

## **Do waiting times in endurance vet gates affect the Cardiac Recovery Index (CRI)?**

M. C. de Mira<sup>1,2</sup>, J. Williams<sup>3</sup>, R. G. dos Santos<sup>4</sup>, P. Rodrigues<sup>5</sup>, B. Arroja<sup>6</sup>, D.J Marlin<sup>7</sup>

<sup>1</sup> MED – Mediterranean Institute for Agriculture, Environment and Development, Institute for Advanced Studies and Research, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554 Évora, Portugal; <sup>2</sup> Faculdade de Medicina Veterinária, Universidade Lusófona de Humanidades e Tecnologia, Campo Grande, 376, 1749-024 Lisboa, Portugal <sup>3</sup> Hartpury University, GL19 3BE, Gloucester, United Kingdom; <sup>4</sup> VALORIZA - Research Centre for Endogenous Resource Valorization, Campus Politécnico, 10, 7300-555 Portalegre, Portugal, <sup>5</sup> Departamento de Medicina Veterinária, Universidade de Évora, Núcleo da Mitra, Apartado 94, 7006-554 Évora, Portugal; <sup>6</sup> Faculdade de Medicina Veterinária, Universidade de Lisboa, Avenida da Universidade Técnica, 1300-477 Lisboa, Portugal; <sup>7</sup> David Marlin Consulting, P.O. Box 187, Cambridge, United Kingdom; [monicademira@gmail.com](mailto:monicademira@gmail.com)

### **Abstract**

The cardiac recovery index (CRI) is currently a key component of veterinary inspections to assess endurance horses metabolic status and fitness. Originally published by Ridgeway, it instructs veterinarians to subtract from the first heart rate ( $HR_1$ ), collected when the horse is initially presented for examination, a second HR ( $HR_2$ ), taken one minute after the horse starts a 125ft (38.1m) out and back trot to assess gait. It is widely believed that an increase of more than 4 bpm from  $HR_1$  might be an indicator of fatigue. The FEI rules instruct the veterinarians to start the stopwatch exactly 1 min after the  $HR_1$  count instead of trot start, as described previously. The aims of this study were to investigate how time delays in the vet gate affect the  $HR_1$  count and the CRI during endurance competitions, and to characterise and compare the time taken by veterinarians to measure the original version of the CRI ( $tCRI_{RIDG}$ ) and the adapted CRI used in FEI endurance events ( $tCRI_{FEI}$ ). Data from 972 veterinary inspections of horses that took place in different endurance competitions in three different venues were collected. There was no association between the time elapsed from entering the vet gate to the start of the  $HR_1$  count or from the  $HR_1$  count to the start of the trot-up and the  $HR_1$  or the CRI ( $P>0.05$ ). However, larger studies involving more venues and different layouts are needed to corroborate our findings and to characterise the sensitivity and

specificity of the CRI regarding the baseline heart rate. Although this study did not show an influence of waiting times on the CRI, a reduced deviation from the mean observed across all veterinarians when using the original Ridgeway guidelines to calculate the CRI ( $tCRI_{RIDG}$ ) seems to point a better time-wise consistency when this version is used.

Keywords: Horse, equine, sports medicine, race, veterinary examination

final version

## Introduction

Competitive endurance rides take place over distances up to 160km in one day against the clock. Similar to human marathons or trail races, they are designed to test the speed and stamina of a horse, in addition to the rider's capacity to conduct the horse across all kinds of terrain. However, equestrian endurance rides are not continuous races. The competition is divided into phases ranging from 16 to 40 km each, followed by a compulsory veterinary inspection which takes place in a designated area known as a "vet gate". A compulsory rest period of between 20 and 60 minutes must take place thereafter. The assessment of the horses by the veterinary commission relies upon three criteria: heart rate recovery, metabolic stability and gait. The purpose of the assessment is to decide if a horse is fit enough to proceed to the next phase or, after the last phase (following completion of the race), if the horse has recovered within the prescribed time period (usually 30 min) to validate the competitor's placement (FEI, 2019).

Physiological recovery in endurance is commonly measured using the cardiac recovery index (CRI), which was first described by Ridgeway in 1991 and is therefore also known as the 'Ridgeway Trot'. Developed by a group of veterinarians involved with the American Endurance Conference (AERC) and based on unpublished observations, its aim was to assess the recovery of horses after passing the finish line by producing a recovery or CRI score. The CRI is currently recorded at each veterinary inspection (inspections after completion of each loop and re-inspections which take place during certain mandatory holds before the horse is allowed to start the next loop) to aid veterinarians in early identification of metabolic disorders and/or to support a decision to eliminate a horse.

