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

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

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Complete List of Authors:	Legaz-Arrese, Alejandro; University of Zaragoza, Section of Physical Education and Sports López-Laval, Isaac; University of Zaragoza, George, Keith; John Moores University Puente-Lanzarote, Juan José; Lozano Blesa University Hospital, Moliner-Urdiales, Diego; University Jaume I, Ayala-Tajuelo, Vicente; Consorcio Hospitalario Provincial de Castellón, Mayolas-Pi, Carmen; University of Zaragoza, Reverter-Masià, Joaquín; University of Lleida
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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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4 Legaz-Arrese A, López-Laval I, George K, Puente-Lanzarote JJ, Moliner-Urdiales D, Ayala-  
5 Tajuelo VJ, Mayolas-Pi C, Reverter-Masià J

6

7 \*Alejandro Legaz-Arrese. Section of Physical Education and Sports, University of Zaragoza. C/Domingo Miral  
8 S/N, 50009 Zaragoza, Spain. Phone: 0034676226874. Fax: 0034976761720. E-mail: [alegaz@unizar.es](mailto:alegaz@unizar.es).

9 Isaac López-Laval. Section of Physical Education and Sports, University of Zaragoza. C/Domingo Miral S/N,  
10 50009 Zaragoza, Spain. Phone: 0034666434773. E-mail: [ilopezlaval@hotmail.com](mailto:ilopezlaval@hotmail.com).

11 Keith George. Resarch Institute for Sport and Exercise Sciences, Liverpool John Moores University, Byron  
12 Street L3 3AF, Liverpool, UK. Phone: +44(0)1519046228. [K.George@ljmu.ac.uk](mailto:K.George@ljmu.ac.uk).

13 Juan José Puente-Lanzarote. Service of Biochemistry, Lozano Blesa University Hospital, C/Domingo Miral  
14 S/N, 30009 Zaragoza, Spain. Phone: 0034976765700. [jjpuente@salud.aragon.es](mailto:jjpuente@salud.aragon.es).

15 Diego Moliner-Urdiales. Department of Education, University Jaume I, Avda Sos Baynat s/n, 12071 Castellón,  
16 Spain. Phone: 0034964728000. E-mail: [moliner18891@hotmail.com](mailto:moliner18891@hotmail.com).

17 Vicente Ayala-Tajuelo. Consorcio Hospitalario Provincial de Castellón, Avinguda del Doctor Clarà, 19, 12002  
18 Castellón, Spain. Phone: 0034964359700. E-mail: [informacion@dipc.es](mailto:informacion@dipc.es).

19 Carmen Mayolas-Pi. Section of Physical Education and Sports, University of Zaragoza. C/Domingo Miral S/N,  
20 50009 Zaragoza, Spain. Phone: 0034976761000. E-mail: [carmayo@unizar.es](mailto:carmayo@unizar.es).

21 Joaquín Reverter-Masià. Research Group Human Movement, University of Lleida, C/Partida Caparrella S/N,  
22 25192 LLeida, Spain. Phone: 0034625375734. E-mail: [reverter@didesp.udl.cat](mailto:reverter@didesp.udl.cat).

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24 \*Corresponding author.

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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:  $0.014 \pm 0.030$ , peak post:  $0.058 \pm$   
38  $0.091 \mu\text{g.L}^{-1}$ ,  $p = 0.000$ ) and NT-proBNP (pre:  $15 \pm 11$ , 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 ( $0.080 \pm 0.115$  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  
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  $\geq 5$  days per week and non-competitive amateur rowers ( $n =$   
107 14) who trained  $\leq 3$  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 After a minimum of 7 days all participants returned to the laboratory to complete the 30 min  
126 rowing test. All participants were fully habituated to the 30 min all-out rowing test protocol  
127 and were asked to abstain from strength training and strenuous exercise for 48 h before  
128 testing. All high-intensity testing sessions occurred at 11:00 am in a sports hall at a  
129 temperature of 18-21 °C and a relative humidity of 50-60%. The rowers completed a self-



