Comparison between specific and nonspecific tests for evaluating the physical fitness of show jumping horses

Article *in* Comparative Exercise Physiology · September 2016

DOI: 10.3920/CEP160018

CITATION
1

READS
50

8 authors, including:

Otavio Augusto Brioschi Soares
Exército Brasileiro
22 PUBLICATIONS **43** CITATIONS
SEE PROFILE

Guilherme C Ferraz
São Paulo State University
71 PUBLICATIONS **167** CITATIONS
SEE PROFILE

Fernando Queiroz de Almeida
Federal Rural University of Rio de Janeiro
115 PUBLICATIONS **249** CITATIONS
SEE PROFILE

Wageningen Academic Publishers

Comparison between specific and nonspecific tests for evaluating the physical fitness of show jumping horses

O.A.B. Soares[1,2*], G.C. Ferraz[1], P. Trigo[3], F.H.F. D'Angelis[1], W.H. Feringer Júnior[1], K.B. Nardi[1], F.Q. Almeida[4] and A. Queiroz Neto[1]

[1]Department of Morphology and Physiology, College of Agricultural and Veterinary Sciences, São Paulo State University, Jaboticabal Campus, Via de Acesso Professor Paulo Donato Castellane s/n, 14884-900 Jaboticabal, SP, Brazil; [2]Veterinary Hospital, Agulhas Negras Military Academy, Brazilian Army, Rod. Presidente Dutra, Km. 306, 27534-970 Resende, RJ, Brazil; [3]La Plata National University, Av 7 877, La Plata, 1900 Buenos Aires, Argentina; [4]Veterinary Institute, Federal Rural University of Rio de Janeiro, Rodovia BR 465, Km 07 s/n, Zona Rural, 23890-000 Seropédica, RJ, Brazil; capvetaugusto@gmail.com

Received: 8 April 2016 / Accepted: 28 August 2016

RESEARCH ARTICLE

Abstract

Show jumping is a century-old Olympic sport performed worldwide. However, despite the prominence of this sport, there is currently no satisfactory evaluation of the physical fitness of its horses. Our study compared two standardised exercise tests (specific and nonspecific for show jumpers) to determine the importance of a show jumping specific evaluation test. Sixteen horses were divided into two performance groups (high and low performance), and all horses performed standardised exercise tests without jumps (SET1) and with jumps (SET2). Heart rate, blood lactate, glucose, blood gas, haematological parameters, and plasma ions were measured before and after the tests, and performance indices were calculated. Both exercise tests (SET1 and SET2) resulted in changes in nearly all measured variables that were expected, based on other studies, for the duration and nature of the exercise performed. Differences between the two performance groups were observed for lactate and glucose, as well as some blood gas variables and performance indicators. These differences might have been the result of better cardiovascular and metabolic adaptation of the high performance group to the show jumping exercises. For the SET1, differences between groups were mainly noted for variables related to aerobic capacity, which suggests that this measurement is important for the evaluation of equine performance in show jumping. The SET2 was capable of detecting different horse performance levels that could not be detected by the SET1, which indicates that a specific test for show jumping (that includes jumping movements) could provide important information for the evaluation of show jumpers. Based on our findings, we recommend that the SET2 be included in future protocols for evaluating jumping horses.

Keywords: sports evaluation, equine performance, horse riding

1. Introduction

Several studies have focused on the physiology of athletic horses, with reference values for horses competing, training, or being tested for various sports, including: racing (Vermeulen and Evans, 2006), trotters (Fortier *et al.*, 2015), polo (Ferraz *et al.*, 2010), endurance riding (Fraipont *et al.*, 2012,) and western sports (Casella *et al.*, 2015). However, for the jumping discipline, although it has been an Olympic sport for over a hundred years, there are only a few physiology studies of these athletes (Art *et al.*, 1990; Bitschnau *et al.*, 2010; Munsters *et al.*, 2015; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2006).

Physiological evaluation of equine performance is usually conducted by submitting athletes to a standardised exercise test (SET); few studies have been conducted with tests specifically designed for jumping horses (Munk *et al.*, 2013; Piccione *et al.*, 2007; Soares *et al.*, 2013; Sommer *et al.*, 2015; Sotero *et al.*, 2014). In human exercise, it is well established that the performance evaluation of individuals should include tests that consider the specificity of motor activity and demands on regulators and body organs responsible for

ISSN 1755-2540 print, ISSN 1755-2559 online, DOI 10.3920/CEP160018

the sport gesture of the discipline in question (Bitschnau *et al.,* 2010; Platonov, 2004). Methodologies and parameters need to be standardisation in order to be able to compare results, and a test for show jumpers should account for the fact that there is an important anaerobic component, but that it is not a maximal effort exercise (Munsters *et al.*, 2015).

There are many physiological variables and indices used for the evaluation of horses, in show jumping and other sports, such as heart rate (HR), blood lactate and glucose, and the indices derived from the relationship between the variables and the exercise workload (Bitschnau *et al.*, 2010; Harris *et al.,* 2007; Sommer *et al.,* 2015). V_{200}, defined as the velocity at which HR is 200 bpm, and VL_4, the velocity at which lactate is 4 mmol/l, are performance indices that have been used in several studies, most of them on thoroughbred horses (Marlin and Nankervis, 2006). More recently, indices more appropriate for measuring competition workload of show jumping have been proposed, such as V_{140} (Harris *et al.,* 2007).

According to Platonov (2004), the indices that are calculated using the association between HR and exercise workload (e.g. V_{140} and V_{200} for horses) measure aerobic capacity; those that use lactate and workload (e.g. VL_2, VL_3, and VL_4) measure aerobic resistance. Only some of these indices have predicted performance in horses, but all of them have been used by some authors and by the hippological literature (Sommer *et al.,* 2015).