The Ridgeway CRI method ( $tCRI_{RIDG}$ ) as originally described (Ridgeway, 1991) consists of the subtraction of a second heart rate ( $HR_2$ ) from the horse's original heart rate measurement when entering the vet gate ( $HR_1$ ), measured exactly one minute after the horse starts a back and forth in-hand trot in a 125 ft alley or lane (38.1m, adapted to 40m by the FEI), where  $CRI = HR_2 - HR_1$  (Mackay-Smith M., 2016). A slightly modified version of the CRI method ( $tCRI_{FEI}$ ) was published by Fielding et al. (2011) and embedded by the FEI with international endurance rules since then and at the time of publication (FEI, 2019)<sup>b</sup>. The  $tCRI_{FEI}$  instructs veterinarians to start the stopwatch not when the horse starts the trot-up, but instead when they finish the  $HR_1$  count (FEI, 2019).

Even if it seems intuitive that the end of HR<sub>1</sub> count matches the start of the trot-up, in reality this is often not the case. The flow of veterinary inspections might be disrupted by logistic factors inherent to endurance competitions, not only the layout of the vet gate, but also the number of veterinarians and trotting lanes available in relation to the number of competitors waiting to be examined, the space or absence of a delay between competitors determining the size of the pack to be examined, the overlap of competitions classes and the efficiency of judges and stewards directing the competitors. For instance, with the purpose of avoiding unfair and uneven waiting times between competitors from entering the vet gate to HR<sub>1</sub> count, more modern permanent venues and major championships will have special corridors for heart rate (HR<sub>1</sub>) measurement at the entrance to the vet gate. Only then can horses with a heart rate meeting the “pass” criteria (most commonly  $\geq 64$ bpm) proceed to a vetting lane. Thus, there is potential for a variable delay between HR<sub>1</sub> and HR<sub>2</sub>, which could potentially affect the tCRI<sub>FEI</sub>.

The impact of time delays and the type of inspection may affect the CRI have to our knowledge not previously been described. Therefore, the aims of this study were to investigate: a) how time delays in the vet gate affect HR<sub>1</sub> and the CRI measurements during endurance competitions; b) to characterise and compare the time taken by veterinarians to measure the original tCRI<sub>RIDG</sub> and the adapted tCRI<sub>FEI</sub>. Additionally, the study attempted to characterise the behaviour of the CRI for inspections after the loop (LoopInsp) and re-inspections within the hold (RIInsp).

We hypothesised that logistics related to waiting times in the vet gate, namely time taken to HR<sub>1</sub> and from HR<sub>1</sub> to the start of the trot would affect the HR<sub>1</sub>, HR<sub>2</sub> and therefore the CRI, and that the tCRI<sub>RIDG</sub> method would demonstrate more time-wise consistency in readings than the tCRI<sub>FEI</sub>.

## **Material and Methods**

The study took place during three international endurance events between June 2018 and April 2019 in Loubejac (LOUB), Lignéres (LIGN) and Uzès (UZES) in France. The study was approved by the FEI Veterinary Committee. Retrospective local climate information was obtained for each venue for the day of study from Weather Underground ([www.wunderground.com](http://www.wunderground.com)). The nearest station with 30min data reporting was identified. These were as follows: Loub - Bergerac Dordogne Perigord Airport, located 46km WNW of

Loubejac; Lign - Chateauroux-Centre Marcel Dassault Airport, located 36km WNW of Lignieres; Uzes - Nimes Ales Camargue Cevennes Airport, located 25km WNW of Uzes (**Table 1**). For data collection, an assistant was assigned to each officiating veterinarian and instructed to record times in a paper-based file of the following events during the veterinary inspections: 1) arrival of a horse at the veterinarian; 2) start and end of the count of HR<sub>1</sub>; 3) start and end of the trot-up; 4) start of the clinical examination; 5) start and end of HR<sub>2</sub>; 6) end of the veterinary inspection. Data from the inspection after arrival from the loop and requested or mandatory re-inspections were used. Additionally, data from the timing systems and veterinary cards<sup>a</sup> were collected for each individual horse, including phase (loop), average speed, horse's recovery time (defined as the time lapse between arrival from the loop and entrance into the vet gate), time horse entered the vet gate, HR<sub>1</sub> and HR<sub>2</sub>. For additional analysis HR<sub>1</sub> was grouped in four categories: HR<sub>1</sub><56bpm; 56≤HR<60 bpm; 60≤HR≤64 bpm and >64bpm. CRI was grouped in six categories: CRI<-8; -8≤CRI<-4; -4≤CRI<0; 0≤CRI≤4; 4<CRI≤8; CRI>8. Since in France the CRI is not measured in the last vet gate after finish, the data from this stage were not used.