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

139

#### 140 *Blood Sampling and Analysis*

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

152

#### 153 *Statistical analysis*

154 Statistical analyses were performed using the IBM Statistical Package for the Social Sciences  
155 (IBM SPSS Statistics, v. 20.0 for WINDOWS). Cohort data are presented as the mean  $\pm$   
156 standard deviation unless otherwise stated. Kolmogorov-Smirnov tests were used to check for  
157 normal distribution and data for cTnI and NT-proBNP were log-transformed prior to  
158 statistical testing. To measure the impact of sampling time during recovery (pre, 5 min, 1, 3,  
159 6, 12, and 24 h post-exercise) as well as athletes status (elite and amateur) upon cTnI and NT-  
160 proBNP mixed model 2-way ANOVAs were performed with post-hoc Bonferroni tests  
161 employed when appropriate. The association between the exercise increase in both  
162 biomarkers and other relevant variables (e.g., baseline biomarker concentration, mean and  
163 max exercise HR) were assessed using bivariate Pearson's product-moment correlation  
164 coefficients. The values were considered to be significant if  $p < 0.05$ .

165

## 166 **Results**

167 The characteristics of the elite and amateur rowers are shown in Table 1. The elite rowers had  
168 more years of training, greater weekly training frequency, and higher weekly training volume  
169 (all  $p < 0.05$ ). Performance during the grade rowing test was greater in the elite rowers ( $294 \pm$   
170  $18$  W vs.  $211 \pm 44$  W;  $p = 0.000$ ) whereas maximum HR was similar between groups (elite:  
171  $196 \pm 7$  beats.min<sup>-1</sup>; amateur  $193 \pm 9$  beats.min<sup>-1</sup>;  $p = 0.372$ ).

172

### 173 *Maximal 30-min rowing test*

174 All of the subjects completed the maximal 30-min rowing test and every blood draw.  
175 Performance during the 30 min all out test was substantially greater in the elite athlete (Table  
176 2). Whilst mean HR was higher in the elite ( $180 \pm 7$  beats.min<sup>-1</sup>) compared to the amateur  
177 rowers ( $171 \pm 12$  beats.min<sup>-1</sup>;  $p = 0.023$ ) there was no difference in the maximum HR (elite

178 rowers:  $195 \pm 7$  beats.min<sup>-1</sup>, amateur rowers:  $188 \pm 11$  beats.min<sup>-1</sup>;  $p = 0.061$ ) or RPE (elite  
179 rowers:  $8.7 \pm 0.5$ , amateur rowers:  $8.6 \pm 0.5$ ;  $p = 0.536$ ).

180

#### 181 *cTnI release*

182 A significant main effect of sampling time was observed for cTnI with an elevation at 3-, 6-,  
183 and 12-h post-exercise compared to baseline ( $p = 0.000$ ) (Table 3). All participants presented  
184 with an increase in cTnI post-exercise with the URL for cTnI exceeded by 2 rowers at all  
185 measurements points and another 10 rowers (8 elite and 2 amateur) having sporadic data  
186 points above the URL during recovery (Fig. 1). The maximum post-exercise cTnI was  
187 observed at 3 h in 11 individuals, 6 h in 19 individuals, and 12 h of recovery in 2 individuals.  
188 A significant main effect for athlete status was observed with cTnI data higher in elite rowers  
189 including pre-exercise values (amateur:  $0.008 \pm 0.015$   $\mu\text{g.L}^{-1}$ ; elite:  $0.019 \pm 0.038$   $\mu\text{g.L}^{-1}$ ;  $p =$   
190  $0.003$ ). There was no significant interaction of test time and athlete status with respect to  
191 cTnI ( $p = 0.311$ ). In support of this the maximal increase in cTnI (peak-baseline) was not  
192 significantly different between groups (elite:  $0.062 \pm 0.083$   $\mu\text{g.L}^{-1}$ ; amateur:  $0.023 \pm 0.021$   
193  $\mu\text{g.L}^{-1}$ ;  $p = 0.145$ ). The absolute post-exercise cTnI values were significantly correlated with  
194 the basal values ( $r = 0.88$ ,  $p = 0.000$ ) as well as mean exercise HR ( $r = 0.35$ ,  $p = 0.048$ )

