similarly increased baseline levels of NT-proBNP, based on the results observed in this
299 study. In a previous study, a significantly higher baseline hs-cTnT concentration was
300 obtained in males compared to females (Mingels et al. 2009). Given that the mean heart size
301 is larger for male and elite athletes than for female and amateur athletes (Legaz-Arrese et al.
302 2006; Legaz Arrese et al. 2005), it is reasonable to expect different cTn reference values
303 between these groups. Future research may wish to address this issue.

304

305 *Post-exercise NT-proBNP peak and kinetics in elite and amateur rowers*

306 This investigation is, to our knowledge, the first study that demonstrates NT-proBNP release
307 as a consequence of a short-duration, high-intensity exercise in elite athletes. Increased NT-
308 proBNP has been reported in multiple prolonged endurance exercise studies (Legaz-Arrese et
309 al. 2011; Neilan et al. 2006; Sahlén et al. 2008; Serrano-Ostáriz et al. 2009), and the current
310 data extend this phenomenon to short-duration, high-intensity exercise. The observed
311 increase are somewhat smaller than previous (ultra) endurance exercise studies (Neilan et al.
312 2006; Serrano-Ostáriz et al. 2009) which may not be surprising when one considers that BNP
313 is elevated in response to volume overload and myocyte stretch (Shave et al. 2007) and this is
314 likely to be stressed to a much greater extent in endurance exercise.

315 Our results demonstrate that like to cTnI, NT-proBNP values post exercise, as well as overall
316 kinetic of appearance, is subject to a degree of heterogeneity. In agreement with the above
317 mentioned study of Legaz-Arrese et al. (2015) and Tian et al. (2012), levels of NT-proBNP
318 increased immediately after exercise and were still elevated at 24 h. The elevation in NT-
319 proBNP at 24 h reflects an increase beyond the kinetics of NT-proBNP and its half-life
320 (Silver et al. 2004). Other factors associated with strenuous exercise, such as a temporary
321 reduction in kidney function and changes in cardiac function and hemodynamics, have been
322 suggested to contribute to a sustained elevation in NT-proBNP (Tian et al. 2012), but this
323 requires further study. It would be of great interest to analyze the NT-proBNP kinetic in
324 endurance events such as marathon, where values are usually higher than the URL.

325 Our results show that although peak NT-proBNP data was heterogeneous the URL was not
326 exceeded by any subject. Contrary to the data for cTnI there was no apparent difference in
327 NT-proBNP between subject groups. In previous studies the influence of training level or
328 athletic status on NT-proBNP release has been controversial (Herrmann et al. 2003; Legaz-

329 Arrese et al. 2011, 2015; Neilan et al. 2006; Scharhag et al. 2006; Serrano-Ostáriz et al.
330 2009), likely because of the inability to precisely control for several variables, such as effort
331 duration. Specifically, our study confirms previous results showing that the baseline NT-
332 proBNP is a key factor related to exercise-induced NT-proBNP increase (Carranza-García et
333 al. 2011; Legaz-Arrese et al. 2011, 2015; Sahlén et al. 2008; Serrano-Ostáriz et al. 2011).
334 Interestingly, we observed greater individual variability in time to peak NT-proBNP than for
335 cTnI, and consequently, previous studies may significantly underestimate NT-proBNP
336 release if a single post-exercise sample is taken. Future studies should be performed to
337 determine NT-proBNP kinetics differences among individuals after different types of
338 exertion.

339

340 *Implications*

341 We do not know whether differences between subjects in the kinetics of both biomarkers may
342 have clinical relevance. Importantly, the kinetics data of cTnI from the current study is
343 somewhat different to that observed for cTn in acute myocardial infarction (Thygesen et al.
344 2012). At 24 h post-exercise all cTnI values were close to pre-exercise levels and below the
345 URL (except the outlier). In addition, the increase in cTnI occurred in the absence of clinical
346 signs and symptoms. This suggests that post-exercise cTnI level may be reflect a
347 physiological, rather than pathological, response to exercise stimulus. Clinicians should be
348 aware regardless of athletic status, it is possible to observe cTnI but not NT-proBNP values
349 exceeding the URL in the first hours of recovery after a short-duration, high-intensity
350 exercise period in a high percentage of individuals. Since cTnI is recommended as a sensitive
351 and specific marker for cardiac damage in the diagnosis of acute myocardial infarction,
352 caution should be taken when interpreting post-exercise cTnI levels. The results of this study
353 are relevant for clinicians as it could improve medical decision making.

