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**Effects of competition on acute phase proteins and lymphocyte subpopulations - oxidative stress markers in eventing horses**

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1 **Effects of competition on acute phase proteins, lymphocyte subpopulations, oxidative stress**  
2 **markers in eventing horses.**

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15 Running head: Acute phase response in exercising horses

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26 **Summary**

27 The aim of the study was to evaluate markers of the acute phase response (APR) in eventing horses  
28 by measuring acute phase proteins (APP) (haptoglobin, Hp, and serum amyloid A, SAA), lysozyme,  
29 protein adducts like pentosidine-like adducts (PENT), malondyaldeyde adducts (MDA),  
30 hydroxynonenal adducts (HNE) and total advanced glycation/glycoxidation end products (AGEs),  
31 complete blood count and lymphocyte subpopulations (CD4+, CD8+ and CD21+) both at rest and at  
32 the end of an eventing competition. Blood samples were collected from 8 Warmblood horses (medium  
33 age  $10 \pm 3$ ) during an official national two-day event competition at rest (R) and 10 minutes after  
34 arrival of the country-cross test on the second day. Exercise caused a significant increase in red blood  
35 cell number, haemoglobin, packed cell volume, neutrophils, white blood cell and lymphocyte number,  
36 however these values remained within the normal range. The CD4+ and CD8+ cells significantly  
37 increased, whereas the CD21+ lymphocytes decreased; a significant increase in serum SAA,  
38 lysozyme and protein carbonyl derivates was also observed. Two day event causes significant  
39 changes in APR markers such as lysozyme, protein carbonyl derivates (HNE, AGEs, PENT) and  
40 lymphocyte subpopulations. Data support the hypothesis that two-day event may alter significantly  
41 APR markers. Limitations of the study were the relatively small sample size and sampling time  
42 conditioned by the official regulations of the event. Therefore further studies are needed to investigate  
43 the time required for recovery to basal values in order to define the possible effects on the immune  
44 function of the athlete horse.

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46

47 **Keywords:** horse, acute phase response, lymphocyte subpopulations, protein carbonyl adducts

48

49 **Introduction**

50 The study of the extent and nature of the acute phase response (APR) to exercise of different intensity  
51 and duration is crucial to optimize horse performance and to preserve animal welfare. The APR is  
52 an immune-based reaction to several non-specific stimuli including exercise, characterized by  
53 oxidative stress and the release of acute phase proteins (APPs) (Scopetta et al., 2012; Fallon, 2001).  
54 Among different exercise where horses are involved, eventing, that represents a demanding discipline  
55 for horses, has received little attention within the scientific available literature. Nevertheless, the  
56 response elicited by this kind of physical stress could have important modulatory effects on  
57 immunocyte dynamics and possibly on immune function. These effects are mediated by different  
58 factors including exercise-induced release of pro-inflammatory cytokines, classical stress hormones  
59 and hemodynamic effects leading to cell redistribution (Pedersen and Hoffman-Goets, 2000).  
60 Particularly, during exercise adrenaline and glucocorticoids modulate the immune system. Immune  
61 cells support production of potent circulating inflammatory mediators, i.e. interleukin (IL)-6, IL-1  
62 and tumour necrosis factor (TNF)- $\alpha$  (Donovan et al., 2007; Holbrook et al., 2010).  
63 The response pattern of the APR could be species specific especially for APPs with the exception of  
64 serum albumin which decreases by 10–30% to several non specific stimuli in all mammalian species  
65 (Suffredini et al., 1999). In horses, serum amyloid A (SAA) is defined as the major APP and  
66 haptoglobin (Hp) as a moderate APP (Cywinska et al., 2012). Blood SAA concentrations markedly  
67 increase in 24 hours in response to infections and surgical trauma as well as to a long distance rides  
68 of 120-160 km (Cywinska et al., 2012; Hulten et al., 1999). Therefore exercise can act as stressor  
69 promoting an APR, however no data are available concerning the APP levels following two day event  
70 competition.  
71 Several reports describe exercise-induced changes in subsets of blood mononuclear cells (McCarthy  
72 and Dale, 1988; Pedersen and Hoffman-Goets, 2000; Pedersen and Nieman, 1998). Specific  
73 populations within the circulating leucocyte pool vary significantly with exercise and there is some  
74 evidence that in humans the CD4<sup>+</sup>/CD8<sup>+</sup> lymphocyte ratio may become significantly reduced (Keast

75 et al., 1988). According to Malinowski and coworkers (2006) a simulated race test causes changes in  
76 the CD4+:CD8+ ratio in Standardbred horses. Nevertheless, few data are available concerning the  
77 effects of exercise on lymphocyte subpopulations in horses.

