Rasayely
International Journal of Equine Science
https://rasayely-journals.com/index.php/ijes
Vol 5(1);60–70, 2026

Original Article Open Access

Tracking Horse and Rider Speed During Warm-Up and CCI4* Short and Long Format Cross-Country Using a Commercial Wearable GPS Sensor

David J. Marlin[1,*], Russell McKechnie-Guire[2], Heather Cameron-Whytock[3], and Andrew Lombard[4]

[1]*AnimalWeb Ltd, The Granary, Hermitage Court, Maidstone, ME16 9NT, United Kingdom*
[2]*Equestrian Performance Research Centre, Hartpury University, Hartpury, Gloucester GL19 3BE, United Kingdom*
[3]*School of Veterinary Medicine, University of Lancashire, Preston, Lancashire, PR1 2HE, United Kingdom*
[4]*Institute for Sport, Physical Education and Health Sciences, University of Edinburgh, United Kingdom*

*Author to whom any correspondence should be addressed; Email: dm@davidmarlin.co.uk

Received: 16 November 2025; Revised: 21 January 2026; Accepted: 30 March 2026; Published: 30 April 2026

Academic Editor: Denise Pereira Leme, Federal University of Santa Catarina, Brazil

Abstract

There is some evidence that appropriate warm-up and pacing are key to successful performance and injury risk reduction in equestrian endurance and horseracing. To date, only limited studies of warm-up for eventing cross-country have been reported, and to our knowledge, there has been no report of continuous cross-country speed and pacing strategy. The aim of the present study was to investigate how riders warm up and the pacing strategy they use on cross-country. Riders competing in CCI4* short (n = 11) and long (n = 7) competition were fitted with a Catapult Vector S7 sensor. Ten horses completed the CCI4*S, and all 7 completed the CCI4*L. Riders spent significantly longer warming up for the CCI4*L (30.2 ± 9.2 min; mean ± SD) than for the CCI4*S (20.7 ± 7.0 min; $P = 0.029$). Mean speed on the CCI4*S was 525 ± 15 m/min (range 500–544 m/min) and was slower than the CCI4*L 557 ± 21 m/min (range 533–584 m/min) ($P = 0.002$). Variance in speed over the whole course for each individual horse (SD/mean*100) was 22 ± 3% for CCI4*S and 24 ± 3% for CCI4*L ($P > 0.05$). Mean jump speed was 404 ± 12 m/min (range 393–424 m/min) for CCI4*S and 393 ± 16 m/min (range 361–405 m/min) for CCI4*L and was not significantly different ($P > 0.05$). Differences were found in mean peak inter-fence/combination speed, 639 ± 20 m/min (range 615–674 m/min) for CCI4*S and 678 ± 28 m/min (range 634–703 m/min) for CCI4*L ($P = 0.004$). High variance in speed over the course and very low or very high fence approach speeds may potentially play a role in fatigue and/or fall risk and warrant further study.

Keywords

Equestrian; competition; jumping; safety; performance; eventing

1. Introduction

Warm-up and effective pacing strategies are recognized as critical components for optimizing human sports performance and reducing injury risk. A well-structured warm-up increases muscle temperature, enhances blood flow, and improves neuromuscular coordination, which collectively prepare the body for the physical demands of exercise. A meta-analysis by [1] demonstrated that warm-ups incorporating dynamic stretching and sport-specific movements can significantly enhance performance metrics such as power output and agility, while lowering the incidence of musculoskeletal injuries. Additionally, pacing strategies tailored to an athlete's physiological capacity and the event's duration help maintain energy efficiency and prevent over-exertion, a key factor in injury risk reduction [2]. Effective pacing minimizes fatigue-induced biomechanical errors, which are linked to strains and sprains [2]. Together, these practices form a foundational approach to maximizing human athletic output and safeguarding long-term health in sports contexts.

Warm-up is also a critical component of equestrian competition. A warm-up period of approximately 10–15 minutes increases muscle temperature by approximately 1–2 °C, enhancing muscle elasticity and reducing the risk of strains or tears. This temperature elevation accelerates enzymatic reactions and improves oxygen delivery via increased blood flow [3]. A variety of authors have studied warm-up in dressage, showjumping, and Thoroughbred and Standardbred racing (see review by [4]), although there are limited studies investigating warm-up for cross-country [5]. With regard to pacing, this has been studied in racehorses [6–8] and in equine endurance [9–11]. In addition, high fence approach speed has been identified as a risk factor for falls in eventing [12]. While a large number of commercial, accurate systems for speed and positioning have been available for some time, such as those produced by Garmin, Apple, and Polar, as far as we are aware, warm-up and eventing cross-country speed patterns have not been reported using such devices.

Burger *et al.* [13] reported on 54 cross-country rounds across 33 horses and five competitions, including CCI4*S and CCI4*L, using a commercial sternally mounted GPS and inertial measurement sensor (Alogo Move Pro Equine Sensor, Alogo Analysis SA, Switzerland). While this sensor has been validated for stride kinematics on the flat and over jumps, the accuracy for speed over longer distances has not been reported [14].

The Catapult Vector S7 is an advanced wearable sensor system designed for elite sports performance monitoring, offering precise tracking of speed, position, and biomechanical metrics. Integrating 10 Hz multi-GNSS (GPS, GLONASS, Galileo) and ClearSky Local Positioning System (LPS) technology, it delivers high-accuracy data in both outdoor and indoor environments, with positional precision below 1 meter indoors and speed measurement errors as low as 0.12–0.21 $m \cdot s^{-1}$ outdoors, validated against laser and motion capture systems [15].

The present study aimed to investigate the use of commercially available sensors to track horse and rider speed and distance during the cross-country phase of CCI4* short (S) and long (L) format competitions using the Catapult Vector S7 sensor. The CCI4*-S (Concours Complet International 4 Star – Short) is an international equestrian eventing competition under FEI rules (Fédération Équestre Internationale) rated at the four-star level. It spans two to three days, including dressage, a shortened cross-country course (5,700–6,840 meters, up to 40 jumps, 10–12 minutes at 570 m/min), and show jumping (450–550 meters, up to 15 efforts, 375 m/min). Horses must be at least 7 years old, and riders must be at least 18 years old. The CCI4*-L (Concours Complet International 4 Star – Long) is an international equestrian eventing competition at the four-star level, using a long format under FEI rules. Held over three to four days, it includes dressage, a longer cross-country course (6,270–7,410 meters, up to 45 jumps, 11–13 minutes at 570 m/min), and show jumping (500–600 meters, up to 15 efforts, 375 m/min). The cross-country phase is the longest and most physically demanding, with frequent acceleration and deceleration, turns, jumps, and often variable terrain and ground conditions. Appropriate warm-up and appropriate speed and pacing strategy are likely to be crucial in eventing, particularly at higher levels, to reduce the risk of early fatigue and falls and to maximize performance. The present study aimed to investigate how riders warm up for CCI4* competition and the pacing strategy they use on cross-country. Specifically, we monitored horse and rider combinations competing at the Bramham International Horse Trials (2023) from the start of warm-up until the end of the cross-country to allow us to investigate the pattern and intensity of both warm-up and competition.