195

#### 196 *NT-proBNP release*

197 There was a main effect of time with an increase in NT-proBNP from pre-exercise at 5 min,  
198 1-, 3-, 6-, 12-, and 24-h post-exercise ( $p = 0.001$ ; Table 3). There was a rise in NT-proBNP  
199 post exercise in all subjects but the URL was not exceeded by any subject (Fig. 2). The  
200 maximum post-exercise NT-proBNP values were observed at 5 min in 10 individuals, 1 h for  
201 4 individuals, 6 h for 7 individuals, 12 h for 4 individuals, and 24 h for 11 individuals. There  
202 was no significant main effect of athlete status on NT-proBNP data and there was no time by

203 athlete status interaction effect. In support of this latter point there was no difference between  
204 the elite and amateur rowers with respect to the peak NT-proBNP increase ( $14 \pm 11$  vs.  $18 \pm$   
205  $13 \text{ ng.L}^{-1}$ , respectively;  $p = 0.470$ ). Basal NT-proBNP values were significantly correlated  
206 with the maximum post-effort values ( $r = 0.83$ ,  $p = 0.000$ ) but there was no correlation  
207 between change in NT-proBNP and cTnI data.

208

### 209 ***Discussion***

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

217

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

219 Our results in rowers extend the findings of Shave et al. (2010b) who employed a 30 min  
220 high intensity run and demonstrate that cTnI is elevated following short-duration, high-  
221 intensity exercise in non-elite athletes. An elevation in cTnI occurred in all participants  
222 despite the relatively short duration and limited exercise volume. In prolonged exercise there  
223 is some evidence to suggest that cTnI release is positively associated with exercise intensity  
224 (Fu et al. 2009; Serrano-Ostáriz et al. 2011; Shave et al. 2007). Whilst the current study does  
225 not compare exercise intensities it adds to the extant data that different types and intensities  
226 of exercise can stimulate an increase in circulating cTnI. According to the results of Shave et  
227 al. (2010b) cTnI release following short-duration intense exercise may be as common as

228 when prolonged exercise trials are studied and the current study supports this contention.  
229 This also underscores the necessity to complete blood draws during recovery (Middleton et  
230 al. 2008).

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

239 Despite the fact that all participants experienced a rise in cTnI post-exercise the magnitude of  
240 peak post-exercise levels was variable, which also supports the data from Shave et al.  
241 (2010b). Recent studies have also demonstrated “positive” high sensitivity cTnT (hs-cTnT)  
242 values after prolonged exercise in most subjects (86-94%) (Mingel et al. 2009; Saravia et al.  
243 2010; Scherr et al. 2011; Tian et al. 2012), but with marked heterogeneity in peak hs-cTnT  
244 (Scherr et al. 2011; Tian et al. 2012). It is not known what personal, environmental or  
245 exercise-related factors mediate the heterogeneity and this requires on-going study. Whilst  
246 we observed variability in the peak cTnI values recorded 94% of participants recorded their  
247 peak cTnI between 3 or 6 h which suggests some consistency in cTnI kinetics and agrees  
248 with previous data gathered after a treadmill run (Tian et al. 2012).

