Running Form Characteristics of the Triple Crown Winner in Japan

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The purpose of this study was to describe the characteristics of fast race horses by analyzing the running form of Deep Impact, the undefeated Japanese triple crown winner in 2005. A high-speed video data of the Kikuka Syo race (Japanese St. Leger, JPN G1, 3,000 m, turf) was taken at a rate of 250 frames/sec. The high-speed video system was set in a left lateral position about 100 m before the finishing post with a field view width of about 16 m. The speed of Deep Impact, 17.8 m/sec, was the fastest of all horses measured (average 16.1 m/sec), the stride frequency, 2.36 strides/sec, was the third largest (average 2.28 strides/sec), and the stride length, 7.54 m, was the longest (average 7.08 m). The diagonal and airborne step lengths of Deep Impact were longer than the average values. The overlap time of Deep Impact was shorter than the average value. The ratio of overlap time to stride duration of Deep Impact was 8.5 %, whereas the average value was 16.9 %. A shorter overlap time was also observed on a common characteristic of Secretariat, the famous elite race horse in USA and correlated to running speed. Thus, these characteristics may be related to effective running form in elite horses.

Key words: *diagonal step length, overlap time, running form, stride frequency, stride length*

Deep Impact was the undefeated Japanese triple crown winner in 2005. Because of his superior speed at races, people say that Deep Impact's running form differs from that of other strong race horses. In addition to his prominent speed, he shows other characteristics in his running form. One characteristic is that the natural wearing of Deep Impact's hindlimb shoes is smaller than that of other strong horses. In general, natural wearing of the shoe on the hind hoof, especially in the toe region, is greater for strong horses as compared to ordinary horses, because the propulsive force on the hindlimb is said to be bigger in strong horses. It is thought that when a strong horse kicks the ground to produce propulsion force, the hoof slides on the ground and the shoe is worn out. A second characteristic is that the ace jockey of Deep Impact has commented that the horse runs as though he is flying in the air. Thus, as mentioned above, it is thought that the running form of Deep Impact might differ from that of other race horses.

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Several studies on the running form of race horses have been reported. For example, Pratt and O'Connor [9] studied the running form of Secretariat and other horses to analyze the safety limit of running speed. Leach *et al.* also studied the change in running form caused by fatigue [6] and the relationship between stride timings in Thoroughbred race horses [7]. In Japan, there have been studies in Thoroughbred race horses on changes in stride length and frequency during the initial sprint [2], the association between running speed and stride length [3] and the effects of treadmill incline on running form at canter [4].

Although there are several studies on the running form of race horse, as mentioned above, the study on Secretariat is the only one on the running form of an elite race horse [9]. The ideal running form differs according to the physique of a horse. However, we think that some characteristics may be common to the running form of faster race horses. The purpose of this study was to describe the characteristics of fast race horses by analyzing the running form of Deep Impact using a high-speed video system.

Materials and Methods

A high-speed video data of the Kikuka Syo race (Japanese St. Leger, JPN G1, at Kyoto race course, distance, 3,000 m; track type, turf; track condition, firm; 3 years old Colt & Filly, Oct. 23, 2005) was taken at a rate of 250 frames/sec. The high-speed video system[1] was set in a left lateral position about 100 m before the finishing post with field view width of about 16 m. At least two strides were taken with this view. One complete stride was used for analysis.

The temporal variables—the stride and airborne duration, the stride frequency, the stance-phase durations of each limb and the overlap time (the period of time that two legs were in contact with the ground)—were measured by the time counter of each frame. Contact with the ground and liftoff were determined from the frame before the fetlock joint was hyperextended and from that after the fetlock joint became straight, respectively.

The hind, diagonal, fore, airborne step and stride lengths were determined by comparison to a calibration bar on the video after the race. A 93-cm calibration bar was placed at three points: one at a distance corresponding to horses running closest to the camera, one at a distance corresponding to horses running farthest from the camera, and one in between. The nearest bar to each horse was defined as the standard. Images showing contact with the ground, liftoff and the calibration bars were captured to a PC from the high-speed video data and the lengths were measured from these images by software[2]. The angles between the palmer side of the metacarpal or metatarsal bone and the ground surface on each limb at the point of contact with the ground and liftoff were measured by the same software. Running speed was calculated as the product of stride length and stride frequency.

Data of each variable was normal distribution, except stride length, confirmed by shapiro-wilk's W-test in commercial software[3]. In data of stride length, one value was outlier, and the distribution of other values looked like normal. When data distributed normal, T-scores (adjusted deviation scores) could be used to compare each measurement values of Deep Impact with those of other horses. In the range of T-score from 20 to 80, 99.74% of total data were included. T-score of Deep Impact was calculated as follow;

$$T\text{-}score=\frac{10\times(X-\bar{X})}{SD}+50$$

X; Values of Deep Impact, $\bar{X}$; Average values, SD; Standard deviations.