2. Materials and Methods

2.1. Horses and Riders

Data were collected from 10 International-level riders competing in either or both the cross-country phases of the Bramham International Horse Trials CCI4*S or the CCI4*L in June 2023. Riders were invited privately and individually to participate by British Equestrian staff, and participation was optional. One rider who was invited declined to participate. A total of 18 cross-country rounds were recorded. Seven riders attempted 11 cross-country rounds on 11 horses (4 riders, 1 round; 2 riders, 2 rounds; and 1 rider, 3 rounds). Seven riders completed 7 cross-country rounds on 7 horses. Details of the horses are given in **Table 1**. Details of the two cross-country courses are given in **Table 2**, along with maps of the course showing the track and jump positions and elevation over distance in Figures S1 and S2 (**Supplementary Materials**).

2.2. Data Collection

Each rider was fitted with a Lycra vest and a GPS sensor (Vector S7, Catapult UK, 2a Southwark Bridge Rd, London SE1 9HA) (**Figure 1**). Catapult Vector S7 is widely used in professional sports such as rugby, football, basketball, American football, and cricket. The sensor is 81 mm × 43 mm × 16 mm and weighs 53 g. The GPS system uses standard GPS, GLONASS, and SBAS and records position ten times per second (10 Hz). Based on pilot data collection prior to this competition, it was not deemed necessary to apply any post-data collection processing to the speed data. The Lycra vest was fitted over the rider's body protector. If an air jacket was used, then this was fitted over the body protector and the Vector S7 sensor. In addition to GPS data at 10 Hz, from which speed is derived, the sensor also provides 3-axis acceleration (±16 g), which is sampled at 1 kHz and output at 100 Hz, and a 3-axis gyroscope, which provides 2000°/s output at 100 Hz.

The sensor was manually activated at the time of fitting to the rider prior to mounting, i.e., before the commencement of warming-up to record warm-up and cross-country.

Table 1: The age, sex, and breeding of the seven horses and rider ID studied in the CCI4*S and eleven horses studied in the CCI4*L competitions at Bramham in 2023.

Competition	Horse	Rider ID	Age (years)	Sex	Breed/Studbook
CCI4*L	L1	1	10	G	Irish Sport Horse (ISH)
CCI4*L	L2	2	11	G	Zangersheide/British Sport Horse
CCI4*L	L3	3	10	G	British Sport Horse (SHBGB)
CCI4*L	L4	4	10	G	Dutch Warmblood (KWPN)
CCI4*L	L5	5	12	G	Irish Sport Horse (ISH)
CCI4*L	L6	6	10	M	British Sport Horse
CCI4*L	L7	7	13	S	British Sport Horse (SHBGB)
CCI4*S	S1	2	11	M	Anglo European Studbook (AES)
CCI4*S	S2	4	9	G	Irish Sport Horse (ISH)
CCI4*S	S3	4	17	G	Irish Sport Horse (ISH)
CCI4*S	S4	5	11	G	Irish Sport Horse (ISH)
CCI4*S	S5	6	10	G	Irish Sport Horse (ISH)
CCI4*S	S6	8	11	M	Anglo European Studbook (AES)
CCI4*S	S7	8	9	G	Irish Sport Horse (ISH)
CCI4*S	S8	8	10	G	Dutch Warmblood (KWPN)
CCI4*S	S9	9	12	M	Sport Horse (British/Irish lineage)
CCI4*S	S10	9	10	M	Holsteiner (HOLST)
CCI4*S	S11	10	12	M	British Sport Horse (SHBGB)

Table 2: Cross-country course characteristics for CCI4*S and CCI4*L at Bramham International Horse Trials in 2023.

	Length (m)	Speed (m/min)	Optimum time (mm:ss)	Jumping efforts	Jumping efforts meter/effort	Total climb (m)	Total descent (m)
CCI4*S	3810	570	6:42	34	112	+88	−94
CCI4*L	5885	570	10:20	41	144	+136	−163

2.3. Data Analysis

After retrieval of the sensors from riders following completion of the cross-country, the sensor data were downloaded via the download dock to the Catapult Openfield Operator Console software. From here, data were exported as CSV files for further analysis in Microsoft Excel. The start and end of cross-country were identified from a combination of the distinctive pattern of speed (see **Figure 2**, **Figure 5**, and **Figure 6**), speed increase, and location on course from the *.kml files overlaid in Google Earth Pro.

Average speed and standard deviation of speed were used to calculate variation in speed as SD/mean*100 (% coefficient of variation; %CV). Average approach speed to each fence or fence complex (identified by both speed nadirs and position from .kml files in Google Earth Pro) and peak and mean speed between fences/fence complexes were calculated using a Python routine run in Google Colab with visual validation. The code is available on GitHub: https://github.com/DJ61M/Cross-Country-Speed-Peak-and-Nadir-Detection-. Shapiro-Wilk tests confirmed that the data assumed a normal distribution and met the requirements for use of parametric statistical tests. Differences between CCI4*S and CCI4*L were investigated with independent t-tests. Significance was set at $P < 0.05$. Differences over time were investigated with ANOVA and post-hoc Tukey's test, where significance was reached. Potential relationships between jumping effort progression and inter-fence peak speed or jump minimum speed were investigated with the Pearson correlation coefficient. Data are reported as mean ± SD. Official times and records (i.e., clear, refusal, fall, hold on course, etc.) for cross-country were obtained from the organizers and from fence judge sheets. Holds on course were identified from the speed data from the sensor in conjunction with the fence judge sheets. The sections of data corresponding to the hold period were removed from the dataset for final analysis.

2.4. Ethical Approval

Specific ethical approval for this study was not required as the study involved only wearing a commercially available non-invasive sensor by athletes already competing under Team GB, posed no greater risk than routine training or wearing a watch, collected fully anonymized data with no identifiable private information, aligned with UK Sport/Team GB performance monitoring protocols, and obtained informed consent consistent with event participation and the Declaration of Helsinki, including permission to use the data collected from them and their horses. For the time that the researchers interacted with the horses and riders, any interaction with the horses was conducted in full compliance with the UK Animal Welfare Act 2006, ensuring that all reasonable steps were taken to meet the animals' welfare needs and to prevent any unnecessary suffering, in line with the Act's provisions and the Five Freedoms framework.