249 As in previous studies (Legaz-Arrese et al. 2011; Serrano-Ostáriz et al. 2011), it is interesting  
250 that the main factor that significantly predicted post-exercise values of cTnI was their  
251 respective pre-exercise values. In a broad range of pathologies and patient groups baseline  
252 cTn values are repeatedly and robustly associated with adverse cardiovascular prognosis and

253 mortality (deFilippi et al. 2010). In healthy population little attention has been focused to the  
254 variability of baseline cTn values and whether this variability may have clinical significance.  
255 On this matter, our results provide that the athletic status may be one of the factors that  
256 determine the heterogeneity in baseline cTnI. Further research into the factors associated with  
257 the inter-subject variability in the baseline values of cTn are required.

258 Certain authors suggest that the post-exercise cTnI release is greater in less well-trained  
259 individuals (Fortescue et al. 2007; Mehta et al. 2012; Mingels et al. 2009; Neilan et al. 2006).  
260 However, other studies did not observe any relationship between training level and cTnI  
261 release (Eijsvogels et al. 2015; Hubble et al. 2009; Jassal et al. 2009; Scherr et al. 2011;  
262 Serrano-Ostáriz et al. 2009). Our results demonstrating greater pre- and post-exercise values  
263 of cTn in elite rowers than in amateur rowers. These data are consistent with our recent  
264 controlled endurance training intervention (Legaz-Arrese et al. 2015) and a field based study  
265 with marathoners (Saravia et al. 2010). Contradiction with previous studies may relate to  
266 differences in exercise regime, training status as well as the limited by the number of blood  
267 samples taken during the recovery period, in past work.

268 There has been some descriptive association between peak post-exercise cTnI and mean  
269 exercise HR (Fu et al. 2009; Legaz-Arrese et al. 2011; Serrano-Ostáriz et al. 2009).  
270 Conversely, the higher absolute and relative work performed by the elite rowers in the 30 min  
271 exercise bout did not result in a greater change in cTnI during recovery when compared to  
272 amateur rowers. Overall there is no convincing evidence that exercise intensity mediated the  
273 cTnI response within the current research design.

274 We do not know the reasons behind the higher cTnI baseline levels in elite vs. amateur  
275 rowers. A previous study also showed that runners with detectable hs-cTnT were  
276 significantly better trained than runners in whom hs-cTnT was non-detectable (Saravia et al.  
277 2010). Also, we observed that a controlled endurance training intervention resulted in higher

278 pre-exercise values of hs-cTnT (Legaz-Arrese et al. 2015). One hypothesis is that this effect  
279 is due to the successive training sessions with limited recuperation time for elite athletes.  
280 However, this seems unlikely to be a factor in this study because subjects were required to  
281 abstain from vigorous athletic activity for 48 h before each exercise test. Furthermore, if the  
282 greater baseline cTnI values were a consequence of incomplete recuperation, they ought to  
283 have similarly increased baseline levels of NT-proBNP, based on the results observed in this  
284 study. In a previous study, a significantly higher baseline hs-cTnT concentration was  
285 obtained in males compared to females (Mingels et al. 2009). Given that the mean heart size  
286 is larger for male and elite athletes than for female and amateur athletes (Legaz-Arrese et al.  
287 2006; Legaz Arrese et al. 2005), it is reasonable to expect different cTn reference values  
288 between these groups. Future research may wish to address this issue.

289

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

291 This investigation is, to our knowledge, the first study that demonstrates NT-proBNP release  
292 as a consequence of a short-duration, high-intensity exercise in elite athletes. Increased NT-  
293 proBNP has been reported in multiple prolonged endurance exercise studies (Legaz-Arrese et  
294 al. 2011; Neilan et al. 2006; Sahlén et al. 2008; Serrano-Ostáriz et al. 2009), and the current  
295 data extend this phenomenon to short-duration, high-intensity exercise. The observed  
296 increase are somewhat smaller than previous (ultra) endurance exercise studies (Neilan et al.  
297 2006; Serrano-Ostáriz et al. 2009) which may not be surprising when one considers that BNP  
298 is elevated in response to volume overload and myocyte stretch (Shave et al. 2007) and this is  
299 likely to be stressed to a much greater extent in endurance exercise.