The CRI was calculated by subtracting HR<sub>1</sub> from HR<sub>2</sub> in accordance with the method described by Ridgeway (Ridgeway, 1991). The data were entered into a Microsoft® Excel® spreadsheet (Version 2016) and the time elapsed from the horse entering the vet gate to reach an available veterinarian and to start the count of HR<sub>1</sub> (valid only for horses arriving from a loop) was calculated. In order to compare the classic tCRI<sub>RIDG</sub> definition of the CRI with the modified tCRI<sub>FEI</sub> version, the times elapsed between the start of the trot-up and the start of HR<sub>2</sub>, and between the end of the HR<sub>1</sub> count and the start of the HR<sub>2</sub> count were calculated.

For further analysis, SPSS® version 22 software (Armonk, NY: IBM Corp.) was used for descriptive and inferential statistics. Since data did not assume a normal distribution, a series of Kruskal Wallis analyses with post hoc Mann Whitney U tests identified if significant differences occurred between the variables recorded across events. A Wilcoxon signed-rank test assessed if calculated CRI values differed between the two tCRI methods. A Spearman correlation analysed if waiting times in the veterinary inspection impacted the HR<sub>1</sub> count and CRI values in the first inspections and re-inspections. Mann Whitney U analyses established if differences in CRI (tCRI<sub>RIDG</sub>) and CRI (tCRI<sub>FEI</sub>) existed between qualified and eliminated horses. Significance was set at P<0.05. HR and CRI variables are reported as mean±SD and median±IQR range.

## Results

Data were obtained from 972 veterinary inspections (745 inspections and 227 re-inspections) of 352 horses. LIGN and UZES competitions took place in very similar weather conditions, but LOUB had higher temperatures (**Table 1**).

**Table 1. Mean ( $\pm$ SD) and range (min-max) for shade temperature, relative humidity, wet bulb temperature, mean wind speed and rainfall, and overall reported condition for Loub, Lign and Uzes on days of data collection between 07:00 and 17:00.**

|             | Shade Temperature (°C) | Relative Humidity (%)   | Wet Bulb Temperature (°C) | Mean Wind Speed (kmh) | Rainfall (mm)      | Overall Condition |
|-------------|------------------------|-------------------------|---------------------------|-----------------------|--------------------|-------------------|
| <b>Loub</b> | 28 $\pm$ 3<br>(22-32)  | 60 $\pm$ 14<br>(43-88)  | 22 $\pm$ 1<br>(20-23)     | 7 $\pm$ 2<br>(2-9)    | 0 $\pm$ 0<br>(0-0) | Fair              |
| <b>Lign</b> | 16 $\pm$ 4<br>(8-21)   | 66 $\pm$ 16<br>(46-100) | 12 $\pm$ 2<br>(7-15)      | 13 $\pm$ 7<br>(2-24)  | 0 $\pm$ 0<br>(0-0) | Fair              |
| <b>Uzes</b> | 15 $\pm$ 3<br>(10-19)  | 41 $\pm$ 6<br>(32-54)   | 9 $\pm$ 2<br>(5-10)       | 23 $\pm$ 2<br>(19-28) | 0 $\pm$ 0<br>(0-0) | Fair              |

Data were collected from horses competing in open classes only (i.e. where there was no speed restriction), namely from 489, 53, 391 and 53 inspections from 80 km, 100 km, 120 km, and 160 km competitions, respectively. Overall 22.5 % (n = 219) horse and rider combinations were eliminated, of which 18.7 % (n = 182) were for gait, 2.9 % (n = 28) were for metabolic reasons and 0.9 % (n = 9) for other reasons. More horses failed to qualify for the next stage in LoopInsp (n = 179; 24 %) than in RInsp (n = 40; 18 %). The HR<sub>1</sub> count was significantly lower in RInsp than in LoopInsp (p < 0.05) and the CRI was significantly higher in RInsp than LoopInsp (p < 0.05; **Table 2**).