Recently, Munk *et al.* (2013) used a SET with jumps to assess the fitness of show jumpers and found that some physiological variables, such as lactate, could be used in this type of SET to evaluate the conditioning period. The development of a specific SET in order to assess the fitness of show jumping horses would be important as it could produce accurate data for performance comparison between horses, evaluate the efficacy of training cycles and evaluate poor performance of individuals. The objective of our study was to propose a specific evaluation methodology for jumping horses, including a SET that includes the sporting movement of the discipline, and to evaluate the necessity for such a SET by comparing two groups of animals with different levels of performance in the sport.

2. Materials and methods

Animals and riders

We used sixteen (thirteen males and three females) Brasileiro de Hipismo horses belonging to the Brazilian Army and stabled in Resende, RJ, Brazil. The horses were 11.6±0.8 (mean ± standard error) years old, 490.2±13.4 kg in weight, and 1.59±0.09 m in height. The four riders (professional jockeys) that took part in the tests were distributed randomly to the mounts. For daily nutritional management, hay was provided *ad libitum* and commercial concentrate (Proequi, Guabi Nutrição e Saúde Animal S.A., Campinas, SP, Brazil) was provided in an amount equal to 1% of body mass. The animals underwent a complete physical examination, as well as haematological, biochemical, and blood gas examinations, in order to determine if the animals were in good health, and if any of the physiological variables were out of the normal range for our laboratory.

Experimental design

Based on the animals' history of participation in sport jumping competitions, the animals were divided into two groups: low performance (LP) and high performance (HP). The LP group included animals with a history of participation only in the Amateur category competitions at the Riding School level, with obstacles at a maximum height of 1.00 m. The HP group included animals with a history (last two years) of participation in Senior category competitions at the CSN and CSN 1* level (different categories of the official Brazilian national show jumping competitions), with obstacles at maximum heights of 1.10 and 1.20 m, respectively (Confederação Brasileira de Hipismo, 2016).

All animals had participated in regular training for at least 10 months. In the HP group, horses were trained an average of four times per week, with two to three stretching sessions followed by jumping gymnastics, and one to two sessions of isolated flexing and a work session outdoors. In the LP group, horses underwent similar training, but with an average of three sessions per week, and jumping gymnastics involving lower heights.

The evaluation methodology included two tests: the standardised exercise test 1 (SET1), a standardised submaximal exercise test used for evaluating the aerobic capacity of jumping horses, based on methods described in Munsters *et al.* (2015); and the standardised exercise test 2 (SET2), proposed as a standardised submaximal exercise test, which included the sporting movements and specific muscle groups for the jumping discipline. We used both tests (SET1 and SET2) to evaluate both groups (HP and LP), and hypothesised that because SET2 comprises greater specificity for sport jumping, there would be differences in the performance indices among the tests and groups (e.g. the SET2 performance indices elevated for the HP group).

The SET1 was conducted on two consecutive mornings (average air temperature of 23.4 °C and relative humidity of 88.5%) on an open arena sand track (400 m in length), with no obstacles. The stages lasted 3 min and were performed at velocities of 160, 280, 400, and 520 m/min, with a 2 min interval between them. The velocities were controlled by a GPS-equipped monitor (RS800CX G3, Polar Electro,

Kempele, Finland) placed on the rider's wrist, and by a sound alert – made by a whistle – from the person timing the test, in order to guarantee the prescribed time and velocities for the stages.

The SET2 was conducted on two consecutive mornings (average air temperature of 23.5 °C and relative humidity of 73.5%) on a covered arena sand track, with ten obstacles arranged in two rows, with a 3 m space between them (total distance of 74 m). Before the test, a 10 min warm-up was performed in the walk and trot gaits. The test consisted of three stages with increasing obstacle heights of 40, 60, and 80 cm (all simple and vertical obstacles). Each stage included four laps of the course (i.e. 40 jumps per stage) at a constant velocity of approximately 300 m/min, and an interval of 3 min between laps. The same GPS-equipped monitor from SET1 was used.

Measured variables and calculated indices

HR was measured using a monitor (Equine RS800CXG3, Polar Electro), installed on the animals and collected by a specific computer program (Polar Pro Trainer Equine Edition, Polar Electro). For the SET1, the average of the last 30 s of each stage was considered the HR (Bitschnau *et al.*, 2010); HR for the SET2 was measured immediately after each stage.

Blood collection, by means of jugular venepuncture, was performed before (baseline) and after each exercise stage of the SET1 (n=5, including baseline) and SET2 (n=4, including baseline). Blood was collected in negative pressure tubes containing sodium fluoride and, immediately after each collection, the blood was centrifuged and the plasma was separated. Lactate and glucose were measured using a bench lactimeter (YSI 2300 Sport L-lactate and glucose analyser, YSI Incorporated, Yellow Springs, OH, USA).

A portable blood gas analysis device (i-STAT Care and CG8+ testing cartridge, Abbott Point of Care, Princeton, NJ, USA) was used to measure the following variables: hydrogenionic potential (pH), partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), base excess (BE), concentration of bicarbonate (HCO_3^-), total concentration of carbon dioxide (tCO_2), oxygen saturation (sO_2), natraemia (Na^+), kalaemia (K^+), and chloraemia (Cl^-). Colorimetric measurements were taken for chloride (Cl^-) ions (BTS 315 spectrophotometer and kit for dosing Cl^-, Labtest Diagnóstica S.A., Lagoa Santa, Brazil). The blood gas variables and ions concentrations were measured before (baseline) and after SET1 (n=2, including baseline) and SET2 (n=2, including baseline). For these variables, the baseline samples were pooled into one baseline mean for the purpose of comparing SET1 and SET2.

For the SET1, the relationship between velocity and HR was estimated by the linear regression, $HR=y_0+a.V$, in which HR was the heart rate, y_0 was the interception with the y-axis, a was the increase coefficient, and V was the velocity, making it possible to calculate the V_{140} and V_{180} indices (velocity at which the horse HR is 140 bpm and 180 bpm, respectively). These indices were chosen because they were expected to be more similar to the velocity at which jumping is performed than the traditional index used for race horses (i.e. V_{200}). The relationship between lactate and velocity was estimated by the equation, $Lactate=y0+a{\cdot}exp(b{\cdot}V)$, in which y_0 was the interception with the y-axis, a was the increase coefficient, b was the exponential increase factor, and V was the velocity (Bitschnau *et al.*, 2010). The resulting information was used to calculate the VL_2, VL_3, and VL_4 indices (velocity at which the horse lactate is 2.0, 3.0, and 4.0 mmol/l, respectively).