78 A heavy acute exercise is also known to induce oxidative stress (OS) (Vider et al., 2001). In this  
79 condition a high concentration of free radicals can damage molecules such as proteins. Specifically,  
80 protein oxidative modification can be due to direct damage by reactive oxygen species or indirectly  
81 by reaction of secondary by-products of OS (Dalle et al., 2003a). In this case, for example, lipid  
82 peroxidation breakdown products such as hydroxynonenal (HNE) and malondialdehyde (MDA) or  
83 advanced glycation/glycooxidation end products (AGEs) such as pentosidine (PENT) (Valle et al.,  
84 2012) are able to link to protein aminoacid residues leading to the formation of protein carbonyl  
85 derivates (Dalle Donne et al., 2003; Traverso et al., 1998). These compounds may be used as measure  
86 of protein damage (Odetti et al., 1999) and markers of oxidative stress. In fact, they are stable adducts  
87 produced early and circulate in the blood for long periods (Dalle Donne et al., 2003 b). In human  
88 plasma and serum samples many of these adducts have been effectively quantified thanks to their  
89 fluorescent properties attributable to double bonds and ring structures in a number of moieties using  
90 fluorometry (Forbes et al., 2005). In humans there are some evidence demonstrating changes in AGEs  
91 following physical activity (Kotani et al., 2011); however, no data are available on sport horses.

92 On the basis of these premises, the aim of the study was to evaluate possible markers of the APR in  
93 eventing horses by measuring APPs (SAA, Hp), lysozime, protein adducts (HNE, MDA, AGEs,  
94 PENT), complete blood count (CBC) and lymphocyte subpopulations (CD4+, CD8+, CD21+) both  
95 at rest and at the end of a 2-day event competition.

96

## 97 **Materials and methods**

98 **Animals**

99           Eight experienced Warmblood horses (5 gelding, one stallion and 2 females), medium age 10  
100  $\pm 3$  (mean  $\pm$  standard deviation (s.d.)), mean body weight  $580\pm 41$  kg were included in the study. All  
101 horses were clinically healthy and had not received any medication during the last 15 days before the  
102 beginning of the study. The animals were kept in the same stable and fed with first cut meadow hay  
103 and commercial cereal-mix feed for sport horses (crude protein 12.5%, crude fat 5.2%, crude ash  
104 8.5%, crude fiber 8.5%, Vitamin E 200 UI/kg and Selenium 0.35 mg/kg) in a ratio forage:concentrate  
105 corresponding to 60:40. They were trained six times a week with a typical conditioning program for  
106 eventing horses: flat work (50 min/day, 3 days/wk.), flat work and jump (50 min/day, 2 days/wk.)  
107 and conditioning (warm up and gallop at 450-480 m/min for 5-8 minutes once a week).

108

#### 109 Competition feature

110           Data were collected during an official national two-day event competition organized by the  
111 Italian Equestrian Federation at Cameri sport club (Italy). The competition was held in May, the  
112 weather conditions remained relatively constant throughout the two days of competition  
113 (environmental temperature 19°C, relative humidity 66 %). The ground conditions made up of grass  
114 were similar for all horses, irrespective of starting order. On day 1, horses performed the dressage  
115 (marks given for medium walk, working-medium-extended trot, working canter, working-medium-  
116 collected canter, shoulder in at trot and rein back) and the show jumping phase (maximum fence 1.20  
117 m; speed 350 m/min). On day 2, animals performed the cross country test on a distance of 3100 m  
118 (maximum distance) (minimum speed 530 m/min and fence 1.10 m maximum height). All horses  
119 competed between 8:30 am and 11:30 am.

120

#### 121 Blood samples collection

122           Blood samples were collected by jugular venipuncture at rest (R), between 8:00 and 9:00 a.m.,  
123 in the original barn, before being moved to the competition site. Horses were moved the day before

124 the competition with a travel of about 50 minutes. A second blood sample was performed within 10  
125 minutes after the end (PC) of the cross country phase on day 2. This time frame was influenced by  
126 the official regulations of the competition. Samples for the determination of APPs and lysozyme were  
127 placed into 10 mL vacutainer tube contain clot activator, allowed to clot at room temperature,  
128 centrifuged at 2500 g for 10 minutes and aliquots of the obtained sera stored at -80°C until analysis.  
129 Blood for the determination of complete blood cell count (CBC), lymphocyte subpopulations was  
130 placed into a 10 mL EDTA vacutainer tube, refrigerated and immediately transferred to the laboratory  
131 for analysis. For protein adducts plasma aliquots were obtained by centrifugation (2500 g for 10  
132 minutes at 4°C) immediately after collection and then stored at -80° C until analysis.

133

#### 134 Complete blood count

135 Complete blood count was performed by using an automated laser cell counter hematology  
136 System (Advia 120, Siemens Diagnostics Inc., Tarrytown, USA) to assess the following parameters:  
137 white blood cell count (WBC,  $10^3/\mu\text{L}$ ), neutrophils (NEUT,  $10^3/\mu\text{L}$ ), lymphocytes (LYM,  $10^3/\mu\text{L}$ ),  
138 red blood cells (RBC,  $10^6/\mu\text{L}$ ), hemoglobin (Hb, g/dL), packed cell volumes (PCV, %), platelets (PLT  
139  $10^3/\mu\text{L}$ ).