**Table 2. Descriptive statistics of HR and CRI in loop inspections and re-inspections.**

|            | HR (bpm) |       | CRI (bpm) |         |
|------------|----------|-------|-----------|---------|
|            | LoopInsp | Rinsp | LoopInsp  | Rinsp   |
| Mean±S.D.  | 59±5     | 52±6  | -1.0±4.0  | 0±4.3   |
| Median±IQR | 60±6     | 52±8  | -1.0±5.0  | 0.0±4.0 |
| Minimum    | 38       | 34    | -21       | -20     |
| Maximum    | 100      | 64    | 16        | 16      |

Significant differences ( $p < 0.05$ ) found between venues for HR<sub>1</sub> and CRI in LoopInsp are depicted in **Table 3**.

**Table 3. HR and CRI in LoopInsp at the different venues. Different letters show significant differences between venues.**

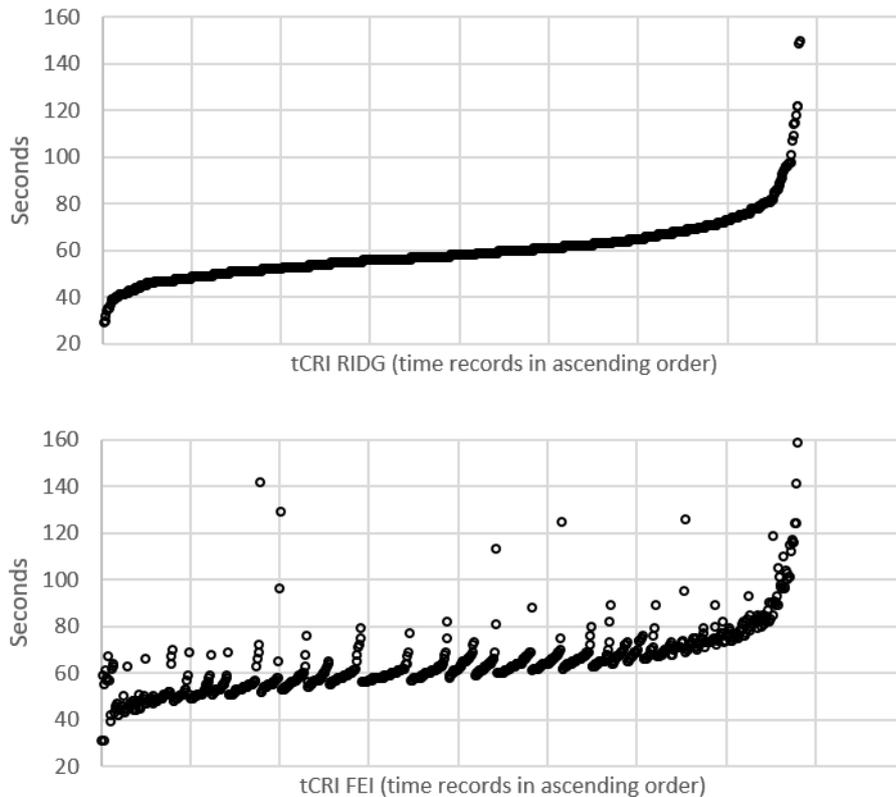
|            | HR (bpm)              |                       |                       | CRI (bpm)             |                      |                       |
|------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------|-----------------------|
|            | LOUB                  | LIGN                  | UZES                  | LOUB                  | LIGN                 | UZES                  |
| Mean±S.D.  | 60.1±7.0              | 58.9±5.0              | 58.7±4.0              | -0.5±5.0              | -0.5±4.0             | -2.0±4.0              |
| Median±IQR | 60.0±6.0 <sup>a</sup> | 60.0±5.0 <sup>b</sup> | 59.0±6.0 <sup>b</sup> | -0.0±7.0 <sup>a</sup> | 0.0±4.0 <sup>a</sup> | -2.0±4.0 <sup>b</sup> |
| Minimum    | 44                    | 80                    | 44                    | -20                   | -12                  | -21                   |
| Maximum    | 100                   | 38                    | 64                    | 9                     | 16                   | 16                    |

Mean, median, maximum and minimum time elapsed from horses entering the vet gate to start of the HR<sub>1</sub> count (for first horse inspections only VG to HR<sub>1</sub>) and the time elapsed from the end of the HR<sub>1</sub> count to the start of the trot are reported in **Table 4**.