3. Results

Complete datasets were successfully obtained from all horse and rider combinations. All horse and rider combinations completed the warm-up (n = 18). All riders completed all cross-country rounds with the exception of the rider undertaking 3 rounds on the CCI4*S, who retired one horse. This combination's data were excluded from further analysis. Therefore, data are presented for 10 combinations in the CCI4*S and 7 combinations in the CCI4*L (n = 17). Air temperature ranged from 20 °C to a high of 22 °C, with relative humidity ranging from 90% to 60%. The wind was around 16–19 km/h. There was no rain. Prior to the competition, there had been little rain, and there had been watering of the course. The going was considered to be good to firm.

3.1. Warm-Up

Riders spent significantly less time warming up for the CCI4*S (20.7 ± 7.0 min) than for CCI4*L (30.2 ± 9.2 min; P = 0.029). Peak warm-up speed was 479 ± 41 m/min for CCI4*S and 537 ± 122 m/min for CCI4*L (P > 0.05). The time between the last period of canter exercise during warm-up and the start of the cross-country was 6.0 ± 2.5 min (range 2.8 to 10.7 min) for CCI4*S and 3.9 ± 2.6 m/min (range 0.2–7.2 min) for CCI4*L (P > 0.05). The time spent standing (once warm-up had started based on walking, trotting, or cantering), walking, trotting, and cantering for CCI4*S and L is shown in **Figure 3**. There was no significant difference between competitions in warm-up duration in stand (P = 0.720), walk (P = 0.094), or canter (P = 0.085), but horses competing in CCI4*L spent significantly longer in trot than horses in CCI4*S (3.7 ± 1.5 min versus 1.5 ± 1.2 min; P = 0.004). The amount of time spent warming-up according to speed is shown in **Figure 4**, with a similar pattern for CCI4*S and CCI4*L.

3.2. Cross-Country

In the CCI4*S, 5 horses were clear inside the time, and 5 were clear inside the time but received jumping penalties. In the CCI4*L, all horses were inside the time, but 3 received jumping penalties. No horses were held on course during the CCI4*S, but 2 horses were held on course during the CCI4*L. The results for horse and rider combinations in this study are shown in **Table 3**.

An example of the speed against distance for rider 10 with fences marked is shown in **Figure 5a** for CCI4*S, with a position plot from the GPS latitude and longitude data in Google Earth in **Figure 6**. An example of the speed against distance for rider 1 with fences marked is shown in **Figure 5b** for CCI4*L.

Figure 1: Catapult Lycra vest and Vector S7 GPS unit in position over body protector.

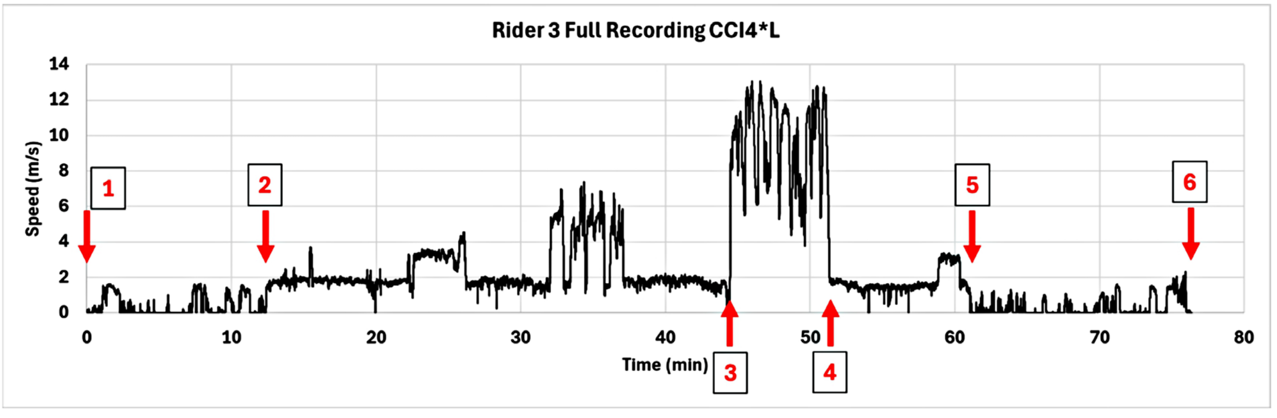

Figure 2: An example of a full recording from Rider 3 for CCI4*L. 1 – Time 0 corresponding to the Catapult sensor being turned on and the start of the recording; 2 – Rider mounts horse; 3 – Start of cross-country; 2–3 – warm-up; 4 – end of cross-country; 3–4 – cross-country; 5 – rider dismounts; 6 – sensor retrieved from rider and turned off to end recording.

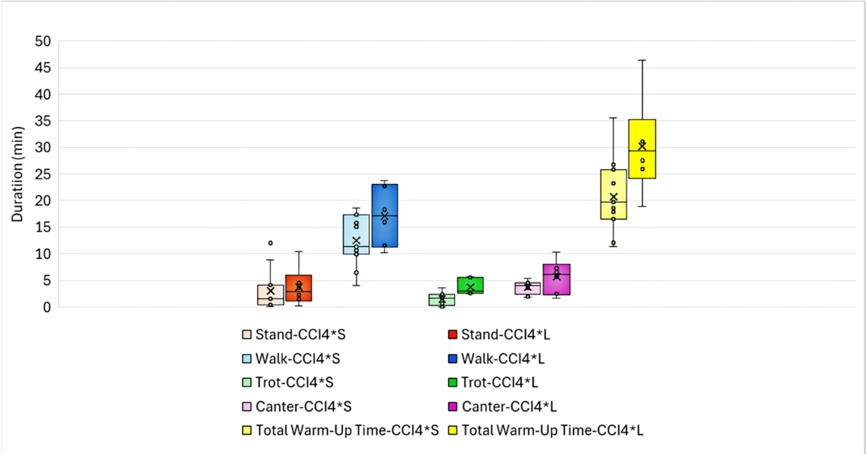

Figure 3: Duration (min) spent in stand, walk, trot, or canter and total warm-up time for horses competing in CCI4*S (n = 11) and CCI4*L (n = 7).