300 Our results demonstrate that like to cTnI, NT-proBNP values post exercise, as well as overall  
301 kinetic of appearance, is subject to a degree of heterogeneity. In agreement with the above  
302 mentioned study of Tian et al. (2012), levels of NT-proBNP increased immediately after

303 exercise and were still elevated at 24 h. The elevation in NT-proBNP at 24 h reflects an  
304 increase beyond the kinetics of NT-proBNP and its half-life (Silver et al. 2004). Other factors  
305 associated with strenuous exercise, such as a temporary reduction in kidney function and  
306 changes in cardiac function and hemodynamics, have been suggested to contribute to a  
307 sustained elevation in NT-proBNP (Tian et al. 2012), but this requires further study.

308 Our results show that although peak NT-proBNP data was heterogeneous the URL was not  
309 exceeded by any subject. Contrary to the data for cTnI there was no apparent difference in  
310 NT-proBNP between subject groups. In previous studies the influence of training level or  
311 athletic status on NT-proBNP release has been controversial (Herrmann et al. 2003; Legaz-  
312 Arrese et al. 2011, 2015; Neilan et al. 2006; Scharhag et al. 2006; Serrano-Ostáriz et al.  
313 2009), likely because of the inability to precisely control for several variables, such as effort  
314 duration. Specifically, our study confirms previous results showing that the baseline NT-  
315 proBNP is a key factor related to exercise-induced NT-proBNP increase (Carranza-García et  
316 al. 2011; Legaz-Arrese et al. 2011, 2015; Sahlén et al. 2008; Serrano-Ostáriz et al. 2011).

317 Interestingly, we observed greater individual variability in time to peak NT-proBNP than for  
318 cTnI, and consequently, previous studies may significantly underestimate NT-proBNP  
319 release if a single post-exercise sample is taken. Future studies should be performed to  
320 determine NT-proBNP kinetics differences among individuals after different types of  
321 exertion.

322

### 323 *Implications*

324 The fact that cTnI elevation was observed in all, in the absence of any other signs or  
325 symptoms of cardiovascular disease as well as with a rapid onset of accumulation and  
326 recovery within the study period would add to the suggestion that this phenomenon is a  
327 normal physiological process. Clinicians should be aware regardless of athletic status, it is



328 possible to observe cTnI but not NT-proBNP values exceeding the URL in the first hours of  
329 recovery after a short-duration, high-intensity exercise period in a high percentage of  
330 individuals. Since cTnI is recommended as a sensitive and specific marker for cardiac  
331 damage in the diagnosis of acute myocardial infarction, caution should be taken when  
332 interpreting post-exercise cTnI levels. The results of this study are relevant for clinicians as it  
333 could improve medical decision making.

334

### 335 *Strengths and limitations*

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

348

### 349 *Conclusions*

350 In conclusion, our results show that 30 min of high-intensity rowing results in the elevation  
351 of both cTnI and NT-proBNP across a 24 h recovery period. Whilst a rise in cTnI and NT-  
352 proBNP was observed in all rowers, the peak values recorded were highly variable with some

353 cTnI data above URL. Kinetic data for cTnI were more consistent and there does not appear  
354 to be an important role for athlete or training status in mediating exercise biomarker  
355 responses beyond the impact of potential group differences in baseline data.

356

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361

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476

477 **Figure Legends**

**Fig. 1.** Individual data points for cTnI ( $\mu\text{g}\cdot\text{L}^{-1}$ ) 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  $0.04 \mu\text{g}\cdot\text{L}^{-1}$ .

**Fig. 2.** Individual data points for NT-proBNP ( $\text{ng}\cdot\text{L}^{-1}$ ) 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 ( $125 \text{ng}\cdot\text{L}^{-1}$ ).

