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Proposal to Rate the Power of a Horse in the International Endurance Championship

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ABSTRACT

Currently, in the International Endurance Championship the winning horse is awarded a certificate and a brief report of its performance. The report mainly reflects stage, position, distance, starting time, arrival time, ride time, and the speed. Unfortunately no mention is made of the average power of the horse ***(P)*** *and the amount of energy* ***(E)*** *expended by the horse in the race. Herein, we have reached an approximate equation to calculate P and E.*

INTRODUCTION

According to Kevin H. Kline (1) in his paper "Managing Heat Stress in Horses", only about 25% of the energy used in the performance horse's working muscles is converted to actual muscle movement. The remaining 75% loss of efficiency is represented by waste heat that becomes very difficult for the horse to dissipate in hot and humid weather. Meanwhile, Hodgson et al (2) had exercised horses at 40, 65, and 90% of their maximum O_2 uptake (VO_2max) until moderately fatigued (approximately 38, 15, and 9 min, respectively) to assess heat loss through different routes. Approximately 4232, 3195, and 2333 kcal of heat were generated in response to exercise at these intensities. Of this, approximately 7, 16, and 20% remained as stored heat 30 min post exercise. Respiratory heat loss, estimated from the temperature difference between blood in the pulmonary and carotid arteries and the cardiac output, was estimated to be 30, 19, and 23% of the heat produced during exercise at the three intensities.

Furthermore, the single most important means the horse has for getting rid of the enormous heat load generated during exercise is evaporation, accounting for about 65% of the heat dissipation (3). Sweat is evaporated off of the skin surface and cools the horse. The lungs account for about another 25%. This capacity of the respiratory tract in dissipating heat from the body becomes very important under conditions of high humidity and high temperatures when evaporation conditions are not favorable. The human sweat rate is only 2-3 L/h while that of the horse can be 10-15 L/h (3)!This indicates that the horse exhausts 6 times the energy exhausted by human beings (100 J per second (4);assuming same exhaust and body temperature.

During exercise, there is a significant increase in the amount of heat produced by working muscles. Muscles cannot transform energy into movement with 100% efficiency (5). Horses transform energy to movement at approximately 25% efficiency. As a result, some of the energy is lost in the form of heat. The rate of heat production by working muscles is proportional to how hard the muscles work. Therefore the faster a horse goes the more heat it produces. The amount of heat a horse produces in a 160 km endurance race would be enough to boil approximately 770 liters of water. That's approximately 7.7 liters per mile.

Fortunately for the horse, it is able to dissipate around 97% of the heat it produces during an endurance race in cool-warm conditions!! If not, its body temperature would increase by around 15°C/h. In response, a horse increases its sweating rate, circulates more blood to the capillaries under the skin and increases its rate of breathing in an effort to release heat build-up.

Commonly observed signs of heat stress are:

- Profuse sweating
- No sweating
- Rapid breathing rate - panting (>20 breaths / min)
- Rapid heart rate (>50 beat/min)
- Skin that is dry and hot
- Unusually high rectal temperatures (>38°C)

This information can be used as data sources for establishing Power Rating equation for horses participating in the International Endurance Race.

METHODOLOGY

The power of a horse in any endurance race can be calculated to best approximation by using the following formula:

$$P = Fv_{av} + H \tag{1}$$

where F is the force produced by the horse during racing the four stages (30km, 30 km, 25km and 15 km). This force can be approximated to be equal the frictional force(μmg), the coefficient of dynamic friction (μ) can be taken as 0.8 and v_{av} is the speed of the horse in m/s during the riding time in seconds. This assumption is accepted by assuming that the horse speed during each stage is nearly constant. However, a precise evaluation of the horse speed could be further achieved by obtaining a rough estimation of speed as a function of time since a horse starts from rest and keeps speeding up reaching some-say- terminal speed and finally at the end of the endurance it slows down. Thus, the first term on the right side of Equation (1) is the horse average mechanical energy used to overcome ground frictional force (the air resistance is negligible since v_{av} < 50 km/hr), while H is the rate of energy that a horse produces as heat. According to Hodgson, et al (2) 2333 kcal of heat is generated in response to exercise at 90% of their maximum O_2 uptake (O_2max) when horses do an exercise for 38 min of 40% of their maximum O_2 uptake. The respiratory loss found 30% of heat produced during exercise. This means that the power H can be as high 7800 W (average). Since horses respire up to 16L/h while human being only up to 3 L/h, then P for horses can be considered to be six folds that human (H for human is 100W (4)), and therefore for a horse is approximately 600W.