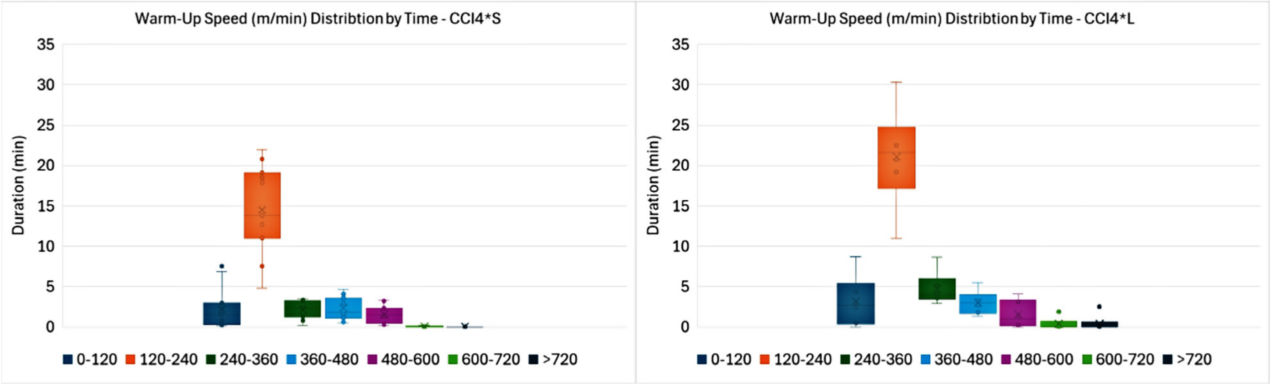

Figure 4: Duration (min) by speed brackets (m/min) for horses competing in CCI4*S (n = 11) and CCI4*L (n = 7).

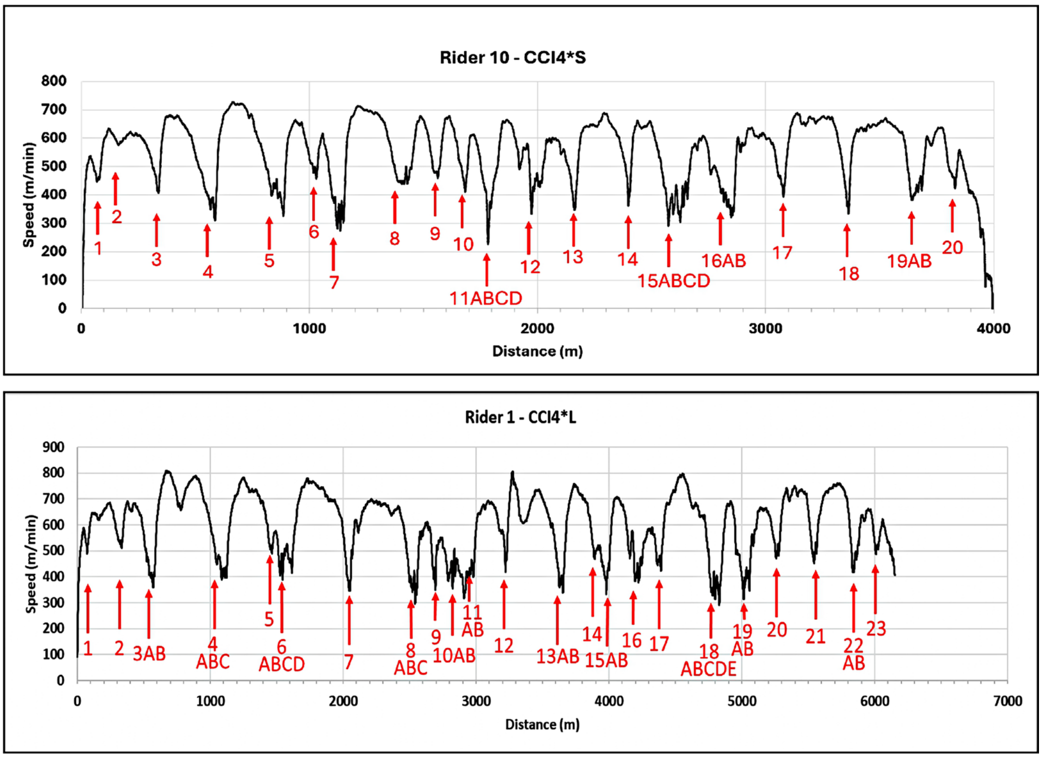

Figure 5: Examples of speed (m/min) versus distance (m) for rider 10 in the CCI4*S (a) and for Rider 1 in the CCI4*L (b). Fence numbers are marked in red.

Table 3: Full results for horses monitored in the CCI4*L (7 combinations) and CCI4*S (11 combinations) at Bramham 2023.

Competition	Horse	Rider	Dressage score	Showjumping penalties	Showjumping time faults	Cross-country jumping penalties	Cross-country time penalties	Final score	Final position
CCI4*L	L1	1	30.8	0	0	0	0	30.8	2
CCI4*L	L2	2	29.9	4	0	20	18.4	72.3	25
CCI4*L	L3	3	29.3	0	0	0	1.2	30.5	1=
CCI4*L	L4	4	29	W	W	20	16.8	W	W
CCI4*L	L5	5	32.3	W	W	11	10.8	W	W
CCI4*L	L6	6	32.2	0	0	0	2.8	35	4
CCI4*L	L7	7	26.5	4	0	0	0	30.5	1=
CCI4*S	S1	2	34.4	8	0	15	8.4	65.8	30
CCI4*S	S2	4	36.9	4	0	0	8.4	49.3	13
CCI4*S	S3	4	32.6	4	0	40	34.4	111	49
CCI4*S	S4	5	37.6	4	0	20	19.2	80.8	40
CCI4*S	S5	6	28.7	4	0	20	18.4	71.1	36
CCI4*S	S6	8	37	0	0	0	13.2	50.2	16
CCI4*S	S7	8	39.9	4	0	20	21.2	85.1	42
CCI4*S	S8	8	33	8	0	R	0	R	R
CCI4*S	S9	9	40.3	0	0.4	0	10.4	51.1	18
CCI4*S	S10	9	39.6	4	0	0	18.4	62	27
CCI4*S	S11	10	36.3	4	0	0	4.8	45.1	7

W = withdrawn; R = retired

3.3. Speed and Speed Variance

Mean speed on the CCI4*S was 525 ± 15 m/min (range 500–544 m/min) and was slower than on the CCI4*L, which was 557 ± 21 m/min (range 533–584 m/min; $P = 0.002$). Variance in speed over the whole course for each individual horse (SD/mean*100) was 22 ± 3% for CCI4*S and 24 ± 3% for CCI4*L ($P > 0.05$). Mean speed for each quarter of the course is shown in **Figure 7**. Mean speed was significantly greater for each quarter and overall for the whole course for CCI4*L compared with CCI4*S, with the exception of the final quarter of the course. Mean speed and %CV of mean speed for CCI4*S and CCI4*L as a % of the course completed are shown in **Figure 8**.