The indices for the SET2 were the lactate difference (LacDif) and glucose difference (GlycDif), which were calculated as the difference between the values before (baseline) and after performing the jump test.

Statistical analysis

An analysis of variance (ANOVA) and post hoc Holm–Sidak test were performed to detect significant differences for the HR, lactate and glucose. Significant differences were calculated between stages and groups for both SET. ANOVA and Holm-Sidak were also used for blood gas variables and differences were calculated between before and after the exercise, between groups and tests. For comparing the V_{140}, V_{180}, VL_2, VL_3, VL_4, LacDif, and GlycDif indices, we used the one-tailed Student's t-test for homoscedastic samples. The significance level adopted was $P \leq 0.05$ and the results are presented as mean ± standard error. The analyses were performed with specific computer programs (Minitab 14, Minitab Inc., State College, PA, USA and Sigmaplot 11, Systat Software, Inc., San Jose, CA, USA).

3. Results

SET1

Heart rate increased with the increasing stages of velocity, but there were no significant differences between the LP and HP groups (P=0.091; Table 1). Lactate was significantly higher for the 400 and 520 m/min stages than for the baseline or the other two stages (P<0.001), and there were no differences between the performance groups (P=0.294). A significantly lower glucose value was noted for the LP group for the 400 m/min stage than for the other stages (P=0.041); in general, a higher glucose was noted for the HP group than for the LP group (P=0.018).

For the SET1 performance indicators, V_{140} was higher in the HP group than in the LP group (P=0.025), but there was no difference between the groups for the V_{180} variable (P=0.0504; Table 2). The variables VL_2, VL_3, and VL_4 did not differ between the groups (P=0.562, 0.443, and 0.320, respectively).

SET2

Heart rate increased as the jump height in the stages increased (P<0.001; Table 3). In the three stages of jumps, lower HR values were noted for the HP group than for the LP group (P=0.002). There was an increase in lactate at each of the exercise stages (P<0.001), as well as significant differences between the groups for all stages (P=0.039). For glucose, only the baseline differed from the other stages (P<0.001), and there were no differences between the groups (P=0.107; Table 3).

The variable LacDif was higher in the LP group (means ± standard error; 3.45±0.35) than the HP group (2.09±0.31; P<0.001), and GlycDif did not vary between the LP group (0.46±0.25) and the HP group (0.43±0.18; P=0.939).

Blood gas analysis and plasma ions

The pH variable differed between the baseline and test measurements, with lower values measured for the SET1 than for the SET2 (P<0.001; Table 4). There were no differences in pH between the groups (P=0.106). The pCO_2 was higher in the SET2 measurement than in the other measurements (P<0.001), with no differences between the groups (P=0.939). For pO_2, compared to the baseline, there was an increase after the SET1 and a decrease after the SET2 (P<0.001), with no difference between the groups (P=0.238).

For the BE, HCO_3, and tCO_2 variables, lower values were noted for the SET1 than for the baseline or SET2 (P<0.001; Table 4). BE was higher in the baseline measurement for the LP group than for the GP group, whereas the opposite was observed for the SET1 and SET2 (P=0.021).

Lower HCO_3 was noted in the SET1 measurement for the LP group than for the GP group (P<0.001), and lower tCO_2 was noted in the SET1 and SET2 measurements for the LP group than for the GP group (P=0.027; Table 4). The sO_2 variable was lower in the SET2 measurement than in the other measurements (P<0.001), with no difference between the groups (P=0.308).

Table 1. Physiological variables of horses submitted to the four velocity stages for the standardised exercise test 1 (nonspecific for show jumping).[1]

Variable[2]	Group[3]	Baseline	160 m/min	280 m/min	400 m/min	520 m/min
HR (bpm)	HP[4]	33.5±2.8[a]	68.0±3.3[b]	84.0±4.6[c]	115.0±4.8[d]	138.0±6,19[e]
	LP[5]	35.3±1.9[a]	66.0±3.0[b]	82.0±3.89[c]	133.0±11.5[d]	157.5±7.28[e]
LAC (mmol/l)	HP[4]	0.78±0.13[a]	0.52±0.04[a]	0.75±0.05[a]	3.23±0.56[b]	7.28±1.24[c]
	LP[5]	0.49±0.03[a]*	0.67±0.05[a]	0.92±0.14[a]	3.52±0.68[b]	9.76±1.54[c]
GLUC (mmol/l)	HP[4]	4.51±0.12[a]	4.43±0.11[a]	4.56±0.17[a]	3.23±0.56[b]	4.73±0.10[a]
	LP[5]	4.16±0.25[a]*	3.81±0.21[a]*	3.66±0.14 [a]*	3.52±0.23[b]	4.1±0.33[a]*

[1] Values are means ± standard errors. For each variable, means followed by different letters indicate significant differences between stages, while means followed by an asterisk indicate significant differences between groups (P≤0.05).
[2] HR = heart rate; LAC = lactate; GLUC = glucose.
[3] HP = high performance group; LP = low performance group.

Table 2. Performance indicators of horses submitted to the standardised exercise test 1 (nonspecific for show jumping).[1]

Group[2]	V_{140}[3] (m/min)	V_{180}[3] (m/min)	VL_2[4] (m/min)	VL_3[4] (m/min)	VL_4[4] (m/min)
HP	450.0±19.7*	607.3±26.9	364.83±21.86	414.00±21.91	450.67±21.80
LP	401.1±11.9	539.5±27.7	348.33±20.64	393.50±21.09	425.83±20.84

[1] Values are means ± standard errors. For each performance indicator, an asterisk indicates a significant difference between groups (P≤0.05).
[2] HP = high performance group; LP = low performance group.
[3] V_{140} and $^1V_{180}$ = velocity at which the heart rate is 140 bpm and 180 bpm, respectively.
[4] VL_2, VL_3, and VL_4 = velocity at which the horse lactate is 2.0, 3.0, and 4.0 mmol/l, respectively.