Its worth mentioning that we have ignored the work spent on overcoming the frictional forces between the bones of the knees and limbs of the horse. Also we had ignored the mechanical power of the heart. This can be easily estimated to be nearly 2 W assuming that the horse circulates 8000 liter of blood per day with an average height of 1.8 m.

Equation (1) can be re-written as follows:

$$P = 0.8mgv_{av} + 600 = \frac{E}{t} \tag{2}$$

The mass of the horse m (in kg) can be measured directly before the race where it might reduce no more than ± 1%. The time t is in seconds.

Example: In an Endurance Ride in Bahrain in November 2005 the horse Chesterfield, ride by His Highness Sheikh Faisal Bin Rashid Al Khalifa, had completed stage 1 (30km) in 1 hr 40 min 38 sec, stage 2 (30km) in 1 hr 25 min 49 sec, stage 3 (25km) in 1 hr 22 min 38 sec and in stage 4 (15 km) in 44 min 35 sec. The horse weight was nearly 500kg. Using Equation 2 we will be able to calculate the Power (P) and Energy (E) spent by each stage and then the overall one

Stage 1 t = 6038 sec, v_{av} = 4.97 m/s (17.9 km/h)

$$P_1 = (0.8 \times 500 \times 9.8 \times 4.97) + (600)$$

$$P_1 = 19482.4 + 600$$

$$P_1 = 20082.4 \text{ Watt } = \frac{20082.4\,\text{W}}{746\,\text{W/hp}} = 26.9\,\text{hp} \approx 27\,\text{hp}$$

Stage 2 t = 5149 sec, v_{av} = 5.83 m/s (20.97 km/h)

$$P_2 = (0.8 \times 500 \times 9.8 \times 5.83) + (600)$$

$$P_2 = 23456.6 \text{ Watt } = 31.4\,\text{hp}$$

Stage 3 t = 4958 sec, v_{av} = 5.04 m/s (18.14 km/h)

$$P_3 = 20356.8\,\text{W} = 27.3\,\text{hp}$$

Stage 4 t = 2675 sec, v_{av} = 5.61 m/s (20.19 km/h)

$$P_4 = 22591.2\,\text{W} = 30.2\,\text{hp}$$

Therefore, the average power of the horse is close to:

$$\overline{P} = 21.6\,\text{kW} = 29\,\text{hp}$$

Therefore, the horse Chesterfield had spent, on the average, 407 MJ (= 11218 kcal) during the four stages of endurance race.

According to Kline (1) only about 25% of energy use in the performance horse's working muscle is converted to actual muscle movement. The remaining (75%) is loss of efficiency in hot or humid weather. This means that we must add 75% of the calculated power to find the actual power a horse had spent during the race. Therefore, for our horse (chesterfield) the 407 MJ represents only the working muscle energy but the total energy is 1627.6 MJ (309.4x10^3 kcal). This means that the total power of chesterfield is 86482.5 W ≅ 86.5 kW ≅116 hp. Comparing this Figure with Hodgson, et al (2) their horse had spent an energy of 4232 kcal (17.7MJ) in 38 min (2280), which means its power was 7763W (10.4hp). This is momentary-like power, i.e. for short distance – fast riding.

CONCLUSION

The total power of a horse in endurance race can be calculated using a simplified equation as follows:

$$P = 4[\mu m g v_{av} + 600] \text{ Watts}$$

The total energy that a horse will spend during the endurance race can be calculated as follows:

$$E(\text{in Joule}) = 4[\mu m g v_{av} + 600]\, t$$

$$E(\text{in kcal}) = 9.6 \times 10^{-4}[\mu m g v_{av} + 600]\, t$$

These two equations can be used in the endurance races and presented to each horse owner or Jocky for a record so that it allows comparison for any future races.