3.4. Time & Distance

The official distance of the course, the distance ridden reported by the Catapult sensor, the official completion time, and the time reported by the Catapult sensor for the CCI4*S and CCI4*L are reported in **Table 4** and **Table 5**. For the CCI4*S, the difference between the official cross-country time and the Catapult-reported time was 2 ± 1 s (range 1–3 s). This represents an error of 0.22 to 0.77%. For the CCI4*L, the difference between the official cross-country time and the Catapult-reported time was greater, 4 ± 6 s (range 1–17 s). However, it was clear that the larger discrepancy was related to the two horses held on course (+6 s and +17 s) and likely due to differences between how the hold was assessed from the recordings and by the official time from the event. Excluding these two horses, the difference was 1 ± 1 s (range −1–2 s). For the Catapult-reported distance traveled compared with the official course distance, for the CCI4*S, this was 121 ± 105 m, representing an average increase over the official course distance of 3%. For the CCI4*L, the average distance was 218 ± 131 m longer than the official course distance, representing an average increase in distance of 3.7%. Therefore, the Catapult system demonstrated high accuracy for both time and distance, with an error always less than 0.05% for time compared with the official time and 3.4 ± 2.5% for distance. It should be remembered that the ridden distance may naturally vary from the official distance due to the specific path riders choose, and that this discrepancy does not necessarily represent a true "error."

3.5. Jump Speed, Maximum Inter-Fence/Combination Speed, and Speed Variance

Mean jump speed was 404 ± 12 m/min (range 393–424 m/min) for CCI4*S and 393 ± 16 m/min (range 361–405 m/min) for CCI4*L and was not significantly different ($P > 0.05$). Mean peak inter-fence/combination speed was 639 ± 20 (range 615–674 m/min) for CCI4*S and 678 ± 28 m/min (range 634–703 m/min) for CCI4*L ($P = 0.004$).

There was no significant correlation between jumping effort progression and inter-fence peak speed or jump minimum speed for CCI4*S (peak speed r^2 0.02 ± 0.02, range 0.00–0.05, $P > 0.05$; minimum jump speed r^2 0.03 ± 0.06, range −0.04–0.17, $P > 0.05$) nor for CCI4*L (peak speed r^2 0.01 ± 0.03, range 0.00–0.07, $P > 0.05$; minimum jump speed r^2 0.03 ± 0.03, range 0.00–0.08, $P > 0.05$).

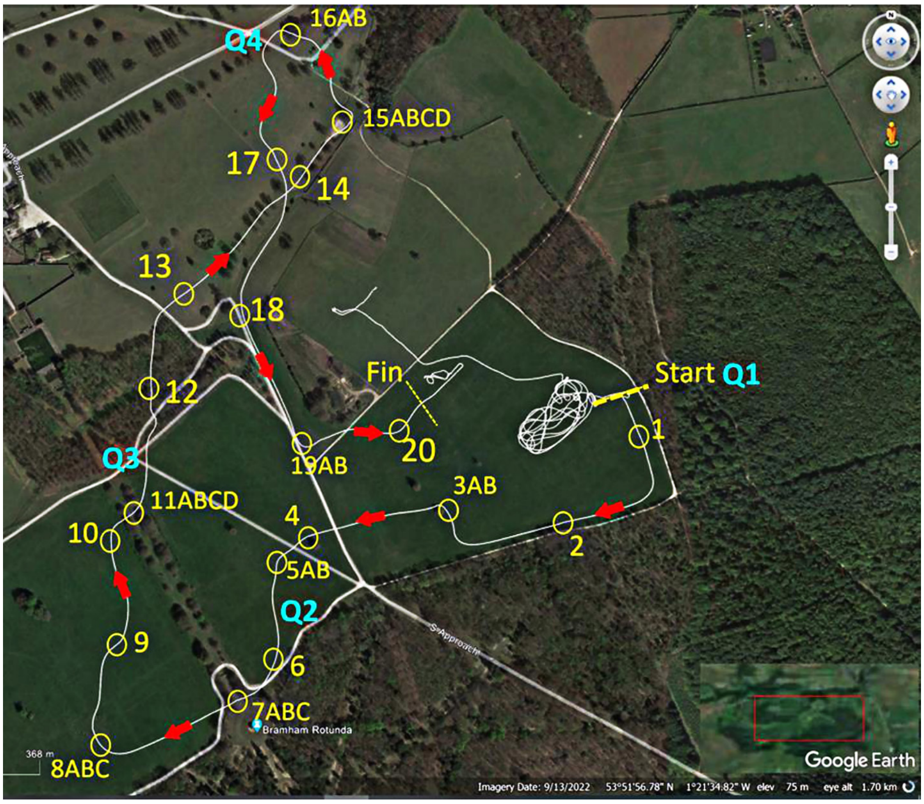

Figure 6: Actual track taken by rider 10 in CCI4*S cross-country overlain on Google Earth (white line) using the exported latitude and longitude data from Catapult. Jump locations are marked in yellow. The start of each quarter of the course is marked by blue Q1–Q4 (See **Figure 7**). Red arrows show the direction of travel.

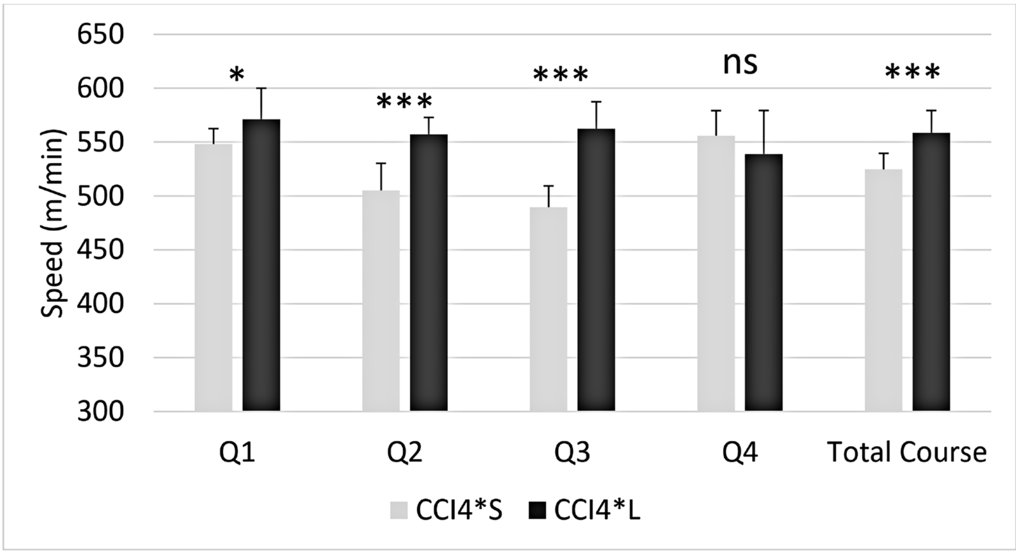

Figure 7: Mean speed (±SD) for each quarter of the course (Q1 to Q4) and the total course for horses competing in the CCI4*S (n = 10) and CCI4*L (n = 7). * = $P < 0.05$; *** = $P < 0.001$.