354

355 *Strengths and limitations*

356 Strengths of the present study include the controlled exercise regimen, matched elite and
357 amateur rowers, serial blood sampling, and the inclusion of cTnI and NT-proBNP values.
358 However, several limitations should be considered. Two of the rowers had cTnI above the
359 URL pre-exercise. The study is limited by only having analyzed associations between
360 biomarkers and athletic status in young male rowers. The impact of age and sex should be
361 studies as factors that may partially mediate the release of cardiac biomarkers with exercise
362 (Scharhag et al. 2008; Shave et al. 2010). The observed differences in the values of cTnI and
363 NT-proBNP between elite and amateur rowers may have resulted from differences in the
364 level of training but could also be associated with other factors, such as genetic differences.
365 To resolve this issue, because of the difficulty of establishing a control group with athletes, it
366 would be also interesting to observe in previously untrained subjects, the effect of training
367 programs on exercise-induced cardiac biomarker release.

368

369 *Conclusions*

370 In conclusion, our results show that 30 min of high-intensity rowing results in the elevation
371 of both cTnI and NT-proBNP across a 24 h recovery period. Whilst a rise in cTnI and NT-
372 proBNP was observed in all rowers, the peak values recorded were highly variable with some
373 cTnI data above URL. Kinetic data for cTnI were more consistent and there does not appear
374 to be an important role for athlete or training status in mediating exercise biomarker
375 responses beyond the impact of potential group differences in baseline data.

376

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381

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501

502 **Figure Legends**

Fig. 1. Individual data points for cTnI ($\mu\text{g.L}^{-1}$) in elite ($n = 18$) (a) and amateur ($n = 14$) (b) rowers at pre-exercise (PRE), as well as 0, 1, 3, 6, 12, and 24 h (0HR, 1HR, 3HR, 6HR, 12HR, 24HR, respectively) after a 30 min maximal rowing test. The horizontal dotted line is the upper reference limit (99th percentile) at $0.04 \mu\text{g.L}^{-1}$.

Fig. 2. Individual data points for NT-proBNP (ng.L^{-1}) in elite ($n = 18$) (a) and amateur ($n = 14$) (b) rowers at pre-exercise (PRE), as well as 0, 1, 3, 6, 12, and 24 h (0HR, 1HR, 3HR, 6HR, 12HR, 24HR, respectively) after a 30 min maximal rowing test. All values were lower than the URL (125ng.L^{-1}).

Table 1. Participant characteristics by athletic status.

	Age (years)	Weight (kg)	Height (cm)	Rowing training history (years)	Rowing training frequency (sessions/week)	Rowing training volume (hours/week)
Elite rowers	21.0 ± 4.1	77.9 ± 6.0	181.4 ± 6.0	8.2 ± 5.4*	6.9 ± 0.3*	22.1 ± 6.6*
Amateur rowers	21.2 ± 2.0	76.6 ± 8.7	177.0 ± 9.0	3.7 ± 1.5	1.6 ± 0.5	2.9 ± 0.8

Note: Values are means ± standard deviations (elite rowers: $n = 18$; amateur rowers: $n = 14$). * Significant differences between elite and amateur rowers.

Table 2. Performance during the maximal 30-min rowing test.

	0-5 min power (W)	5-15 min power (W)	15-25 min power (W)	25-30 min power (W)	Mean power (W)	Percentage of max power (%)
Elite rowers	260 ± 23*	254 ± 22*	251 ± 23*	286 ± 27*	259 ± 23*	88 ± 3*
Amateur rowers	165 ± 48	156 ± 37	157 ± 33	179 ± 37	161 ± 36	76 ± 5

Note: Values are means ± standard deviations (elite rowers: $n = 18$; amateur rowers: $n = 14$). * Significant differences between elite and amateur rowers. Similar pacing strategy was observed in both groups, with a significant increase in rowing performance in the last 5 min.