Table 3. Physiological variables of horses submitted to three jump height stages in the standardised exercise test 2 (specific for show jumping).[1]

Variable[2]	Group[3]	Baseline	40 cm	60 cm	80 cm
HR (bpm)	HP	36.4±2.3^{a}	117.4±5.7^{b}	140.0±3.8^{c}	155.6±4.5^{d}
	LP	34.3±2.5^{a}	124.1±3.2^{b*}	153.9±4.0^{c*}	174.6±6.0 ^{d*}
LAC (mmol/l)	HP	0.78±0.13^{a}	1.82b±0.30	2.14±0.33^{c}	2.87±0.31^{d}
	LP	0.49±0.03^{a*}	2.29±0.23 ^{b*}	3.18±0.29^{c*}	3.93±0.37^{d*}
GLUC (mmol/l)	HP	4.65±0.13^{a}	3.89±0.23^{b}	3.98±0.19^{b}	4.22±0.14^{b}
	LP	4.87±0.22^{a}	4.26±0.12^{b}	4.32±0.18^{b}	4.32±0.13^{b}

[1] Values are means ± standard errors. For each variable, means followed by different letters indicate significant differences between stages, and means followed by an asterisk indicate significant differences between groups (P<0.05).
[2] HR = heart rate; LAC = lactate; GLUC = glucose.
[3] HP = high performance group; LP = low performance group.

Table 4. Blood gas variables and plasma ions of horses submitted to the standardised exercise tests 1 (SET1) and 2 (SET2).[1,2]

Variables[3]	Baseline		SET1		SET2	
	HP	LP	HP	LP	HP	LP
pH[3]	7.421±0.042^{a}	7.430±0.008^{a}	7.372±0.017^{c}	7.337±0.026^{c}	7.407±0.009^{b}	7.374±0.017^{b}
pCO_2 (mmHg)[4]	47.79±0.8^{a}	47.67±0.54^{a}	46.72±0.75^{a}	46.30±2.22^{a}	52.24±1.30^{b}	53.04±2.09^{b}
pO_2 (mmHg) [5]	35.33±1.13^{a}	31.22±1.22^{a}	39.25±2.50^{c}	37.38±1.68^{c}	26.63±1.05^{b}	28.13±1.39^{a}
BE (mmol/l) [6]	6.78±0.39^{a}	7.33±0.61^{a*}	1.88±1.23^{b}	-1.25±1.03^{b*}	8.12±0.83^{a}	5.63±1.02^{a*}
HCO_3^- (mmol/l)[7]	30.77±0.36^{a}	31.51±0.49^{a}	26.71±1.00^{b}	24.14±0.66^{b*}	32.35±0.71^{a}	30.39±0.86^{a}
tCO_2 (mmol/l)[8]	31.89±0.41^{a}	33.00±0.47^{a}	28.25±1.01^{b}	25.37±0.63^{b*}	33.75±0.72^{a}	31.62±0.87^{a*}
sO_2 (%)[9]	64.22±1.86^{a}	58.89±2.45^{a}	63.50±3.78^{a}	59.13±4.40^{a}	42.25±3.29^{b}	43.75±3.72^{b}
Na^+ (mmol/l)[10]	136.50±0.27^{a}	136.11±0.45^{a}	140.43±0.49^{c}	140.50±0.84^{c}	139.43±0.67^{b}	138.75±0.41^{b}
K^+ (mmol/l)[11]	4.02±0.10^{a}	3.84±0.08^{a}	5.20±0.06^{b}	5.54±0.21^{b}	5.17±0.10^{b}	5.14±0.13^{b}
Cl^- (mmol/l)[12]	103.76±2.90^{a}	106.09±2.49^{a}	105.48±2.20^{a}	104.97±1.39^{a}	110.03±1.75^{b}	109.8±1.82^{b}

[1] Values are means ± standard errors. For each variable, means followed by different letters are significantly different between tests and means followed by an asterisk are significantly different between groups (P≤0.05). Baselines in this table are the average of the SET1 and SET2 baselines.
[2] HP = high performance group; LP = low performance group;
[3] pH = hydrogenionic potential; pCO_2 = partial pressure of carbon dioxide; pO_2 = partial pressure of oxygen; BE = base excess; HCO_3^- = concentration of bicarbonate; tCO_2 = total concentration of carbon dioxide; sO_2 = oxygen saturation; Na^+ = natraemia; K^+ = kalaemia; Cl^- = chloraemia.

There was an increase in plasma concentrations of K^+ after the two tests (P<0.001; Table 4). For Na^+ there was a decrease in plasma concentration for the SET2 and a sharper decrease for the SET1 (P<0.001). For the Cl^- variable, there was an increase only for the SET2 (P=0.023). There were no differences between the HP and LP groups for any of the ions studied (P=0.472, 0.678 and 0.760 for Na^+, K^+, and Cl^-, respectively; Table 4).

4. Discussion

Heart rate, lactate and glucose

For the SET1, there were no differences between the groups for HR or lactate. This could mean that HP and LP horses had a similar cardiovascular adaptation to the SET1 exercise. For the SET2, lower HRs were noted for the HP group, which was likely because of the animals' higher level of sporting competition experience, affording them greater cardiovascular adaptation to the jumping exercises. The difference in results for the SET1 and SET2 suggests

the importance of a specific performance test to evaluate and compare show jumpers.

Desmecht *et al.* (1996) reported that jumping horses elevate their lactate after exercise. In general, they produce lower lactate compared to racing or trotting modalities, but higher lactate compared to horses that exercise for longer periods of time (e.g. endurance riding). Similarly, the present study noted elevated levels of lactate after the SET2 exercise, when compared with the baseline, and these levels were considerably lower than the levels reported for other disciplines, such as eventing (Muñoz *et al.,* 1998), turf (Bayly *et al.*, 1983), trotting (Ronéus *et al.*, 1999), or polo (Ferraz *et al.*, 2010). These results indicate that show jumpers have an anaerobic component to their energy supplement metabolism, but not at the same high level as noted for other sporting horses.