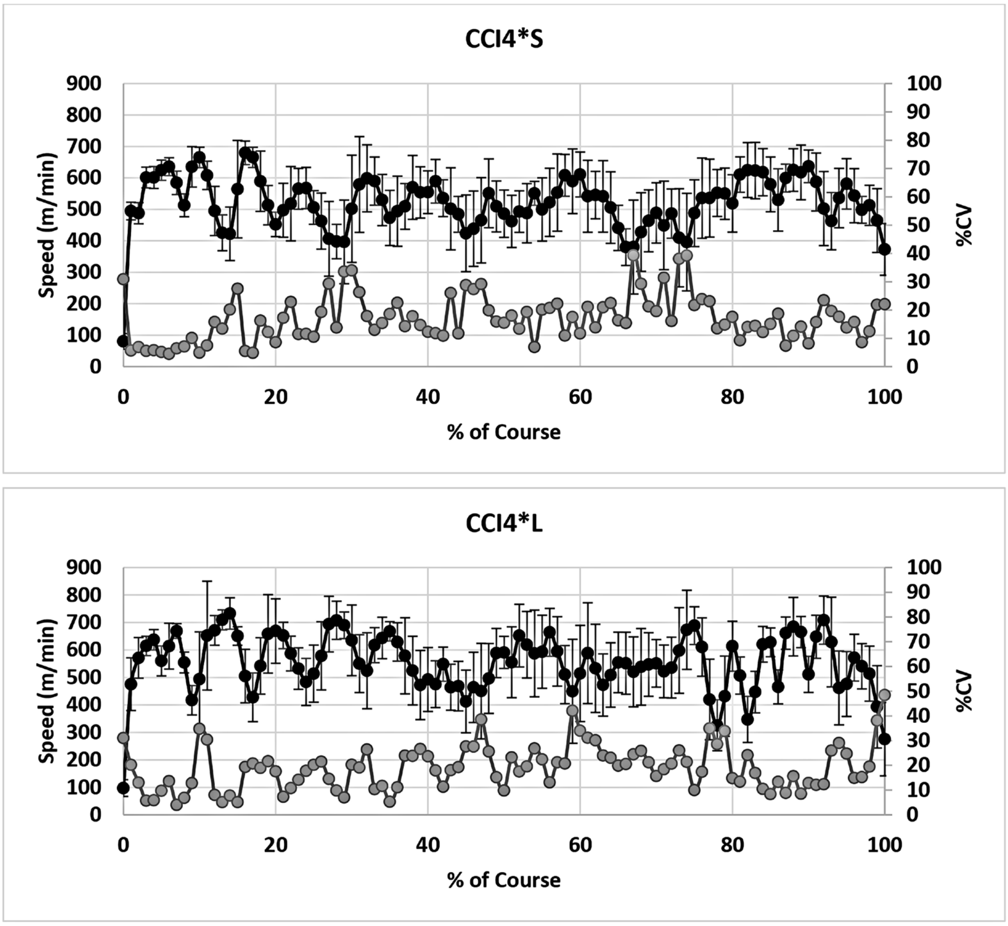

Figure 8: (a, b) Mean ± SD speed (m/min; black circles) and %CV of speed (SD/mean speed*100; grey circles) as % of course completed for combinations completing the CCI4*S (n = 10) and CCI4*L (n = 7).

4. Discussion

Riders spent longer warming-up for CCI4*L (~30 min) than CCI4*S (~21 min). However, for both S and L, the majority of warm-up time was spent in walk. The required average speed for S and L was 570 m/min, and only two horses approached that intensity during the warm-up, both in L. In human sport, for most activities, research suggests a warm-up intensity of 50 to 80% of maximal effort or competition intensity, with the lower end for endurance-based sports and the higher end for high-intensity sports, with a duration of 10–20 min with a gradual increase in intensity [1,16–18]. As far as we are aware, there is only one previous report of warm-up duration in eventing [5]. Valle *et al*. [5] recorded speed and heart rate using a Polar Pro Trainer 5 in 5 horses competing in an intermediate 2-day event (Distance: 2,460 m; Speed: 510 m/min; Time: 4:50 min; Fence height: 1.05 m) and 5 horses competing in an advanced 2-day event (Distance: 2,700–3,100 m; Speed: 520–530 m/min; Time: 5:20–5:51 min; Fence height: 1.10–1.15 m). Mean warm-up time was 28 min for both the intermediate and advanced competitions. Mean warm-up speed was 119 m/min and 170 m/min for the intermediate and advanced competitions, respectively, while peak mean warm-up speed was 379 m/min and 433 m/min, respectively. There were no significant differences between intermediate and advanced. Compared with the present study at a higher level, warm-up duration was similar for L (30 min vs 28 min) but shorter for S (21 min vs 28 min).

Warm-up should be used to increase body temperature, which increases aerobic efficiency and to ensure a high degree of splenic contraction, which in turn will increase oxygen uptake kinetics [3]. Warm-up that is of too low an intensity and/or completed too long before the start of competition will be less effective due to failure to sufficiently mobilize red blood cells into the circulation and/or allowing significant re-uptake of red blood cells by the spleen. The time between the last cantering exercise in warm-up and the start of the cross-country did not differ between S and L. Overall, the mean duration was around 5 min, but varied from as little as 0.2 to 10.7 min. If it is assumed that warm-up should be at 80% of competition intensity, then 80% of 570 m/min is equivalent to 456 m/min. However, as mean peak speeds were 638 m/min for CCI4*S and 678 m/min for CCI4*L, this would equate to warm-up speeds of 510 and 542 m/min, respectively. It appears that, on average, less than a few minutes was spent at this intensity for either CCI4*S or L. A typical warm-up for a human athlete for an event at 90–100% VO_2max and lasting around 10 min might consist of Extended Light Aerobic Activity (5–10 minutes), Dynamic Stretching and Mobility Exercises (5–7 minutes), High-Intensity Intervals (4–6 minutes), and finally Event-Specific Drills (3–5 minutes), with the entire warm-up lasting approximately 15–25 minutes, and concluding the warm-up shortly before the event to maintain the physiological benefits [1,16].

Table 4: Cross-country official distance and time, and Catapult sensor-reported distance, time, and calculated speed and faults for 10 horses and riders competing in the CCI4*S. Horse 11 is not shown as it was retired by the rider at 1400 m into the course.