When T-scores of Deep Impact were over 60 or under 40 (± 15.87%), those values were defined as significant.

Results

Of the 16 horses starting the race, the variables of 13 could be measured. There were no data for the other 3 horses because they were on the far side of other horses and thus it was not possible to see their hooves at the point of contact with the ground or liftoff.

Finish time of the Kikuka Syo race (distance, 3,000 m; track type, turf; track condition, firm) was 3:04.6, lap time at last 800 m and 600 m was 47.8 sec and 35.7 sec, respectively. Winner was Deep Impact, and the final margin was by 2 length to Admire Japan (second place). At about 100 m before the finishing post, the speed of Deep Impact was 17.8 m/sec, which was significantly faster and the fastest of all measurable horses; by contrast, the average speed of all measurable horses was 16.1 m/sec (Fig. 1). The stride frequency of Deep Impact, at 2.36 strides/sec, was the third greatest, whereas the average value was 2.28 strides/sec. The stride length of Deep Impact (7.54 m) was significantly

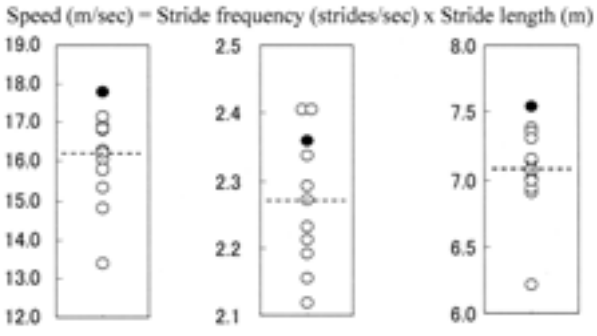

Fig. 1. Comparison of speed, stride frequency and stride length of Deep Impact (●) and other horses (○) at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005 at Kyoto racecourse). Dashed lines shows the average values of all measurable horses.

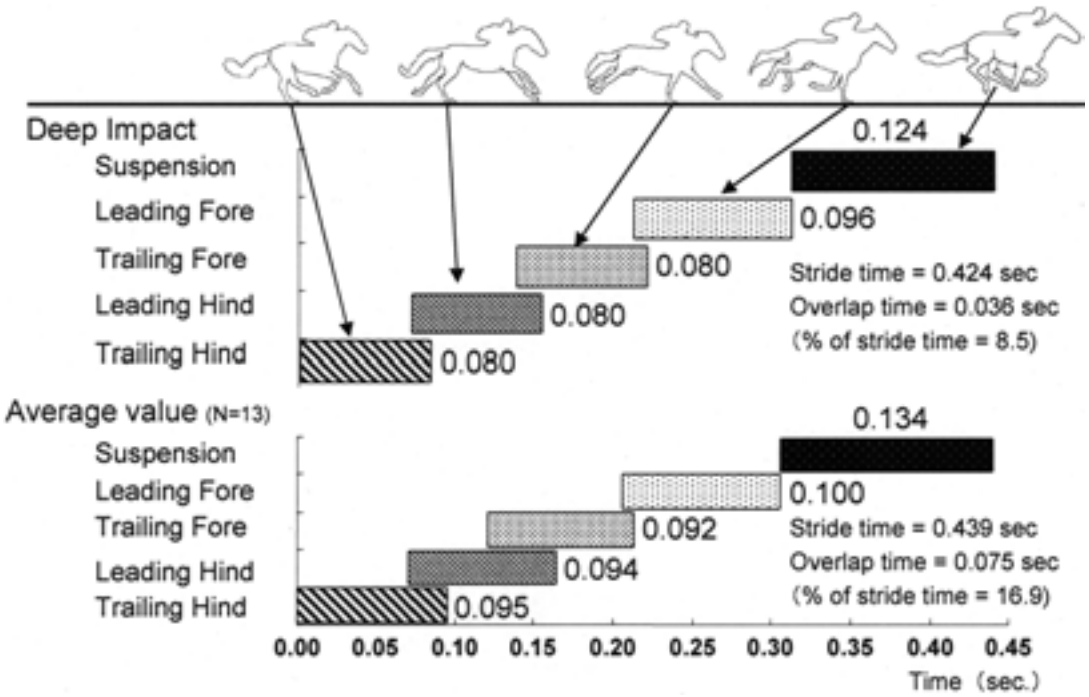

Fig. 2. Gait diagram at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005).