Other studies investigating jumping horses in real (Vincze *et al.*, 2010) or simulated competitions (Fazio *et al.,* 2014) revealed considerable differences in the post exercise lactate: 1.5-3.5 mmol/l for Vincze *et al.* (2010) and 5.0 mmol/l for Fazio *et al.* (2014). Compared to these studies, our SET2 resulted in intermediate post exercise lactate values (2.87 mmol/l for the HP group, and 3.93 mmol/l for the LP group). These differences in lactate values are likely due to differences in the number and height of jumps: 11-14 jumps of 100-120 cm in Vincze *et al.* (2010), 12 jumps of 130 cm in Fazio *et al.* (2014), and 40 jumps of each height (40 cm, 60 cm, and 80 cm) in the present study.

Some authors have reported that horses would experience an extra physical burden by utilising the muscle group responsible for the sport jumping movement (Aguilera-Tejero *et al.*, 2000; Art *et al.*, 1990). As Lekeux *et al.* (1991) revealed, the HR (189.2±3.5 bpm) and lactate (8.7±0.5 mmol/l) measured after a jumping event clearly exceeded those expected for exercises at 400 m/min, which indicated that obstacle jumping was an intense exercise that involved the use of anaerobic metabolism. More recently, Sloet van Oldruitenborgh-Oosterbaan *et al.* (2006) conducted an experiment comparing the performance of horses on the same course, with and without jumps, and demonstrated that the jumps caused an increase in lactate, and therefore a demand for anaerobic metabolism. Our study supports these research findings. We noted that for each increase in jump height, there was an increase in the lactate level, and this might have been due to the recruitment of a higher intensity of glycolytic fibres responsible for the jump movement (Boffi, 2007), changes in muscle blood circulation (Art *et al.*, 1990), or the velocity changes required in a course with jumps (Bobbert and Santamaría, 2005).

As for the difference between the groups (HP and LP), the highest lactate levels were noted for the LP group, which is likely linked to insufficient adaptation of muscle physiology for the jumping exercise. The continuous training of the HP animals has likely resulted in the adaption of muscles to cope with the imbalance between energy generated and energy used per unit of time, which is required for the jumping motion (Rivero and Boffi, 2007). The lower lactate as an indicator of better performance (i.e. HP group) has also been noted by Munk *et al.* (2013), who reported lower after jump exercise lactate after a period of conditioning, and by Roberts *et al.* (2014), who reported that the lactate was positively correlated with the number of faults in the course and a decrease in the technical standards of the jumps. These results, as well as ours, indicate that lactate after a series of jumps is an important performance indicator for horses of this sport.

Because glucose is an active part of energy metabolism, researchers have used glucose measurement as an indicator of aerobic metabolism adaptation, and in turn, a performance indicator (Ferraz *et al.,* 2008). In our study, glucose decreased during exercise for both the SET2 and SET1. Some researchers have also reported lower glucose during jumping exercises (Art *et al.*, 1990; Lekeux *et al.*, 1991; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2006). This decrease is probably linked to increased circulating insulin in the exercising muscle, causing more exposure of glucose transporters in the cell membrane, as well as increased glucose uptake caused by the muscle contraction (Goodyear and Kahn, 1998).

There were differences between the groups in their glucose response to exercise, with the glucose level always lower in the HP group during exercise. Differentiation between trained and untrained horses for glycaemic and insulin response to feeding has been previously reported (Ralston, 2002), but there have been no reports regarding a difference in response to the exercise for horses at different levels of physical fitness. In human literature, it is relatively well documented that trained individuals have greater sensitivity to insulin (Boulé *et al.*, 2005; Goodyear and Kahn, 1998), a fact that theoretically would cause trained animals to have lower glucose after exercise. However, as Pösö *et al.* (2008) revealed, glucose metabolism during exercise is complex, and further studies on horses are needed to clarify these issues.

Performance indices

Lekeux *et al.* (1991) reported that it would be important for jumping horses to have a high aerobic capacity. However, other researchers (Boffi, 2007; Marlin and Nankervis, 2006) and some horse experts, such as trainers and riders, have questioned this statement. The horses in our study had average V_{140} values comparable with those reported by Marlin and Nankervis (2006). On the other hand, Harris *et al.* (2007), using a heterogeneous group of horses (breed and age), but with an athletic level (riding schools) and

protocol similar to our study, reported V_{140} values a little lower than our values, indicating that such animals probably had lower aerobic capacity for the exercise.

The highest V_{140} values were noted for the HP horses, and this revealed that, despite the similar aerobic capacity of the HP and LP horses (equal post exercise HR), the HP horses likely had slightly higher aerobic capacity than the animals in the LP group. This could indicate that, despite the known importance of anaerobic metabolism for jumping events, aerobic capacity is also important in the competitive differentiation of animals of this sport, and that the V_{140} index was adequate to differentiate performance groups.

The lack of V_{180} differentiation between the groups is likely because neither group would have experience training at this exercise intensity, and therefore animals from both groups would have the same level of adaptation to this burden.

In the present study, the VL_2, VL_3, and VL_4 performance indices for the SET1 were not significantly different between the HP and LP groups. These results can be explained by the great individual variation of aerobic resistance, indicated by high standard errors of the VL_2, VL_3, and VL_4 data, and may indicate little actual difference between the groups, because both groups had similar aerobic resistance levels, even at different performance levels (100 cm versus 110/120 cm).

In addition, it is important to keep in mind that the aptitude for jumping, besides the physical conditioning components, is considerably influenced by the technique, which means that animals with lower physical fitness and excellent technique could achieve relatively high performance levels. This fact could also contribute to the non-differentiation of the groups regarding their aerobic resistance. Our findings reinforce the complexity of evaluating the show jumping horse. In our study, the HP group demonstrated greater aerobic capacity (measured by the V_{140} and V_{180}), but similar aerobic resistance (measured by the variables of association between lactate and workload) to the LP group. The differentiation of these two physical skills is evident, and it may suggest that the higher intensity training performed by the HP animals, in order to achieve higher competitive levels, had a greater effect on the aerobic capacity of the animals than their resistance. This is consistent with the literature, which mentions that the training aimed at improving aerobic resistance would not often be practiced by jumping sport athletes (Marlin and Nankervis, 2006).