**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 ( $\text{ng.L}^{-1}$ ) 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)						
	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

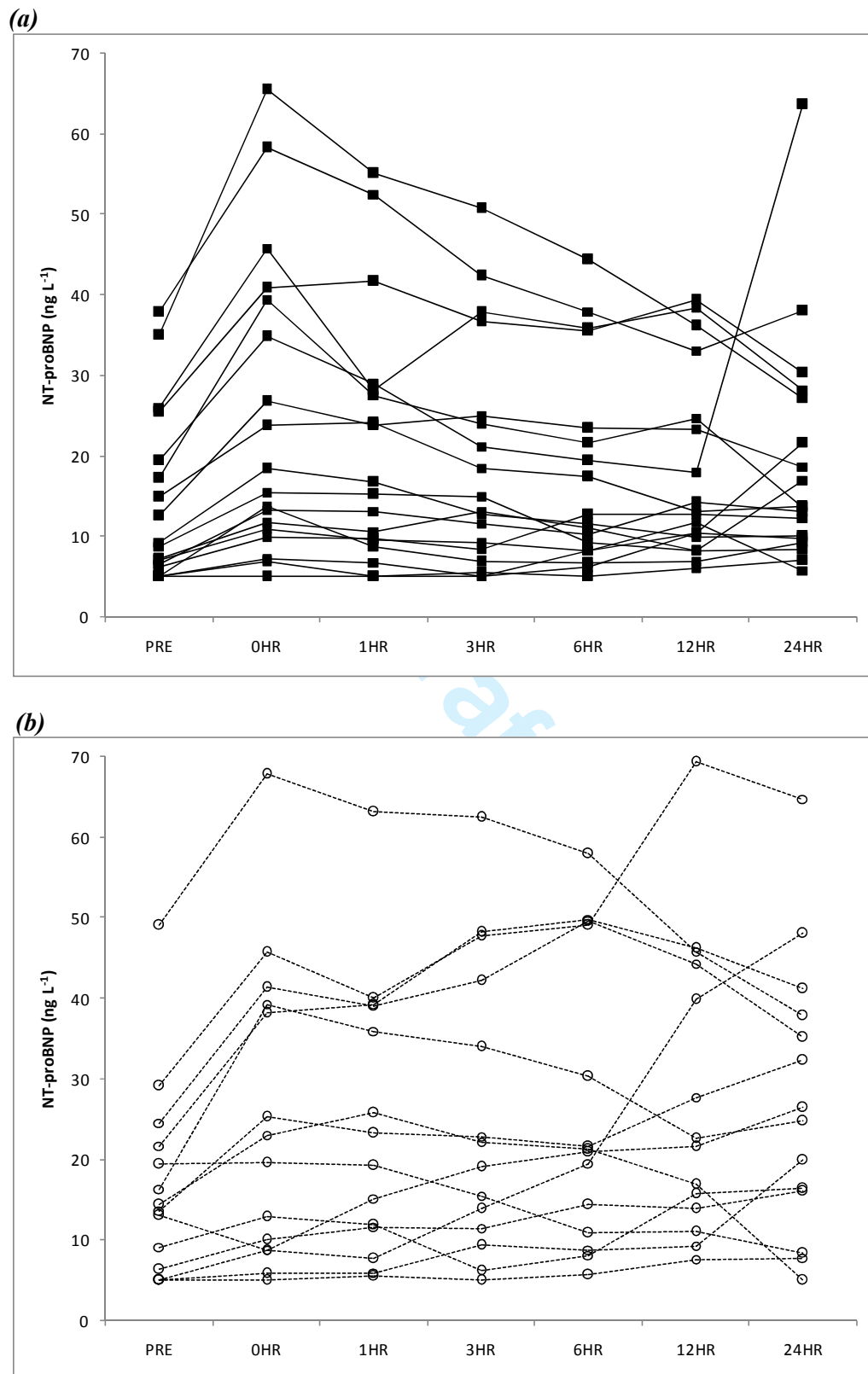
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cardiac biomarkers exceeding the URL.

Draft



Fig. 2



Draft