140

#### 141 Lymphocyte subpopulations

142 Lymphocyte subpopulations were characterized by flow cytometry using monoclonal  
143 antibodies against the following antigens: CD21+ (CA2.1D6, Serotec, B cells, Serotec, Kidlington,  
144 UK), CD4+ (CVS4, Serotec, T-helper, Serotec, Kidlington, UK), CD8+ (CVS8, Serotec, T-  
145 cytotoxic/suppressor, Serotec, Kidlington, UK). For surface staining, 100  $\mu\text{L}$  of whole blood were  
146 incubated with monoclonal antibodies at the appropriate dilution for 30 min at 4 °C. After two washes  
147 with phosphate-buffered saline (PBS), cells were incubated with 10  $\mu\text{L}$  of 1:5 diluted fluorescein  
148 isothiocyanate (FITC)-labeled goat anti mouse immunoglobulin F (ab') 2 fragment (SouthernBiotech,



149 Birmingham, USA) for 30 min at 4 °C. Negative controls consisted of cells incubated with  
150 fluoresceinated goat anti mouse antibody alone. Two milliliters of lysing solution (ammonium  
151 chloride) were added and left for 20 min at room temperature. Cells were then washed twice and  
152 resuspended in 0.5 mL of PBS.

153 A minimum of 10000 events from a gated lymphocyte population was acquired and analyzed on a  
154 Epics XL-MCL flow cytometer (Coulter, cCoulter® Epics® XL-MCL™ Miami, USA), thus  
155 obtaining percentages of the different subpopulations. Absolute lymphocyte subset counts were  
156 calculated as the product of the lymphocyte absolute count and the lymphocyte subset percentage.

157

158 Protein carbonyl adducts

159 Delipidated plasma samples were analyzed for fluorescence modification with  
160 spectrophotofluorometer at wave-length of 370-nm excitation (EX)/440-nm emission (EM) for total  
161 AGE adducts (AGEs), 335-nm EX/385-nm EM for pentosidine-like adducts (PENT), 390-nm  
162 EX/460-nm EM for malondyaldeyde adducts (MDA), 356-nm EX/460-nm EM for hydroxynonenal  
163 adducts (HNE) and 280EX/390-nm EM for triptophane (Trip).

164 Control of the absorbance of the protein solution was performed in order to rule out any possible  
165 interference with the evaluation of fluorescence: the absorbance of the protein solution at the  
166 wavelengths used for fluorescence excitation never exceeded 0.1; therefore absorbance should not  
167 have been significant as possible interference on the evaluation of fluorescence. Fluorescence  
168 intensity was expressed in arbitrary units (AU) of fluorescence per g of total proteins.

169

170 Acute phase proteins and lysozyme

171 Serum SAA and Hp concentrations were measured using a commercial assay kits (Phase, Tridelta  
172 Ltd. Ireland). Serum lysozyme was assessed by the lyso-plate assay method according to Osserman  
173 and Lawlor (1966); briefly, serum samples were reacted with a suspension of *Micrococcus*

174 *lysodeikticus* in agar gel in 10-cm Petri dishes. Under these conditions, lysozyme concentration  
175 ( $\mu\text{g}/\text{mL}$ ) is proportional to the diameter of lysis areas and is determined from a standard curve created  
176 with a standard lysozyme preparation (Sigma-Aldrich SRL, Milano).

177

178 Protein content determination

179 Plasma protein content was determined using the BCA protein assay kit according to the  
180 manufacturer's instructions (Pierce, BCA Protein Assay).

181

182 Statistical analysis

183 Statistical analyses were performed with SPSS software package (SPSS, Chicago, Illinois, USA).

184 After checking the normality, a paired sample t-test was used to compare the values for lymphocyte

185 subpopulation data, protein carbonyl adducts data, acute phase proteins and lysozyme and complete

186 blood count data at rest and after exercise. Statistical significance was set at  $p \leq 0.05$ . All measurements

187 were performed in triplicate and data are expressed as mean  $\pm$  SD

188

## 189 **Results**

190 Complete blood cell count

191 Exercise caused a significant increase in red blood cell number, haemoglobin concentration, packed

192 cell volume percentage, neutrophils, white blood cells numbers, and lymphocytes and a decrease in

193 platelet number (Table 1). However all the values were in the reference range values according to

194 the Laboratory of the Department of Veterinary Sciences, University of Turin

195

196 Lymphocyte subpopulation

197 The absolute number of CD4+ cells was significantly higher after exercise ( $1650 \pm 110 \cdot 10^3 \text{ cell}/\mu\text{L}$ ,

198  $p = 0.01$ ) compared to basal values ( $1260 \pm 80 \cdot 10^3 \text{ cell}/\mu\text{L}$ ), while the relative percentage with respect