**Table 4. Time elapsed from entering the vet gate to HR<sub>1</sub>, from HR<sub>1</sub> to the start of the trot and to perform CRI count according to tCRI<sub>RIDG</sub> and tCRI<sub>FEI</sub>**

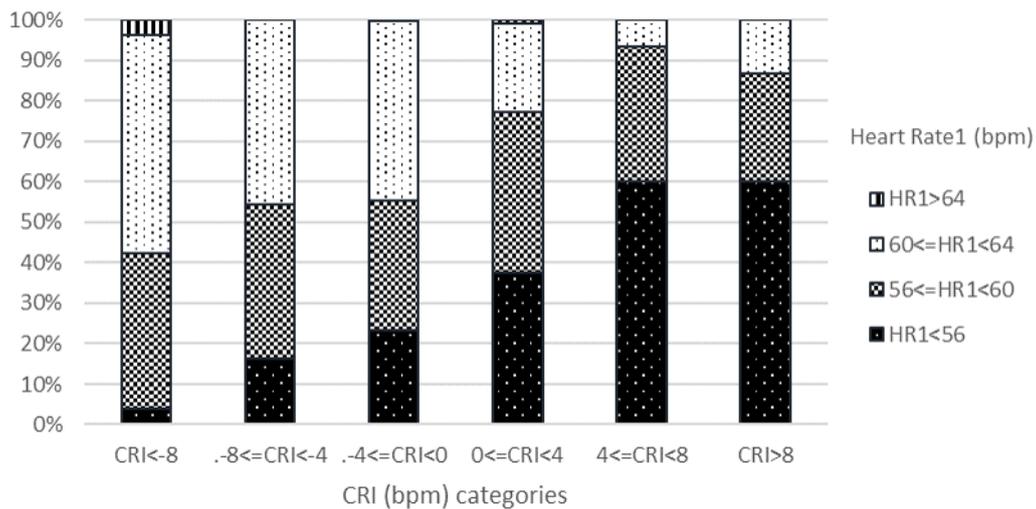
|            | VG to HR <sub>1</sub> | HR <sub>1</sub> to Trot | tCRI <sub>RIDG</sub> | tCRI <sub>FEI</sub> |
|------------|-----------------------|-------------------------|----------------------|---------------------|
| Mean±S.D.  | 1m28s ±1m18s          | 6s±11s                  | 1m0s±13s             | 1m05s±16s           |
| Median±IQR | 1m10s±54s             | 3s±7s                   | 58s±12s              | 1m3s±14s            |
| Minimum    | 4s                    | 0s                      | 29s                  | 31s                 |
| Maximum    | 20m4s                 | 3s±5s                   | 2m30s                | 04m33s              |

No association could be found between the times elapsed from entering the vet gate to the start of the HR<sub>1</sub> count, from the HR<sub>1</sub> count to the start of the trot-up and of other stages of the inspection, and the HR<sub>1</sub> or the CRI ( $P>0.05$ ). The time used to measure the tCRI<sub>RIDG</sub> version versus the tCRI<sub>FEI</sub> version is represented in **Table 4**. Although significant differences were found between veterinarians ( $p < 0.05$ ) for both tCRI<sub>RIDG</sub> and tCRI<sub>FEI</sub>, the tCRI<sub>RIDG</sub> method was more consistently conducted time-wise compared to the tCRI<sub>FEI</sub> method (**Fig.1**).



**Fig. 1.** Time spent in CRI evaluation: original (Ridgeway) vs. modified (FEI) definition

No association was found between  $HR_1$  and CRI, except for the 160 km category where moderate and very strong negative correlations were found in the inspections after the loop ( $r^2 = -0.5$ ;  $p < 0.05$ ) and in the re-inspections ( $r = -0.9$ ,  $p < 0.01$ ), respectively. However, there were a higher proportion of horses with  $CRI \geq 4$  in horses with  $HR_1 < 60$  bpm. For qualified horses, the distribution of the CRI was significantly different ( $p < 0.05$ ) among the heart rate categories of  $HR_1 > 56$  bpm,  $56 \text{ bpm} \geq HR_1 < 60$  bpm and  $60 \text{ bpm} \geq HR_1 \leq 64$  bpm in the first inspections after the loop and re-inspections, but not for eliminated horses (see Fig 2). In the inspections after the loop horses within the categories of  $HR_1 > 56$  bpm ( $n = 113$ ; 20%),  $56 \text{ bpm} \geq HR_1 < 60$  bpm ( $n = 234$ ; 41%) had significantly higher CRIs than the category of  $60 \text{ bpm} \geq HR_1 \leq 64$  bpm ( $n = 216$ ; 39%). Within re-inspections the CRI was significantly higher for horses with a  $HR_1 < 56$  bpm ( $n = 130$ ; 70%), horses with  $56 \text{ bpm} \geq HR_1 < 60$  bpm ( $n = 36$ ; 19%), but not  $60 \text{ bpm} \geq HR_1 \leq 64$  bpm ( $n = 17$ ; 9%). The overall  $HR_1$  for different CRI categories are presented in Fig.2.