As Bitschnau *et al.* (2010) revealed, in the sporting evaluation context, the results of a test should be transferable to the daily training routine. Animals with the higher performance history (HP group) showed aerobic resistance similar to the lower performance animals (LP group), as shown by the VL_2, VL_3, and VL_4 indices. However, the SET2 showed lower lactate and LacDif final values, which could suggest more fitness for jumping, and greater fitness could be signalled by the lower accumulation of lactate in the bloodstream. Overall, these results suggest that more specific evaluations, such as the SET2, must be added to traditional incremental velocities testing (e.g. SET1) for show jumpers.

Blood gas analysis and plasma ions

The present study revealed a decrease in blood pH after jumping exercises (SET2), which was similar to a previous report of a slight decrease in pH after exercise (Piccione *et al.*, 2004), but different from other reports of no change in pH values (Aguilera-Tejero *et al.*, 2000; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2006). Piccione *et al.* (2004) reported that for this type of exercise, changes caused by muscle energy generation, mainly anaerobically, might lead to metabolic acidosis. A decrease in pH occurs when the organic buffer mechanisms are no longer sufficient to maintain blood acid-base balance (Piccione *et al.*, 2004). This apparent inconsistency in results might be explained by differences in the jumping exercise intensities, as well as recent competitive history and environmental conditions. These findings reinforce the idea of the need for standardisation of specific tests for the sport, both for understanding the physiological changes resulting from the jump sporting movement, and for evaluating and comparing horses that practice this sport.

For the standard exercise test (SET1), a decrease in pH was noted after exercise, which is consistent with the reports for exercises of similar intensity (Taylor *et al.*, 1995), but lower than the decrease in pH observed for more intense exercises (Andrews *et al.*, 1995; Ferraz *et al.*, 2010).

For pO_2 and pCO_2, our SET2 results corroborate what is found in the literature, which shows a decrease in pO_2 and an increase in pCO_2 immediately after exercise, likely due to the accentuated use of oxygen and carbon dioxide production in muscle cells during the exercise (Ainsworth, 2008). These results, as well as the slight decrease in pH, could also be explained by changes in respiratory dynamics, such as an increase in frequency and decrease in volume, thus characterising a shallow breath, and subsequent gas exchange on a smaller scale. The galloping and breathing cycles in horses are coupled, and this prevents any significant increase in respiratory rate and, unlike humans, an inability of horses to perform compensatory hyperventilation during exercise (Attenburrow and Goss, 1994). The results obtained in the SET2 suggest that this type of exercise (galloping and several jumps) also causes this type of hindrance.

After performing the SET1, there was an increase of pO_2 and maintenance of pCO_2 values, which differed from

the behaviour of these variables after the SET2, and in most studies in the literature. These differing results are likely explained by the time interval between the end of the exercise and the blood collection that, even though as brief as possible, was still longer than in the SET2, due to factors inherent to the type and size of the tracks used for both tests. This small difference (5-10 s) in collection time might have influenced the behaviour of partial pressures by allowing hyperventilation after gallop, returning the pCO_2 levels to normal and raising pO_2, resembling a typical recovery behaviour, as described in the literature (Aguilera-Tejero *et al.*, 2000; Art *et al.*, 1990; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2006). Another possible influential factor that could explain the behaviour of the blood gas variables is the difference in air humidity between the days that the horses were tested (SET1 88.5% and SET2 73.5%). In a more humid condition, horses tend to hyperventilate more following moderate exercise, in order to regulate body temperature (Marlin and Nankervis, 2006), and, as consequence, partial pressures of O_2 and CO_2 would change.

As for the oxygen saturation values (sO_2), the baseline values (before the exercise) were slightly lower in the present study (58-64%) than in the reports by Piccione *et al.* (2004; 70-81%), which might be attributed to the large genetic and fitness differences among the horses studied, as well as climatic differences (differences in timing and location of the studies). Similar to the previous studies, saturation values were lower after the jumping exercises (SET2), and were likely the result of two factors: the Bohr effect, regarded as the deviation of the right oxyhaemoglobin saturation curve caused by rising temperatures and pH drop (Ainsworth, 2008); and the lower partial pressure of oxygen (Fenger *et al.*, 2000). In our study, an increase in body temperature (unpublished data), as well as a decrease in blood pH and pO_2, were noted after the SET2, and certainly contributed to the decrease in sO_2.

In general, the baseline values for BE, HCO_3^-, and tCO_2, as well as their decrease after the SET1 exercise, were similar to those reported in the literature for moderate to high intensity exercises (Aguilera-Tejero *et al.*, 2000; Ferraz *et al.*, 2010; Piccione *et al.*, 2004). The HCO_3^- values after the SET1 were more similar to moderate exercise results, such as those previously reported for jumping events (Aguilera-Tejero *et al.*, 2000; Piccione *et al.*, 2004), than to results reported for more intense exercise, such as polo events (Ferraz *et al.*, 2010), and this indicates that the SET1 was a sub-maximal intensity test. In humans, the blood buffering capacity, which is affected by the concentration of HCO_3^-, affects performance in athletes performing successive sprints (Edge *et al.*, 2006). After the SET1, higher HCO_3^- values were noted for the HP group than for the LP group, which could indicate greater blood buffering capacity and, similar to what occurs in humans, more exercise adaptation.

Increased Na^+ and K^+ concentrations after various exercises, including jumping, has been reported, and converges with our findings for both the SET2 and SET1 (Aguilera-Tejero *et al.*, 2000; Art *et al.*, 1990; Ferraz *et al.*, 2010), and is probably linked to the movement of fluids from intra and extracellular spaces to the vascular compartment, resulting in a transient increase in total plasma volume, as well as an increase in the concentrations of certain plasma ions and proteins (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2006). In Schott *et al.* (2005), the K^+ values after exercise reached 10 mmol/l, which was considerably higher than the values found in our study (5.14-5.54 mmol/l). This difference might be explained by the lower intensity of exercise performed in our study.