199 to the total lymphocyte population was decreased ( $54.51 \pm 6.05$  % vs  $60.73 \pm 5.50$  %,  $p = 0.002$ )  
200 (Fig 1a-1d). Similar results were obtained also for the CD8<sup>+</sup> cell subpopulation ( $300 \pm 30$  10<sup>3</sup> cell/ $\mu$ L,  
201 R, vs  $620 \pm 90$  10<sup>3</sup> cell/ $\mu$ L, PC,  $p = 0.007$ ) (Fig 1b). However, the relative percentage was increased  
202 after competition ( $20.66 \pm 7.90$  % vs  $13.71 \pm 2.28$  %,  $p=0.02$ ) (Fig 1d). The CD4<sup>+</sup>:CD8<sup>+</sup> ratio was  
203 significantly ( $p = 0.047$ ) decreased at the end of the event compared to its value at rest ( $3.03 \pm 0.6$  vs  
204  $4.62 \pm 0.4$ ,  $p = 0.047$ ). From rest to after the event, the CD21<sup>+</sup> subpopulation significantly decreased  
205 ( $270 \pm 30$  10<sup>3</sup> cell/ $\mu$ L, R, vs.  $160 \pm 20$  10<sup>3</sup> cell/ $\mu$ L, PC,  $p = 0.01$ , Figure 1c) and represented a smaller  
206 portion of lymphocytes in percentage ( $12.80 \pm 4.27$  % vs.  $5.25 \pm 1.49$  %,  $p = 0.002$ ; Figure 1d).

207

#### 208 Acute phase proteins and lysozyme

209 After exercise, a significant increase in serum SAA ( $1.96 \pm 0.55$   $\mu$ g/mL, R, vs  $3.91 \pm 0.73$   $\mu$ g/mL,  
210 PC;  $p = 0.001$ ) and lysozyme ( $3.35 \pm 0.85$   $\mu$ g/mL vs  $4.52 \pm 1.57$   $\mu$ g/mL;  $p = 0.05$ ) was observed.  
211 No significant changes of HP concentration was observed ( $0.91 \pm 0.42$  mg/mL vs.  $1.29 \pm 0.55$  mg/mL;  
212  $p = 0.169$ )

213

#### 214 Protein carbonyl adducts

215 Exercise caused a significant ( $p < 0.05$ ) increase of blood concentration in total AGE adducts,  
216 pentosidine-like adducts, hydroxynonenal adducts and tryptophan. For MDA adducts, besides a trend  
217 suggesting an increase at the end of competition, no significant differences were observed ( $p = 0.058$ )  
218 (Fig 2).

219

## 220 4. Discussion

221 To our knowledge, this is the first study investigating the effects of exercise on acute phase response  
222 in eventing horses. The modifications observed in complete blood cell count may be considered as  
223 typical expected exercise-induced responses in performance horse (Jumping Endurance and

224 Standardbred horses) (Cuniberti et al., 2012). White blood cells and neutrophils increase during and  
225 after exercise, whereas lymphocyte concentrations increase during acute exercise and fall below basal  
226 values after long-duration physical exercise (Pedersen and Hoffman-Goets, 2000). In our study, both  
227 neutrophil and lymphocyte number increase after exercise. However, according to Malinowski et al.,  
228 (2006) in the horse the magnitude of lymphocyte number modifications due to exercise depends on  
229 age and training. The increase in the total number of red blood cells, packed cell volume and  
230 haemoglobin concentration can be ascribed both to spleen contraction regulated by catecholamine  
231 and to sweating that causes fluids loss (Cuniberti et al., 2012).

232 In our in-field study, for practical reasons, we did not measure horse body weight at the end of  
233 competition, therefore we did not estimate the possible dehydration percentage. However, protein  
234 concentration before and at the end of competition, that could reflect dehydration and fluid loss (Rose  
235 and Hodgson, 2005) is not significant and minimal ( $5.75\pm 0.38$  vs  $6.14 \pm 0.45$ ). For this reason we can  
236 assume that the effect of dehydration is negligible and the variation of the observed parameters is not  
237 masked by this effect. This is also confirmed by the fact that the lymphocyte undergo to a real  
238 redistribution. In fact interestingly, we found a significant increase in the number of CD4+ and CD8+  
239 cells after exercise. It has been postulated that the activation of the sympathetic system and the  
240 increased levels of circulating catecholamines during exercise leads to increased lymphocyte  
241 concentration due to the recruitment of lymphocyte subpopulations to the vascular compartment  
242 (Gannon et al., 2001). Although the number of lymphocyte subpopulation increases, the percentage  
243 of CD4+ decreases probably due to the fact that NK cells increase more than other lymphocyte  
244 subpopulations such as the helper CD4+ (Fry et al., 1992). As a consequence, in our study the  
245 CD4+:CD8+ ratio significantly decreased in response to exercise. This finding agrees with the results  
246 obtained by Malinowski and coll., (2006) where the acute response to exercise influence the percent  
247 CD4+ and CD8+ both in unfit and trained Standardbred mares.

248 As far as CD21+ lymphocytes are concerned, in our study a significant exercise-induced reduction  
249 was observed. In humans several reports have documented either increased or unchanged B  
250 lymphocyte numbers after exercise (Tvede et al., 1989; Pedersen and Hoffman-Goets, 2000). No data  
251 concerning CD21+ lymphocyte modifications related to exercise in horses are available in literature.  
252 According to Stull and coll. (2008), in horses long-distance road transport induces a decline in CD21+  
253 lymphocyte subpopulation. Both during transport and exercise the redistribution of lymphocyte  
254 subpopulations may represent a cortisol-mediated stress response.