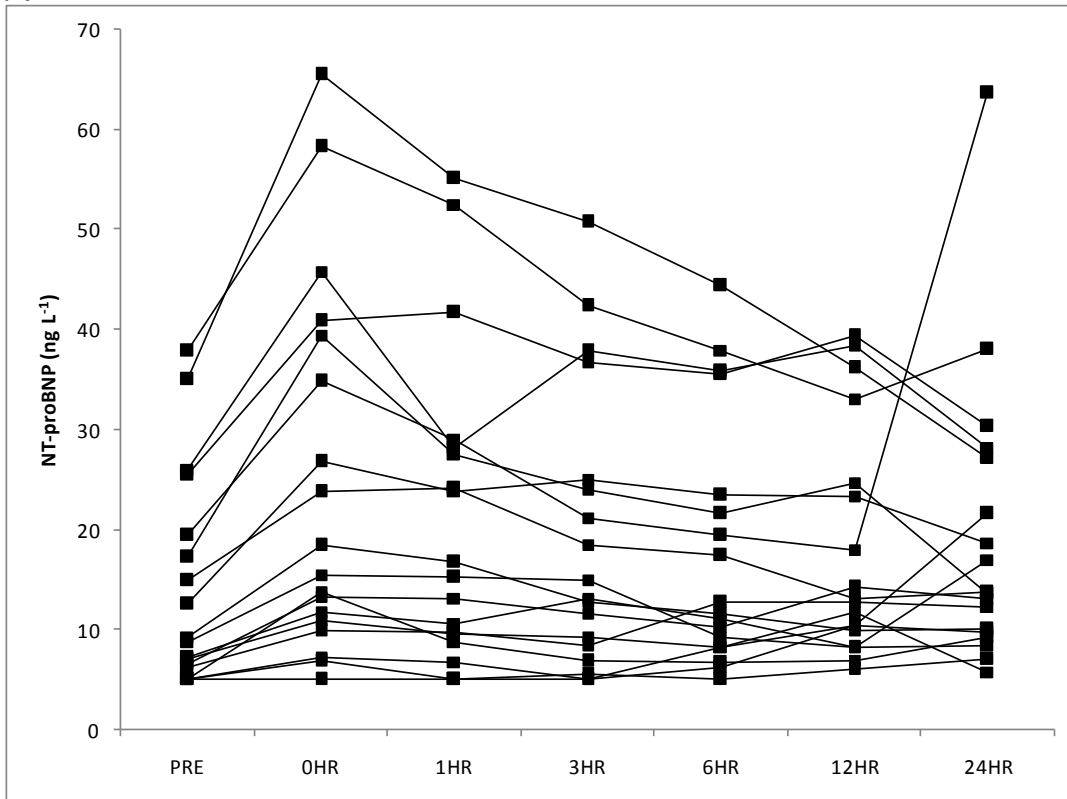
Table 3. cTnI ($\mu\text{g.L}^{-1}$) and NT-proBNP (ng.L^{-1}) before and after 30 min of high-intensity rowing exercise.

		Pre-exercise	5 min post	1 h post	3 h post	6 h post	12 h post	24 h post	<i>p</i> value		
									Time	Group	Time x Group
cTnI	Elite rowers	0.019 ± 0.038 (6)	0.022 ± 0.048 (6)	0.030 ± 0.051 (17)	0.069 ± 0.095 (44)	0.079 ± 0.116 (50)	0.045 ± 0.073 (28)	0.023 ± 0.046 (6)	0.000	0.010	0.311
	Amateur rowers	0.008 ± 0.015 (7)	0.008 ± 0.013 (7)	0.011 ± 0.018 (7)	0.025 ± 0.028 (14)	0.028 ± 0.029 (21)	0.020 ± 0.019 (21)	0.007 ± 0.007 (7)			
NT-proBNP	Elite rowers	14 ± 11 (0)	25 ± 18 (0)	21 ± 16 (0)	19 ± 14 (0)	18 ± 12 (0)	18 ± 11 (0)	19 ± 14 (0)	0.001	0.322	0.171
	Amateur rowers	17 ± 12 (0)	25 ± 19 (0)	25 ± 17 (0)	26 ± 18 (0)	26 ± 18 (0)	28 ± 18 (0)	27 ± 17 (0)			

Note: Values are means ± standard deviations (elite rowers: $n = 18$; amateur rowers: $n = 14$). In brackets the percentage of subjects with serum cardiac biomarkers exceeding the URL.

Fig. 2

(a)



(b)