Class	Rider number	Hold on course	Official distance (m)	Ridden distance from Catapult (m)	Difference (m)	Official time (mm:ss)	Catapult time (mm:ss)	Difference (s)	Catapult average speed (m/min)	Time faults	Jumping penalties
CCI4*S	1	N	3810	3884	74	07:35	07:36	1	512	21.2	20
CCI4*S	2	N	3810	3960	150	07:30	07:31	1	528	19.2	20
CCI4*S	3	N	3810	3869	59	07:03	07:06	3	549	8.4	0
CCI4*S	4	N	3810	3869	59	07:08	07:09	1	542	0	0
CCI4*S	5	N	3810	4119	309	08:08	08:09	1	506	0	40
CCI4*S	6	N	3810	4113	303	07:15	07:17	2	567	0	0
CCI4*S	7	N	3810	3943	133	07:28	07:29	1	528	18.4	20
CCI4*S	8	N	3810	3869	59	07:28	07:30	2	518	0	0
CCI4*S	9	N	3810	3840	30	06:54	06:56	2	557	4.8	0
CCI4*S	10	N	3810	3845	35	07:03	07:04	1	540	0	15
			Mean	3931	121	07:21	07:22	2	535	14.4	12
			SD	105	105	00:21	00:21	1	20	7.3	14
			Min	3840	30	06:54	06:56	1	506	0	0
			Max	4119	309	08:08	08:09	3	567	21.2	40

Table 5: Cross-country official distance and time, and Catapult sensor-reported distance, time, and calculated speed and faults for 7 horses and riders competing in the CCI4*L.

Class	Rider number	Hold on course	Official distance (m)	Ridden distance from Catapult (m)	Difference (m)	Official time (mm:ss)	Catapult time (mm:ss)	Difference (s)	Catapult average speed (m/min)	Time faults	Jumping penalties
CCI4*L	1	N	5885	6067	182	10:20	10:21	1	587	0.0	0
CCI4*L	2	N	5885	6038	153	11:06	11:05	−1	544	18.4	20
CCI4*L	3	Y	5885	6310	425	10:23	10:40	17	608	1.2	0
CCI4*L	4	N	5885	6041	156	11:02	11:04	2	548	16.8	20
CCI4*L	5	Y	5885	6263	378	10:47	10:53	6	581	10.8	11
CCI4*L	6	N	5885	6038	153	10:27	10:28	1	578	2.8	0
CCI4*L	7	N	5885	5961	76	10:10	10:10	0	586	0.0	0
			Mean	6103	218	10:36	10:40	4	576	7.1	7
			SD	131	131	00:21	00:21	6	23	8.1	10
			Min	5961	76	10:10	10:10	−1	544	0	0
			Max	6310	425	11:06	11:05	17	608	18.4	20

Optimal speed and pacing are critical factors in success in many human and equestrian sports, with initial high speed or high variation in speed linked to early elimination or poor performance. The use of inappropriate and highly variable pacing strategies has been associated with poor performance in human endurance running [19–21]. Interestingly, riders who adopted a more consistent pacing strategy in equine endurance racing were less likely to be eliminated for metabolic- or lameness-related problems [9,10]. In particular, the speed selected to complete loop 1 of races was influential with respect to non-completion for gait-related reasons, with horses whose riders selected unsustainable initial speeds on loop 1 more likely to subsequently be eliminated due to lameness [9,10]. The overall race strategy, combined specifically with loop 2 pace, appears key to preventing elimination for metabolic reasons. Race speed has previously been related to increased levels of horse elimination in endurance races [22], leading to suggestions that non-completion could be due to owners and riders selecting inappropriate race strategies to facilitate success.

Burger *et al*. [13] reported mean and peak speed between jumps of 583 m/min and 735 m/min for the second minute of the cross-country, respectively, combined for all competitions studied, and 579 m/min and 751 m/min, respectively, for the last minute of the cross-country. These were not significantly different between the second minute and the last minute. In contrast, in the present study, the mean peak inter-fence/combination speed was lower (639 m/min for CCI4*S and 678 m/min for CCI4*L) and significantly greater for the CCI4*L. The reason for the difference between the CCI4*S and CCI4*L may be related to the average distance between jumping efforts of 112 and 144m, respectively, allowing more time for horses to reach a higher peak speed before the need to slow down for the next obstacle. Mean speed at jumps was reported to be 415 m/min and 441 m/min (second and last minute, respectively) and was not significantly different [13] and compares closely to the present study, where mean jump speed over the whole course was 404 m/min for CCI4*S and 393 m/min for CCI4*L and was not significantly different.

With respect to the CCI4* compared with the CCI4*L, in terms of the pacing strategy, riders in the CCI4*L maintained a similar average speed across all 4 quarters of the course, while riders in the CCI4*S slowed from Q1 to Q2 and Q2 to Q3, increasing speed in Q4 to that in Q1. This suggests the horses were not fatigued and that potentially the drop in speed during the middle of the course was likely linked to the nature of the fences, as challenging fences are usually avoided very early and/or very late in cross-country courses. It also suggests that riders may adopt a similar approach at the start and end of the cross-country. In addition, as mentioned above, jumping efforts are more frequent in CCI4*S compared with CCI4*L.

From an applied perspective, riders spend the majority of the time warming up in walk and trot with little, if any, exercise approaching the speeds they will ride at on the course. In terms of common approaches in human sport, this would seem less than optimal. In addition, riders in the present study appear to rapidly accelerate and decelerate rather than attempt a more constant speed. Analysis of cross-country warm-up and competition using wearable technology has the potential to inform coaches and riders on how to optimize strategy to delay the onset of fatigue and ensure clear rounds within the time. Given that of 18 horses monitored, 8 incurred cross-country jumping penalties, 1 retired on course, and 15 received cross-country time penalties, it would appear that there is an opportunity to improve.

4.1. Limitations

Limitations of this study include the relatively small number of horse and rider combinations studied (n = 18). It is important to consider that the reported data in this study are effective for the rider, as the sensor was mounted on the rider. However, as the riders' motion while mounted is only likely to vary imperceptibly from that of the horse, any error in the reported speed of the horse-rider combination will likely be minimal.

5. Conclusion

In conclusion, the present study has demonstrated that the Catapult Vector S7 sensor system is suitable and accurate for determining speed and distance traveled during high-level eventing cross-country competition, including warm-up. In addition, a number of significant differences between CCI4*S and CCI4*L format events were observed, which may suggest riders adopt different strategies for these different events.

Supplementary Materials

Supplementary Materials include maps of the CCI4*S and CCI4*L cross-country courses showing track layout, jump positions, and elevation profiles over distance.

Acknowledgments

The researchers would like to thank Sarah Verney for help with logistics at the event, the organizers of Bramham International Horse Trials, who provided access to the event, and the riders and their staff for participating.

Authors' Contributions

D.J.M.: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. H.C.W.: Investigation, Data curation, Writing – review & editing. R.M.G.: Conceptualization, Methodology, Investigation, Writing – review & editing. A.L.: Methodology, Formal analysis, Supervision, Writing – review & editing.

Data Availability

Requests for access to the data should be directed to the corresponding author. Reasonable requests to access data will be considered. Certain data may be withheld if it is considered that this could potentially be used to identify individual athletes based on existing information in the public domain relating to the specific event at which the data were collected.

Funding

Equipment was provided at no cost by Catapult UK. The cost of travel, food, accommodation, and analysis time was provided by the British Equestrian World Class Performance program.