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اقتراح بإدراج قدرة الحصان في مسابقات القدرة العالمية

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ملخص
حالياً، في سباقات القدرة العالمية، يتم منح الحصان الفائز شهادة تحوي تقرير موجز عن أداء الحصان الفائز. ويعكس ذلك التقرير المراحل التي اجتازها الحصان الفائز، وترتيبه، والمسافة الكلية التي قطعها، وبداية السباق، وزمن وصول الحصان لخط النهاية، وزمن انطلاق الحصان، ومتوسط سرعته. للأسف لا يتم ذكر قدرة الحصان الفائز ولا الطاقة التي استهلكها في السباق. وفي هذا البحث تم اشتقاق علاقة تقريبية تسمح بحساب هذين العنصرين للحصان الفائز أو المشارك.

Erratum

The following is answers provided by Dr Elani,U ,on the behalf of the authors, which was in response to some readers inquiry regarding his paper published in Vol 2 entitled "A simplified method…".

Dear Prof. Alnaser,

Thanks for your call. Regarding our paper: "A simplified method…". As you mentioned I checked a step by step our paper. Here are our comments:

1. There are no problems in the raw data. It was our mistake in Tables 5 & 6. Where the second and third columns should be interchanged as attached in our file.
2. There are no diffuse radiation readings at all in our paper. The Id is the beam (direct) solar radiation W/m2 and not the diffuse component of solar radiation.
3. The IR readings are overestimated due to the small sensitivity in the old instrument, where the spectral region lies between 4 to 50 micro-meters, manufactured 1978.
4. Yes there are some readings of Total It solar radiation over 1000 W/m2, and this is possible in the old scaling of the equipment. However this in not big problem in the analysis since the readings were converted and normalized for the analytical pcedure given in the paper.

We suggest you to mention in the following issue of your journal only about Tables 5 & 6 and the overestimated readings of infrared radiation due to the sensitivity (4-50 micro-meter) of the used instrument at that time.

I hope this will solve the problem. Thanks so much for your comments on our paper.

Best Regards

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Table 1. UV solar radiation in Jan 1986, Riyadh, Saudi Arabia

Day	Total (Wm^{-2}) I	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	823	454	13
2	780	33	13
3	841	514	14
4	836	673	14
5	780	743	12
6	783	767	13
10	761	517	13
12	828	420	14
15	852	589	15
16	1025	658	17
18	910	462	15
21	929	635	16
22	859	752	15
24	694	372	10
29	816	695	14
30	416	30	8
31	810	197	15

Table 2. Average monthly variation of total, direct and UV solar radiation in the year 1985, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	960	615	37
2	966	665	37
3	1026	649	39
4	976	596	34
5	1015	469	37
6	1002	589	37
7	998	632	36
8	970	614	35
9	959	636	34
10	926	742	32
11	824	676	26
12	736	724	24

Table 3. Average monthly variation of total, direct and UV solar radiation in the year 1987, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	743	789	28
2	813	795	23
3	923	681	24
4	938	788	26
5	915	689	25
6	875	739	26
7	987	732	38
8	1002	771	38
9	958	783	28
10	835	836	24
11	762	753	20
12	682	734	16

Table 4. Average monthly variation of total, direct and UV solar radiation in the year 1989, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	1100	923	18
2	1120	927	22
3	1131	892	23
4	1120	899	42
5	1110	870	30
6	875	896	29
7	866	778	28
8	898	813	27
9	937	721	25
10	924	766	20
11	1028	849	16
12	1051	793	17

Table 5. Daily variation of total, direct and IR solar radiation in Dec 1990, Riyadh, Saudi Arabia

Day	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	IR (Wm^{-2}) I_{IR}
1	941	875	536
2	947	867	542
3	952	877	555
4	930	831	544
5	927	742	557
9	1024	897	534
10	996	805	549
14	996	762	552
15	981	803	547
19	969	754	555
20	944	707	549
22	947	694	552
26	959	752	547
27	960	784	555
30	951	726	560
31	950	720	540

Table 6. Average monthly variation of total, direct and IR solar radiation in the year 1991, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	IR (Wm^{-2}) I_{IR}
1	923	650	310
2	1026	665	310
3	976	649	364
4	1015	596	407
5	1002	469	390
6	996	589	328
7	970	632	441
8	959	614	443
9	926	636	443
10	624	742	419
11	736	676	202
12	740	724	306