**Fig.2.** Distribution of heart rate frequencies according to CRI category in all horses in LoopInsp and RInsp

No significant differences were found in the CRI of qualified *versus* eliminated horses in inspections or re-inspections ( $P > 0.05$ ). There was no association between recovery time, i.e. the time a horse takes to meet the heart rate criteria of less than or equal to 64 bpm before entering the vet gate, and the CRI ( $P > 0.05$ ). However, horses with CRI between -4 and -1 had shorter recovery times than horses with CRI between 0 and 4 or higher.  $HR_1$  was not affected by recovery time, except in eliminated horses where recovery times were higher in horses with  $HR_1 > 60$ bpm.

## Discussion

Interruptions to the flow of the veterinary inspections occur frequently (MM, personal observation) due to logistic reasons inherent to endurance competitions, which can result in involuntary and variable waiting times. In a busy vet gate, most commonly there will be a wait from the entrance into the vet gate to an available veterinarian in a trotting lane that is also usually assigned to perform the  $HR_1$  count. The delay can also occur from the  $HR_1$  count to the start of the trot-up in the following situations: when one or more veterinarian(s) are temporarily assigned to perform only the  $HR_1$  count in a crowded vet gate; when the display of the gate is such that specific corridors at the entrance of the vet gate are assigned just for

HR<sub>1</sub> count; occasionally when the veterinarian is called to participate in a voting panel (three veterinarians need to be anonymously consulted to eliminate a horse) in a different lane. Thus, delays can occur either from the entrance into the vet gate to the HR<sub>1</sub> count and/or from HR<sub>1</sub> count to the start of the trot-up. Less commonly, the trotting time will be delayed, because a horse might not be willing to trot straight away or not want to return; this can be due to factors such as young age, inexperience and/or tiredness.

To our knowledge, the impact of waiting times inside the vet gate in HR<sub>1</sub> and the CRI have not been investigated before. The findings of this study suggest that the CRI and the HR<sub>1</sub> are not significantly affected by variability in the waiting times between the phases of the veterinary inspection, outside of 160km races. No association could be established overall, between venues or competition classes. This is important, because even if the time spent inside the vetting area does not influence the competition results directly, the CRI value, although not a fixed parameter for elimination *per se*, might influence the decision of the veterinary commission to eliminate a horse, call for a requested re-inspection or trigger a withdrawal by a competitor (Robert *et al.*, 2002).

As expected, the duration of the tCRI<sub>RIDG</sub> showed more consistency than the tCRI<sub>FEI</sub>. The tCRI<sub>RIDG</sub> seems to be more appropriate, since it has fewer steps in between the counts, namely the waiting time between HR<sub>1</sub> and the start of the trot. Even if the CRI was not affected by time delays, our findings would advocate that the phrasing in the FEI rules should be changed to the tCRI<sub>RIDG</sub> since it better matches the reality of the vet gate logistics worldwide, especially at major championships.

Though used extensively worldwide, few peer-reviewed reports have evaluated the use of the CRI since the unpublished observations resumed by Slusher, McKay-Smith, and Ridgeway in the proceedings of the Annual Convention of the American Association of Equine Practitioners (AAEP) in 1991 (Ridgeway, 1991; Slusher, 1991). This work observed that fit horses quickly regained their resting heart rate compared to metabolically compromised horses, which would show more labile and higher heart rates after brief exercise (Slusher, 1991). However, it is worth noting that the tCRI<sub>RIDG</sub> method was meant to be used 15 minutes after horses had passed the finish line (Ridgeway, 1991) in order to score the recovery category and not to eliminate horses during the phases of the competition. It was only later that it was adopted worldwide at recovery checks, called re-inspections by the FEI, then to become mandatory for every inspection, including the inspections performed immediately

after each phase in races (FEI, 2019). Since then, veterinarians have been instructed to trot the horses immediately after HR<sub>1</sub> collection in all inspections instead of performing the metabolic examination first as previously prescribed. One of the peer-reviewed studies investigated the CRI in recovery checks, now named by the FEI as re-inspections, only before the last loop (Robert *et al.*, 2002) and the other report studied the risk factors of elimination which included the CRI, but did not specify which type of inspections were used for the study (Fielding *et al.*, 2011). The first study concluded that a CRI  $\geq 4$  had only a predictive value for elimination in the final vet gate if HR<sub>1</sub> > 60 bpm. The second study concluded that the odds of elimination were increased with a CRI > 4.