255 According to our results, eventing causes a significant increase in SAA and lysozyme levels. It has  
256 been shown that during the acute phase response, SAA increases within 4 hours reaching the  
257 maximum serum levels 24-48 hours after the initiating stimulus (Petersen et al., 2004). Although the  
258 precise biological function of increased SAA expression has not been fully elucidated, it has been  
259 suggested that SAA is involved in chemotaxis of leucocytes and T cells, inhibition of platelet  
260 activation, and induction of calcium mobilization by monocytes (Zimlichman et al., 1990; Badolato  
261 et al., 1995). A 10-fold increased in circulating SAA concentrations has been observed in horses after  
262 long-distance ride (Cywinska et al., 2012). In our study, at the end of competition a 2-fold increase  
263 in SAA concentrations was found compared to pre-race values. It should be considered that in humans  
264 and horses individual variations in SAA levels have been described (Hulten et al., 1999, 32).  
265 Moreover, while the effects of endurance exercise on APPs have been extensively documented and  
266 the hypothesis that strenuous exercise is analogous to the APR elicited by tissue injury has been  
267 confirmed, no data concerning eventing horses are available. In humans, for example, an acute phase  
268 response does not seem to occur in a variety of field and court sports, whereas in ultramarathon  
269 runners acute phase reactants are significantly affected by exercise (Fallon, 2001, Fallon et al., 2001).  
270 Therefore, our results confirm that SAA is the most sensitive APP in horses although eventing seems  
271 to elicit a mild response compared with long-distance endurance races.

272 Studies of the exercise/stress influence on lysozyme concentrations in horses are scarce. According  
273 to Sotirov and coworkers (2004) exercise has no negative effects on equine innate immune factors.  
274 In our study a significant increase of circulating lysozyme was found at the end of competition  
275 (Sotirov et al., 2004). It has been demonstrated that increased levels of glucocorticoids and  
276 catecholamines during exercise stimulate the secretion of different neutrophil granule proteins such  
277 as lysozyme in blood (Morozow et al., 2003). In swimming rats and treadmill runner athletes the  
278 plasma lysozyme content is increased by 41% following intensive exercise load. In humans, several  
279 studies have documented the effects of exercise on salivary lysozyme concentration (Papacosta and  
280 Nassis 2011). It has been suggested that the lysozyme response to exercise depends on exercise  
281 intensity with a significant increase following acute bouts of intense exercise and no changes at lower  
282 workload (West et al., 2010).

283 The main biological functions of Hp are represented by binding hemoglobin and preventing iron loss,  
284 bacteriostatic and immunomodulatory effects and regulation of lipid metabolism (Murata et al.,  
285 1993). In horses fluctuations in blood Hp concentrations have been observed in case of natural  
286 diseases, experimental-induced inflammation and after surgery (Pollock et al., 2005). In unhealthy  
287 horses the circulating Hp levels increase slowly after surgery and they are still elevated by 72 hours  
288 after the initial stimulus (Pollock et al., 2005). Controversial data have been published on Hp levels  
289 in horse after physical exercise (Pellegrini Masini et al., 2003; Fazio et al., 2010). According to Fazio  
290 and coworkers (2010), serum Hp concentrations significantly increase during a typical thoroughbreds  
291 training. By contrast, in endurance horses neither limited nor long distance rides seem to significantly  
292 affect peripheral Hp concentrations (Cywinska et al., 2012). In another study, Scoppetta et al., (2012)  
293 found that Hp is highly reduced immediately after the race. The decreased Hp levels may be related  
294 to its binding with hemoglobin released into circulation following exercise-induced haemolysis.  
295 Haptoglobin levels in our study are in line with those measured by Cywinska and coworkers  
296 (Cywinska et al., 2012) and do not seem to be significantly affected by eventing exercise.

297 Even though horses can be considered as excellent models for studying reactive species production  
298 due to their high aerobic capacity, data on exercise-induced oxidative stress in horses are  
299 heterogeneous and mainly concern racehorses. In the present research an increase in the fluorescence  
300 related to lipoxidation (HNE adducts) and glycoxidation adducts (total AGE and PENT) was  
301 observed. Exercise-induced protein carbonylation, has previously been described both in  
302 Thoroughbred (Duberstein et al., 2009) and Standardbred horses (Kinnunen et al., 2005). Kinnunen  
303 and coworkers 2005 showed that an increased concentration of plasma and muscle protein carbonyls  
304 can be detected after a single session of moderate intensity exercise. The increased protein carbonyl  
305 derivatives levels are detectable immediately after exercise and are still elevated after 4 h of recovery,  
306 returning to pre-exercise values within 24 h of recovery. MDA adducts in our study tended to increase  
307 after exercise, although the modification was not statistically significant. We therefore hypothesize  
308 that lipid peroxidation plays a minor role in protein damage and/or that the generation of protein  
309 carbonyl derivatives from this pathways occurs later. The increase in tryptophan fluorescence observed  
310 at the end of competition could be ascribed to the alteration in protein organization which leads the  
311 exposition of tryptophan residues due to the bound of the aldehyde in other positions in the protein  
312 (Traverso et al. 2004). Our results suggest that competition causes increased protein carbonyl  
313 derivatives that may predispose eventing horses to tissue damage and inflammation. However, the life  
314 span of the stress response in terms of oxidation end products should be further investigated to  
315 estimate the quantity of dietary antioxidants required by horses especially during the competition  
316 season.