In a previous study, a slight decrease in the plasma concentration of Cl^- was reported after exercise (Muriel, 2007), but in our study there was no change in the SET1, and even a slight increase in the SET2. A difference in the type and intensity of the exercises studied might explain these differing results.

The main findings revealed by the present study were the V_{140} and glucose differences between groups in SET1, the HR, lactate and LacDif differences between groups in all stages in SET2, and the differences between groups in BE, HCO_3^- and tCO_2 for the blood gas variables.

Overall, the SET1 (traditional methodology) revealed differences between the HP and LP groups mainly for variables related to aerobic capacity (V_{140}), which suggests that aerobic capacity is important for evaluating the performance of show jumping horses. However, there were differences between the two groups for the SET2 that were not noted for the SET1 (e.g. differences in LacDif and HCO_3^-).

These results indicates that a specific test, that includes the sport jumping movement and the measurement of HR, lactate and possibly some blood gas variables, could add important information for the evaluation of show jumping horses.

5. Conclusions

Our study suggests that a SET that includes jumping should be used when evaluating jumping horses to detect differences between performance levels that are not detected using the traditional method. Studies with show jumpers in other performance levels (e.g. Olympic level) could further elucidate the important factors for the evaluation of these athletes.

Acknowledgements

We thank the Brazilian Army and, in particular, the Veterinary Hospital of Agulhas Negras Military Academy, for their support. This study was funded by the Fundação de Pesquisa de São Paulo, FAPESP.

References

Aguilera-Tejero, E., Estepa, J.C., López, I., Bas, S., Mayer-Valor, R. and Rodriguez, M., 2000. Quantitative analysis of acid-base balance in show jumpers before and after exercise. Research in Veterinary Medicine 68: 103-108.

Ainsworth, D.M., 2008. Lower airway function: responses to exercise and training. In: Hinchcliffe, K.W., Kaneps, A.J., Geor, R.J. (eds.) Equine exercise physiology. WB Saunders, London, UK, pp. 193-211.

Andrews, F.M., Geiser, D.R., White, S.L., Williamson, L.H., Maykuth, P.L. and Green, E.M., 1995. Haematological and biochemical changes in horses competing in a 3 Star horse trial and 3-day-event. Equine Veterinary Journal Supplement 20: 57-63.

Art, T., Amory, H., Desmecht, D. and Lekeux, P., 1990. Effect of show jumping on heart rate, blood lactate and other plasma biochemical values. Equine Veterinary Journal Supplement 9: 78-82.

Attenburrow, D.P. and Goss, V.A., 1994. The mechanical coupling of lung ventilation to locomotion in the horse. Medical Engineering and Physics 16: 188-192.

Bayly, W.M., Grant, B.D., Breeze, R.G. and Kramer, J.W., 1983. The effect of maximal exercise on acid-base balance and arterial gas tension on Thoroughbred horses. Equine Exercise Physiology 1: 400-408.

Bitschnau, C., Wiestner, D.S., Trachsel, D.S., Auer, J.A. and Weishaupt, M.A., 2010. Performance parameters and post exercise heart rate recovery in Warmblood sports horses of different performance levels. Equine Veterinary Journal 42: 17-22.

Bobbert, M.F. and Santamaría, S., 2005. Contribution of the forelimbs and hindlimbs of the horse to mechanical energy changes in jumping. Journal of Experimental Biology 208: 249-260.

Boffi, F.M., 2007. Principios de entrenamiento. In: Boffi, F.M. (ed.) Fisiologia Del Ejercicio em Equinos. Inter-Médica Editorial, Buenos Aires, Argentina, pp. 145-151.

Boulé, N.G., Weisnagelagel, S.J., Lakka, T.A., Tremblay, A., Bergman, R.N., Rankinen, T., Leon, A.S., Skinner, J.S., Wilmore, J.H., Rao, D.C. and Bouchard, C., 2005. Effects of exercise training on glucose homeostasis: the heritage family study. Diabetes Care 28: 108-114.

Casella, S., Vazzana, I., Giudice, E., Fazio, F. and Piccione, G., in press. Relationship between serum cortisol levels and some physiological parameters following reining training session in horse. Animal Science Journal 87: 729-735.

Confederação Brasileira de Hipismo, 2016. Regulamento de Salto CBH 2016. Available at: http://tinyurl.com/zwh8qmg.

Desmecht, D., Linden, A., Amory, H., Art, T. and Lekeux, P., 1996. Relationship of plasma lactate production to cortisol release following completion of different types of sporting events in horses. Veterinary Research Communication 20: 371-379.

Edge, J., Hill-Haas, S., Goodman, C. and Bishop, D., 2006. Effects of resistance training on H+ regulation, buffer capacity, and repeated sprints. Medicine and Science in Sports and Exercise 38: 2004-2011.

Fazio, F., Casella, S., Assenza, A., Arfuso, F., Tosto, F. and Piccione, F., 2014. Blood biochemical changes in show jumpers during a simulated show jumping test. Veterinarski Arhiv 84: 143-152.

Fenger, C.K., McKeever, K.H., Hinchcliff, K.W. and Kohn, C.W., 2000. Determinants of oxygen delivery and hemoglobin saturation during incremental exercise in horses. American Journal of Veterinary Research 61: 1324-1332.

Ferraz, G.C., D'Angelis, F.H.F., Teixeira-Neto, A.R., Freitas, E.V.V., Lacerda-Neto, J.C. and Queiroz-Neto, A., 2008. Blood lactate threshold reflects glucose responses in horses submitted to incremental exercise test. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 60: 256-259.

Ferraz, G.C., Soares, O.A.B., Foz, N.S.B., Pereira, M.C. and Queiroz-Neto, A., 2010. The workload and plasma ion concentration in a training match session of high-goal (elite) polo ponies. Equine Veterinary Journal Supplement 42: 191-195.