As expected, our findings were that HR<sub>1</sub> was higher in LoopInsp than RInsp. But they also showed that the CRI was higher in RInsp than LoopInsp. In-between venues, the CRIs were only different in LoopInsp, with LOUB, the venue with warmer weather, showing higher HR<sub>1</sub>, but surprisingly not higher CRI. UZES had the highest CRI, which is most likely explained by the lower HR<sub>1</sub> counts recorded here.

Every endurance veterinarian and most riders/trainers worldwide are taught that a CRI higher than 4 bpm is a 'red flag' regarding the metabolic status of horses. However, the fact that the baseline HR<sub>1</sub> should be taken into consideration when interpreting CRI values is not as widely acknowledged. The 4 bpm value was based on the observations that sound horses were expected to return to (or be even lower than) the baseline measurement and that fatigued horses would have an elevation in the CRI of 4 to 20bpm (Slusher, 1991). Nonetheless, the behaviour of the CRI in relation to different HR<sub>1</sub> and the various timings after the conclusion of the phase was never statistically studied. Ridgeway highlighted that a rise of the CRI of 4 bpm when the HR<sub>1</sub> of a horse was close to resting values (40 to 48 bpm) had little significance and suggested that horses with higher HR<sub>1</sub> should be penalized more heavily. Both Fielding (2011) and Robert (2002) found a predictive value for elimination for a CRI > 4, but Robert did not find a predictive value of the CRI *per se*, but only in association with HR<sub>1</sub> of more than 60bpm. Indeed, a recent non peer-reviewed publication stressed that the two criteria should be taken into account when interpreting the CRI: the magnitude of the heart rates, i.e. if both heart rates are greater than 60 bpm, and the difference between heart rate counts (Gillespie, 2015). Our results also advocate that CRI > 4 in horses with a HR<sub>1</sub> lower than 60bpm lack accuracy and should be interpreted with caution. Independently of the outcome, horses with lower heart rates showed higher CRIs and horses with HR<sub>1</sub> between 60 and 64 bpm tended to have a lower CRI. Although a correlation between HR<sub>1</sub> and CRI could

not be established, the proportion of horses with a CRI  $\geq 4$  was higher in horses with  $HR_1 < 60$  bpm (92% n=55). Our findings suggest that the closer the  $HR_1$  is to the resting heart rate of a non-exercised horse, the higher the CRI might be. For instance, a CRI of 8 in a horse that presents a  $HR_1$  of  $\leq 56$  bpm might be a physiological rise and not be related to metabolic compromise. Therefore, best condition calculations or special classification protocols that take into account the CRI obtained in vet gates might not entirely reflect the metabolic status of a horse. Since we could not find any significant differences for the CRI between qualified and eliminated horses in inspections after the loop or re-inspections, and no associations between variables, a predictive value was not attempted. We could not find any correlation for any elimination, lameness or metabolic-related factors with CRI, in contrast to what has been previously reported (Trevillian, 1997).

Endurance competitions have become very competitive in the last decade. Due to the awareness of the impact of the recovery time in the final results, but also in the market value of a horse, most top horses will enter the vet gate within 3 minutes. Our study did not show any association between recovery time and the CRI for qualified or eliminated horses. However, qualified horses registered lower recovery times and this most likely reflects the preparedness of those horses. We could not find those differences in eliminated horses. This supports the study by Younes *et al.* (2016), reporting that the recovery time is the most sensitive indicator of eliminations in endurance horses.

Elimination rates in endurance rides are high and mostly due to lameness (Bennet and Parkin, 2018; Marlin and Williams, 2018; Nagy *et al.*, 2014). The subjectivity of gait assessment often elicits confrontations between riders/trainers/owners and veterinarians (Mira *et al.*, 2019). In a preliminary study using a portable system based on inertia sensors horses were instrumented after  $HR_1$  count and before the start of the trot. (Lopes *et al.*, 2018), Although not timed in this study, instrumentation of horses is reported to take two to three minutes (Equinosis, 2019), which means a delay between  $HR_1$  and  $HR_2$  counts. However, CRI performed according to the  $tCRI_{RIDG}$  version would not be affected by the delay since the minute starts when the horse commences the trot-up.