317

## 318 **5. Conclusions**

319 Our data support the hypothesis that two-day event may alter significantly APR markers such as acute  
320 phase proteins, lysozyme, protein carbonyl derivatives, complete blood count and lymphocyte  
321 subpopulations. These preliminary findings were obtained during an official competition on a

322 restricted number of horses and the variation of parameters studied could be influenced by sampling  
323 time, that was conditioned by the official regulations of the event. Further studies are needed to  
324 investigate the time required for recovery to basal values in order to define the possible effects on the  
325 immune function of the athlete horse.

326

### 327 **Conflict of interest statement**

328 All authors declare they have no financial or commercial conflicts of interest.

329

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335

### 336 **References**

337 Badolato, R.; Johnston, J.A.; Wang, J.M.; McVicar, D.; Xu, L.L.; Oppenheim, J.J.; Kelvin, D.J.,  
338 1995: Serum amyloid A induces calcium mobilization and chemotaxis of human monocytes  
339 by activating a pertussis toxin-sensitive signaling pathway. *The Journal of Immunology* **15**,  
340 4004-4010.

341 Cuniberti, B.; Badino, P.; Odore, R.; Girardi, C.; Re, G., 2012: Effects induced by exercise on  
342 lymphocyte  $\beta$ -adrenergic receptors and plasma catecholamine levels in performance horses.  
343 *Research in Veterinary Science* **92**, 116-120.

344 Cywinska, A.; Szarska, E.; Gorecka, R.; Witkowski, L.; Hecold, M.; Bereznowski, A.;  
345 Schollenberger, A.; Winnicka, A.: 2012: Acute phase protein concentrations after limited



346 distance and long distance endurance rides in horses. *Research in Veterinary Science* **93**,  
347 1402-1406.

348 Cywinska, A.; Wyszynska, Z.; Gorecka, R.; Szarska, E.; Witkowski, L.; Dziekan, P.; Winnicka, A.;  
349 Schollenberger, A., 2010: The effect of the 162 km endurance ride on equine peripheral blood  
350 neutrophil and lymphocyte functions. *Polish Journal of Veterinary Sciences* **13**, 279-285.

351 Dalle, I.; Rossi, R.; Giustarini, D.; Milzani, A.; Colombo, R., 2003: Protein carbonyl groups as  
352 biomarkers of oxidative stress. *Clinica Chimica Acta* **329**, 23-38.

353 Dalle-Donne I.; Giustarini, D.; Colombo, R.; Rossi, R.; Milzani, A., 2003: Protein carbonylation in  
354 human diseases. *Trends in Molecular Medicine* **9**, 169-176.

355 Donovan, M.J.; Jayakumar, A.; McDowell, M.A., 2007: Inhibition of groups 1 and 2 CD1 molecules  
356 on human dendritic cells by Leishmania species. *Parasite Immunology* **29**, 515-524.

357 Duberstein, K. J.; Johnson, S. E.; McDowell, L.R.; Ott E.A., 2009: Protein carbonyl assay to measure  
358 oxidative stress in muscle of exercising horses supplemented with vitamin E. *Equine and*  
359 *Comparative Exercise Physiology* **61**, 1-5.

360 Fallon, K.E., 2001: The acute phase response and exercise: the ultramarathon as prototype exercise.  
361 *Clinical Journal of Sport Medicine* **11**, 38-43.

362 Fallon, K.E.; Fallon, S.K.; Boston, T., 2001: The acute phase response and exercise: court and field  
363 sports. *British Journal of Sports Medicine* **35**, 170-173.

364 Fazio, F.; Assenza, A.; Tosto, F.; Casella, S.; Piccione, G.; Caola, G., 2010: Modifications of some  
365 acute phase proteins and the white blood cell count in thoroughbreds during training.  
366 *Veterinary Record* **4**, 370-373.

367 Forbes, J.M.; Soldatos G.; Thomas M.C.; 2005: Below the radar: advanced glycation end products  
368 that detour "around the side". Is HbA1c not an accurate enough predictor of long term  
369 progression and glycaemic control in diabetes? *The Clinical Biochemist Review* **26**, 123-134.

370 Fry, R.W.; Morton, A.R.; Crawford, G.P. ; Keast, D., 1992: Cell numbers and in vitro responses of  
371 leucocytes and lymphocyte subpopulations following maximal exercise and interval training  
372 sessions of different intensities. *European Journal of Applied Physiology* **64**, 218-227.

373 Gannon, G.A.; Rhind, S.G.; Shek, P.N. ; Shephard, R.J., 2001: Differential cell adhesion molecule  
374 expression and lymphocyte mobilisation during prolonged aerobic exercise. *European*  
375 *Journal of Applied Physiology* **84**, 272-282.

376 Rose, R.J.; Hodgson D. R., 2005: Manuale di clinica del cavallo. Delfino Antonio Editore, Italy.

377 Holbrook T.C.; McFarlane D.; H.C. Schott I. 2010: Neuroendocrine and non-neuroendocrine markers  
378 of inflammation associated with performance in endurance horses. *Equine Veterinary Journal*  
379 **42**, 123–128.