Conflicts of Interest

Andrew Lombard is employed part-time by Catapult as a consultant. David Marlin and Russell McKechnie-Guire work part-time for Team GB Equestrian. Heather Cameron-Whytock declares no conflicts of interest.

Ethical Approval

Specific ethical approval for this study was not required as the study involved only wearing a commercially available non-invasive sensor by athletes already competing under Team GB, posed no greater risk than routine training or wearing a watch, collected fully anonymized data with no identifiable private information, aligned with UK Sport/Team GB performance monitoring protocols, and obtained informed consent consistent with event participation and the Declaration of Helsinki, including permission to use the data collected from them and their horses. For the time that the researchers interacted with the horses and riders, any interaction with the horses was conducted in full compliance with the UK Animal Welfare Act 2006, ensuring that all reasonable steps were taken to meet the animals' welfare needs and to prevent any unnecessary suffering, in line with the Act's provisions and the Five Freedoms framework.

Declaration of Generative AI and AI-Assisted Technologies

The authors confirm that no Generative AI or AI-assisted technologies were used in the writing, editing, or preparation of this manuscript. The entire content was authored solely by the individuals listed.

References

[1] Fradkin AJ, Zazryn TR, Smoliga JM. Effects of warming-up on physical performance: a systematic review with meta-analysis. Journal of Strength and Conditioning Research 2010;24:140–8. https://doi.org/10.1519/jsc.0b013e3181c643a0.

[2] Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. British Journal of Sports Medicine 2009;43:392–400. https://doi.org/10.1136/bjsm.2008.050799.

[3] McCutcheon LJ, Geor RJ, Hinchcliff KW. Effects of prior exercise on muscle metabolism during sprint exercise in horses. Journal of Applied Physiology 1999;87:1914–22. https://doi.org/10.1152/jappl.1999.87.5.1914.

[4] Frippiat T, Votion D-M. Warm-up strategies and effects on performance in racing horses and sport horses competing in Olympic disciplines. Animals 2024;14:945. https://doi.org/10.3390/ani14060945.

[5] Valle E, Odore R, Zanatta PR, Badino P, Girardi C, Nery J, *et al*. Estimation of the workload in horses during an eventing competition. Comparative Exercise Physiology 2013;9:93–101. https://doi.org/10.3920/cep12028.

[6] Spence AJ, Thurman AS, Maher MJ, Wilson AM. Speed, pacing strategy and aerodynamic drafting in Thoroughbred horse racing. Biology Letters 2012;8:678–81. https://doi.org/10.1098/rsbl.2011.1120.

[7] Liss M, Wilk I, Tkaczyk S, Janczarek I. Racing speed of Thoroughbred horses at different phases of races in Poland. Pferdeheilkunde Equine Medicine 2018;34:454–60. https://doi.org/10.21836/pem20180507.

[8] Mercier Q, Aftalion A. Optimal speed in Thoroughbred horse racing. PLOS ONE 2020;15:e0235024. https://doi.org/10.1371/journal.pone.0235024.

[9] Marlin D, Williams J. Equine endurance race pacing strategy differs between finishers and non-finishers in 120 km single-day races. Comparative Exercise Physiology 2018;14:11–8. https://doi.org/10.3920/cep170027.

[10] Marlin D, Williams J. Equine endurance race pacing strategy and performance in 120-km single-day races. Journal of Equine Veterinary Science 2018;67:87–90. https://doi.org/10.1016/j.jevs.2018.03.013.

[11] Bennet ED, Parkin TDH. Fédération Equestre Internationale (FEI) endurance events: riding speeds as a risk factor for failure to qualify outcomes (2012–2015). The Veterinary Journal 2018;236:37–43. https://doi.org/10.1016/j.tvjl.2018.04.012.

[12] Nylund LE, Sinclair PJ, McLean AN, Cobley S. Development of a video analysis protocol and assessment of fall characteristics in equestrian cross-country eventing. Scandinavian Journal of Medicine & Science in Sports 2021;31:2187–97. https://doi.org/10.1111/sms.14037.

[13] Burger D, Vidondo B, Gerber V, Deillon D, Müller A, Scheidegger M, *et al*. High-level competition exercise and related fatigue are associated with stride and jumping characteristics in eventing horses. Equine Veterinary Journal 2024;56:631–41. https://doi.org/10.1111/evj.13999.

[14] Guyard KC, Montavon S, Bertolaccini J, Deriaz M. Validation of Alogo Move Pro: a GPS-based inertial measurement unit for the objective examination of gait and jumping in horses. Sensors 2023;23:4196. https://doi.org/10.3390/s23094196.

[15] Crang ZL, Duthie G, Cole MH, Weakley J, Hewitt A, Johnston RD. The validity of raw custom-processed global navigation satellite systems data during straight-line sprinting across multiple days. Journal of Science and Medicine in Sport 2024;27:204–10. https://doi.org/10.1016/j.jsams.2023.12.004.

[16] Bishop D. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. Sports Medicine 2003;33:439–54. https://doi.org/10.2165/00007256-200333060-00005.

[17] Burnley M, Doust JH, Jones AM. Effects of prior warm-up regime on severe-intensity cycling performance. Medicine & Science in Sports & Exercise 2005;37:838–45. https://doi.org/10.1249/01.mss.0000162617.18250.77.

[18] Stewart IB, Sleivert GG. The effect of warm-up intensity on range of motion and anaerobic performance. Journal of Orthopaedic & Sports Physical Therapy 1998;27:154–61. https://doi.org/10.2519/jospt.1998.27.2.154.

[19] Ely MR, Martin DE, Cheuvront SN, Montain SJ. Effect of ambient temperature on marathon pacing is dependent on runner ability. Medicine & Science in Sports & Exercise 2008;40:1675–80. https://doi.org/10.1249/mss.0b013e3181788da9.

[20] Haney T, Mercer J. A description of variability of pacing in marathon distance running. International Journal of Exercise Science 2011;4:133–40. https://doi.org/10.70252/rhgb2099.

[21] Renfree A, Gibson ASC. Influence of different performance levels on pacing strategy during the Women's World Championship marathon race. International Journal of Sports Physiology and Performance 2013;8:279–85. https://doi.org/10.1123/ijspp.8.3.279.

[22] Adamu L, Noraniza MA, Rasedee A, Bashir A. Effect of age and performance on physical, hematological, and biochemical parameters in endurance horses. Journal of Equine Veterinary Science 2013;33:415–20. https://doi.org/10.1016/j.jevs.2012.07.015.

How to Cite
Marlin DJ, McKechnie-Guire R, Cameron-Whytock H, Lombard A. Tracking Horse and Rider Speed During Warm-Up and CCI4* Short and Long Format Cross-Country Using a Commercial Wearable GPS Sensor. Int J Equine Sci 2026;5(1):60–70.