We acknowledge that only three venues were studied and that this might not reflect the waiting times of busier competitions and/or different weather conditions. Therefore, larger studies involving more venues and different setups are needed to corroborate our findings. Also, the low numbers of eliminations, were too small to determine the added value of the

CRI to the different types of inspections and to determine significant cut-off values for specific heart rates. More studies are needed to characterize the sensitivity and specificity of the CRI regarding the baseline heart rate.

Although this study did not show an influence of waiting times on the CRI, reduced deviation from the mean was observed across inspecting veterinarians using the original Ridgeway guidelines to calculate the CRI, indicating more consistency. We would therefore suggest that the FEI veterinarian rules should be updated accordingly for improved coherence.

Furthermore, the future use of instrumentation of horses with sensors for gait analysis in the future to determine / judge / evaluate lameness related eliminations should not interfere with the concept of the CRI.

### Footnotes:

<sup>a</sup> The clinical exam and the trot evaluation is registered at every veterinary examination in a specific card that accompanies each horse throughout the competitions.

<sup>b</sup> The CRI was updated in the veterinary FEI rules in 2020 to the version originally described by Ridgeway as recommended by this paper.

### References

- Bennet, E.D. and Parkin, T.D.H., 2018. Fédération Equestre Internationale endurance events: Risk factors for failure to qualify outcomes at the level of the horse, ride and rider (2010–2015). *The Veterinary Journal* 236: 44-48.  
<https://doi.org/10.1016/j.tvjl.2018.04.011>
- Equinosis, 2019. What can I expect during an objective lameness evaluation for my horse? Available at: <https://equinosis.com/horse-owner-faqs-lameness-evaluation/>.
- FEI, 2019. Veterinary Regulations. Available at: <https://inside.fei.org/sites/default/files/2019%20VRs%20final%20-%20Clean.pdf>
- Fielding, C.L., Meier, C.A., Balch, O.K. and Kass, P.H., 2011. Risk factors for the elimination of endurance horses from competition. *J Am Vet Med Assoc* 239: 493-498. 10.2460/javma.239.4.493
- Gillespie, J.R., Kerr, J., Adamson, B., Ellery, J., 2015. Adding to our understanding of cardiac recovery index at endurance rides. *Endurance News*: 19-24.
- Lopes, M.A.F., Eleuterio, A. and Mira, M.C., 2018. Objective Detection and Quantification of Irregular Gait With a Portable Inertial Sensor-Based System in Horses During an Endurance Race—a Preliminary Assessment. *Journal of Equine Veterinary Science* 70: 123-129. <https://doi.org/10.1016/j.jevs.2018.08.008>
- Mackay-Smith M., B.B., Cohen, M., Nelson T., Ridgway K., Steere J., 2016. Guidelines for Control Judges and Treatment Veterinarians at AERC Endurance Competitions. Available at: <https://aerc.org/static/upload/CJHandbook2016.pdf>.

- Marlin, D. and Williams, J., 2018. Equine endurance race pacing strategy differs between finishers and non-finishers in 120 km single-day races. *Comparative Exercise Physiology* 14: 11-18. 10.3920/cep170027
- Mira, M.C.d., Santos, C., Lopes, M.A. and Marlin, D.J., 2019. Challenges encountered by Federation Equestre Internationale (FEI) veterinarians in gait evaluation during FEI endurance competitions: an international survey. *Comparative Exercise Physiology* 0: 1-8. 10.3920/cep180058
- Nagy, A., Murray, J.K. and Dyson, S.J., 2014. Descriptive epidemiology and risk factors for eliminations from Federation Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). *Equine Vet J* 46: 38-44. 10.1111/evj.12069
- Ridgeway, K.J., 1991. Inride veterinary examination, postride examination and judging of best condition., *American Association of Equine Practitioners Annual Convention (AAEP)*. pp. 815-826.
- Robert, C., Benamou-Smith, A. and Leclerc, J.L., 2002. Use of the recovery check in long-distance endurance rides. *Equine Vet J Suppl*: 106-111. 10.1111/j.2042-3306.2002.tb05400.x
- Slusher, S.H.M.-S., M.P., 1991. Endurance ride veterinary control, *Annual Convention of the American Association of Equine Practitioners*. pp. 793-805.
- Trevillian, C.H., J.; Yovich, J., 1997. Evaluation of Cardiac Recovery Index and Clinicopathological parameters in Endurance Horses. *Australian Veterinary Journal* 15: 84-88.