380 Hulten, C.; Sandgren, B.; Skioldebrand, E.; Klingeborn, B.; Marhaug, G.; Forsberg, M., 1999: The  
381 acute phase protein serum amyloid A (SAA) as an inflammatory marker in equine influenza  
382 virus infection. *Acta Veterinaria Scandinavica* **40**, 323-333.

383 Keast, D.; Cameron, K. ; Morton, A.R., 1988: Exercise and the immune response. *Sports Medicine*  
384 **5**, 248-267.

385 Kinnunen, S.; Hyyppa, S., Lehmuskero, A.; Oksala, N.; Maenpaa, P.; Hanninen, O.; Atalay, M., 2005:  
386 Oxygen radical absorbance capacity (ORAC) and exercise induced oxidative stress in trotters.  
387 *European Journal of Applied Physiology* **95**, 550-556.

388 Kotani, K.; Caccavello, R.; Sakane, N.; Yamada, T.; Taniguchi, N.; Gugliucci, A., 2011: Influence  
389 of physical activity intervention on circulating soluble receptor for advanced glycation end  
390 products in elderly subjects. *Journal of Clinical Medicine Research* **3**, 252-257.

391 Malinowski, K.; Shock, E.J.; Rochelle, P.; Kearns, C.F.; Guirnalda, P.D.; McKeever, K.H., 2006:  
392 Plasma beta-endorphin, cortisol and immune responses to acute exercise are altered by age  
393 and exercise training in horses. *Equine Veterinary Journal supplement* **36**, 267-273.

394 McCarthy, D.A.; Dale, M.M., 1988: The leucocytosis of exercise. A review and model. *Sports*  
395 *Medicine* 6, 333-363.

396 Morozov, V.I.; Pryatkin, S.A.; Kalinski, M.I.; Rogozkin, V.A., 2003: Effect of exercise to exhaustion  
397 on myeloperoxidase and lysozyme release from blood neutrophils. *European Journal of*  
398 *Applied Physiology* **89**, 257-262.

399 Murata, H.; Miyamoto, T., 1993: Bovine haptoglobin as a possible immunomodulator in the sera of  
400 transported calves. *British Veterinary Journal* **149**, 277-283.

401 Odetti, P.; Garibaldi, S.; Noberasco, G.; Aragno, I.; Valentini, S.; Traverso, N.; Marinari, U.M., 1999.  
402 Levels of carbonyl groups in plasma proteins of type 2 diabetes mellitus subjects. *Acta*  
403 *Diabetologica* **36**, 179-183.

404 Osserman, E.F.; Lawlor, D.P., 1966: Serum and urinary lysozyme (muramidase) in monocytic and  
405 monomyelocytic leukemia. *The Journal of Experimental Medicine* **124**, 921-952.

406 Papacosta, E.; Nassis, G.P., 2011. Saliva as a tool for monitoring steroid, peptide and immune markers  
407 in sport and exercise science. *The Journal of Experimental Medicine* **14**, 424-434.

408 Pedersen, B.K.; Nieman, D.C., 1998: Exercise immunology: integration and regulation. *Immunology*  
409 *Today* **19**, 204-206.

410 Pedersen, B.K.; Hoffman-Goetz, L., 2000: Exercise and the immune system: regulation, integration,  
411 and adaptation. *Physiological Reviews* **80**, 1055-1081.

412 Pellegrini Masini, A.; Tedeschi, D.; Baragli P.; Sighieri C.; Lubas G., 2003: Exercise-induced  
413 intravascular haemolysis in standardbred horses. *Comparative Clinical Pathology* **12**, 45-48.

414 Petersen, H.H.; Nielsen, J.P.; Heegaard, P.M.; 2004: Application of acute phase protein  
415 measurements in veterinary clinical chemistry. *Veterinary Research* **35**, 163-187.

416 Pollock, P.J.; Prendergast, M.; Schumacher J.; Bellenger C.R.; 2005: Effects of surgery on the acute  
417 phase response in clinically normal and diseased horses. *Veterinary Record* **23**, 538-42.

418 Scoppetta, F.; Tartaglia, M.; Renzone, G.; Avellini, L.; Gaiti, A.; Scaloni, A.; Chiaradia, E., 2012:  
419 Plasma protein changes in horse after prolonged physical exercise: a proteomic study. *Journal*  
420 *of Proteomics* **75**, 4494-4504.

421 Sotirov L.; Goundasheva D.; Dzhelebov P., 2004: Lysozyme and complement response to exercise  
422 in horses with booster vaccination against influenza virus and equine herpes virus 4/1 L.  
423 *Revue de Médecine Vétérinaire* **155**, 449-452.

424 Stewart, I.B.; McKenzie, D.C., 2002: The human spleen during physiological stress. *Sports Medicine*  
425 **32**, 361-369.

426 Stull, C.L.; Morrow, J.; Aldridge, B.A.; Stott, J.L.; McGlone, J.J., 2008: Immunophysiological  
427 responses of horses to a 12-hour rest during 24 hours of road transport. *Veterinary Record*  
428 **162**, 609-614.