Fortier, J., Deley, G., Goachet, A.G. and Jullian, V., 2015. Quantification of the energy expenditure during training exercises in Standardbred trotters. Animal 9: 793-799.

Fraipont, A., Van Erck, E., Ramery, E., Fortier, G., Lekeux, P. and Art, T., 2012. Assessing fitness in endurance horses. Canadian Veterinary Journal 53: 311-314.

Goodyear, L.J. and Kahn, B.B., 1998. Exercise, glucose transport and insulin sensitivity. Annual Review of Medicine 49: 235-261.

Harris, P., Marlin, D.J., Davidson, H., Rodgerson, J., Gregory, A. and Harrison, D., 2007. Practical assessment of heart rate response to exercise under field conditions. Equine and Comparative Exercise Physiology 4: 15-21.

Lekeux, P., Art, T., Linden, A., Desmecht, D. and Amory, H., 1991. Heart rate, hematological and serum biochemical responses to show jumping. Equine Exercise Physiology 3: 385-390.

Marlin, D. and Nankervis, K., 2006. Equine exercise physiology. Blackwell Publishing, Oxford, UK.

Muñoz, A., Riber, R., Santisteban, R., Rubio, M.D., Agüera, E.I. and Castejón, F.M., 1998. Cardiovascular and metabolic adaptations on horses competing in cross-country events. Journal of Veterinary Medical Science 61: 13-20.

Munk, R., Møller, S. and Lindner, A., 2013. Effects of training with different interval exercises on horses used for show jumping. Comparative Exercise Physiology 9: 33-41.

Munsters, C.C.B.M., Van Iwaarden, A., Van Weeren, R. and Sloet van Oldruitenborgh-Oosterbaan, M.M., 2015. Exercise testing in Warmblood sport horses under field conditions. Veterinary Journal 200: 11-19.

Muriel, M.G., 2007. Equilíbrio hidroelectrolítico. In: Boffi, F.M. (ed.) Fisiologia del ejercicio em equinos. Inter-Médica Editorial, Buenos Aires, Argentina, pp. 87-104.

Piccione, G., Ferrantelli, V., Fazio, F., Percipalle, M. and Caola, G., 2004. Blood-gas profile in the show jumper undergoing increasing workloads during a 2-day event. Comparative Clinical Pathology 13: 43-50.

Piccione, G., Giannetto, C., Fazio, F., Di Mauro, S. and Caola, G., 2007. Hematological response to different workload in jumper horses. Bulgarian Journal of Veterinary Medicine 10: 21-28.

Platonov, V.N., 2004. Tratado geral de treinamento desportivo. Phorte Editora, São Paulo, Brazil.

Pösö, A.R., Hyypä, S. and Geor, R.J., 2008. Metabolic responses to exercise and training. In: Hinchcliffe, K.W., Kaneps, A.J. and Geor, R.J. (eds.) Equine exercise physiology. WB Saunders, London, UK, pp. 248-272.

Ralston, S., 2002. Insulin and glucose regulation. Veterinary Clinics of North America Equine Practice 18: 295-304.

Rivero, L.L. and Boffi, F.M., 2007. Respuesta y adaptación: aparato musculoesquelético. In: Boffi, F.M. (ed.) Fisiologia del ejercicio em equinos. Inter-Médica Editorial, Buenos Aires, Argentina, pp. 106-116.

Roberts, C., Harris, P., Murray, R., Cnockaert, R. and Roberts, C., 2014. The relationship between blood lactate, serum muscle enzymes, jumping performance and muscle soreness in show jumping horses. Equine Veterinary Journal Supplement 46: 9.

Ronéus, N., Essén-Gustavsson, B., Lindholm, A. and Persson, S., 1999. Muscle characteristics and plasma lactate and ammonia response after racing in Standardbred trotters: relation to performance. Equine Veterinary Journal 31: 170-173.

Schott II, H.C., Bohart, G.V. and Eberhart, S.W., 2005. Potassium and lactate uptake by noncontracting tissue during strenuous exercise. Equine Veterinary Journal Supplement 34: 532-538.

Sloet van Oldruitenborgh-Oosterbaan, M.M., Spierenburg, A.J. and Van Den Broek, E.T.W., 2006. The workload on riding-school horses during jumping. Equine Veterinary Journal Supplement 36: 93-97.

Soares, O.A.B., D'Angelis, F.H.F., Feringer-Júnior, W.H., Nardi, K.B., Trigo, P., Almeida, F.Q., Miranda, A.C.T., Queiroz-Neto, A. and Ferraz, G.C., 2013. Serum activity of creatine kinase and aminotransferase aspartate enzymes of horses submitted to muscle biopsy and incremental jump test. Revista Brasileira de Saúde e Produção Animal 14: 299-307.

Sommer, L.H., Munk, R., Nielsen, S.M. and Lindner, A., 2015. Training of horses used for show jumping and its effect on V4. Journal of Equine Veterinary Science 35: 301-308.

Sotero, R.C., Soares, O.A.B., Queiroz-Neto, A., Simões, H.G. and Ferraz, G.C., 2014. Cost of transport as a discriminator of conditioning in horses submitted to incremental jumping tests. Equine Veterinary Journal Supplement 46: 25-26.

Taylor, L.E., Ferrante, P.L., Kronfeld, D.S. and Meacham, T.N., 1995. Acid-base variables during incremental exercise in sprint-trained horses fed a high-fat diet. Journal of Animal Science 73: 2009-2018.

Vermeulen, A.D. and Evans, D.L., 2006. Measurements of fitness in Thoroughbred racehorses using field studies of heart rate and velocity with a global positioning system. Equine Veterinary Journal Supplement 36: 113-117.

Vincze, A., Szabó, C., Hevesi, Á., Veres, S., Ütő, D. and Babinszky, L., 2010. Effect of age and event on post exercise values of blood biochemical parameters in show jumping horses. Acta Agraria Kaposváriensis 14: 185-191.