429 Suffredini, A.F.; Fantuzzi, G.; Badolato, R.; Oppenheim, J.J.; O'Grady, N.P., 1999: New insights into  
430 the biology of the acute phase response. *Journal of Clinical Immunology* **19**, 203-214.

431 Traverso, N.; Menini, S.; Cosso, L.; Odetti, P.; Albano, E.; Pronzato, M.A.; Marinari, U.M., 1998:  
432 Immunological evidence for increased oxidative stress in diabetic rats. *Diabetologia* **41**, 265-  
433 270.

434 Traverso, N.; Menini, S.; Maineri, E.P.; Patriarca, S.; Odetti, P.; Cottalasso, D.; Marinari, U.M. ,  
435 Pronzato, M.A., 2004: Malondialdehyde, a lipoperoxidation-derived aldehyde, can bring  
436 about secondary oxidative damage to proteins. *The Journals of Gerontology Series A:*  
437 *Biological Sciences and Medical Sciences* **59**, 890-895.

438 Tvede, N., Heilmann, C., Halkjaer-Kristensen, J. , Pedersen, B.K., 1989: Mechanisms of B-  
439 lymphocyte suppression induced by acute physical exercise. *Journal of Clinical & Laboratory*  
440 *Immunology* **30**, 169-173.

441 Valle, E., Storace, D., Sanguineti, R., Carter, R., Odetti, P., Geor, R.; Bergero, D., 2012: Association  
 442 of the glycoxidative stress marker pentosidine with equine laminitis. *The Veterinary Journal*  
 443 doi: 10.1016/j.tvjl.2012.10.030

444 Vider, J.; Lehtmaa, J.; Kullisaar, T.; Vihalemm, T.; Zilmer, K.; Kairane, C.; Landor, A.; Karu, T.;  
 445 Zilmer, M., 2001: Acute immune response in respect to exercise-induced oxidative stress.  
 446 *Pathophysiology* **7**, 263-270.

447 West, N.P.; Pyne, D.B.; Kyd, J.M.; Renshaw, G.M.; Fricker, P.A.; Cripps, A.W., 2010: The effect of  
 448 exercise on innate mucosal immunity. *British Journal of Sports Medicine* **44**, 227-231.

449 ZimLichman, S.; Danon, A.; Nathan, I.; Mozes, G.; Shainkin-Kestenbaum, R., 1990: Serum amyloid  
 450 A, an acute phase protein, inhibits platelet activation. *Journal of Laboratory and Clinical*  
 451 *Medicine* **116**, 180-186.

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461 **Table 1**  
 462 Complete blood cell count in eventing horses at rest and after competition

	Rest	After competition	p*	Reference values* <sup>1</sup>
WBC (x10 <sup>3</sup> cell/μL)	5.76 ± 0.74	7.74 ± 0.74	0.002	4.30-14.80
Neutrophils (x10 <sup>3</sup> cell/μL)	3.21 ± 0.52	4.30 ± 1.02	0.005	2.20-8.10

Lymphocytes (x10 <sup>3</sup> cell/ $\mu$ L)	2.12 $\pm$ 0.38	3.02 $\pm$ 0.52	0.002	1.70-5.80
RBC (x10 <sup>6</sup> cell/ $\mu$ L)	8.05 $\pm$ 0.76	10.01 $\pm$ 0.77	0.003	4.45-12.0
Hemoglobin (g/dL)	13.88 $\pm$ 1.08	17.56 $\pm$ 1.54	0.002	11.30-18.90
PCV %	34.94 $\pm$ 2.77	45.24 $\pm$ 4.93	0.003	31.10-50.50
Platelets (x10 <sup>3</sup> cell/ $\mu$ L)	131.75 $\pm$ 23.63	89.25 $\pm$ 36.63	0.003	69.90-250.80

463

464 Results are mean values  $\pm$  sd. WBC, white blood cell count; lymphocytes; RBC, red blood cells;

465 PCV, Packed Cell Volume;

466 \*Statistical analysis performed by paired sample *t* test.

467 \*<sup>1</sup> Reference range values according to the Laboratory of the Department of Veterinary Sciences,

468 University of Turin

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470

471 **Fig. 1**

472 a) Number of CD4+ cells at rest (R, dot filled bar) and after competition (PC, line filled bar) (\**p*

473  $\leq$  0.05)

474 b) Number of CD8+ cells at rest (R) and after competition (PC) (\**p*  $\leq$  0.05)

475 c) Number of CD21+ cells at rest (R) and after competition (PC) (\**p*  $\leq$  0.05)

476 d) Lymphocyte subpopulation percentage at rest (R) and after competition (PC) (\**p*  $\leq$  0.05)

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478

479 **Fig 2**

480 Mean  $\pm$  SEM values for protein carbonyl adducts (AGEs, total AGE adducts; PENT, pentosidine-like

481 adducts; MDA, malondyaldeyde adducts; HNE, hydroxynonenal adducts; Trip, triptophane)

482 before (R, dot filled bar) and after competition (PC, line filled bar) (\**p*  $\leq$  0.05)

483