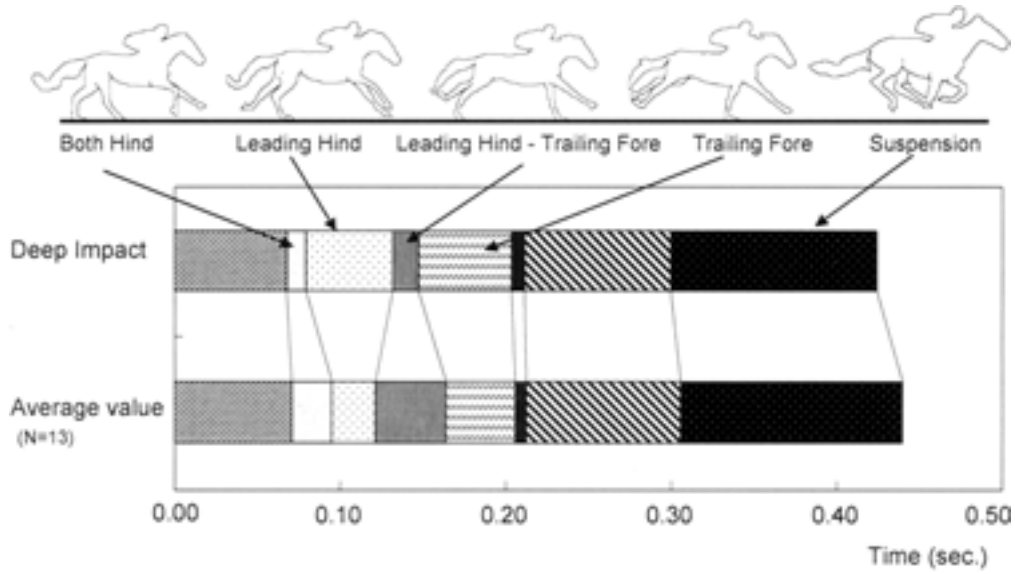

Fig. 3. Comparison of gait diagram at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005).

longer and the longest of all measurable horses, whereas the average value was 7.08 m.

The stance durations of limbs of Deep Impact, except leading forelimb, were significantly shorter (Fig. 2). The airborne duration of Deep Impact (0.124 sec) was not longer than the average value (0.134 ± 0.016 s) (Fig. 2). The overlap time of Deep Impact was significantly shorter (Figs. 2 and 3). In particular, the

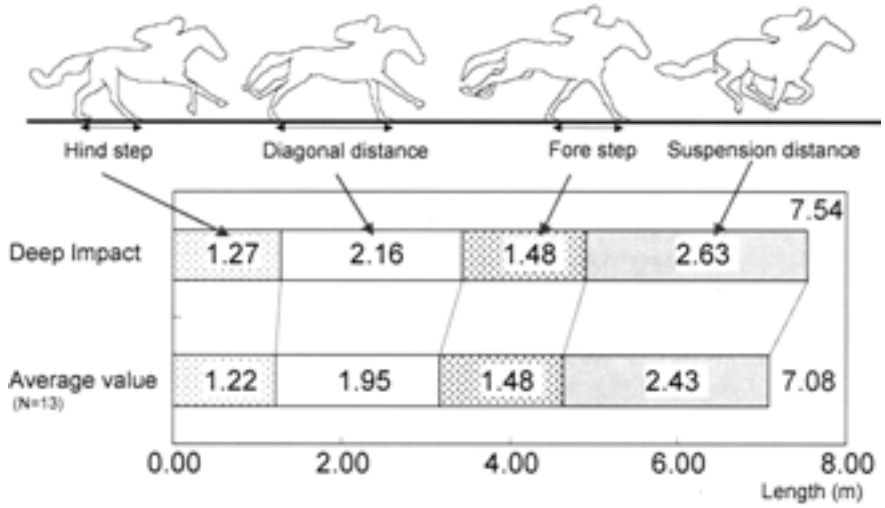

Fig. 4. Comparison of hind step, diagonal step and fore step length at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005).

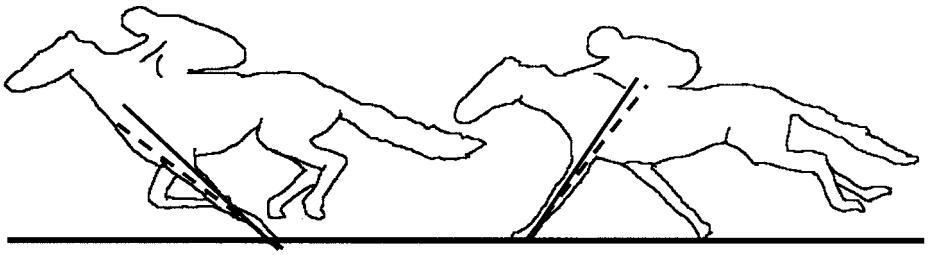

Fig. 5. Comparison of degree of lead forelimb at the point of contact with the ground and liftoff at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005). Deep Impact, dashed lines; average value, black lines.

overlap times between the hindlimbs and between the leading hindlimb and trailing forelimb were notably shorter. The ratio of overlap time to stride duration of Deep Impact, 8.5%, was significantly smaller, whereas the average value was 16.9%.

The airborne step length of Deep Impact was significantly longer and the diagonal step length tended to be longer (T-score 59.5), whereas the hind and fore step lengths of Deep Impact did not differ from the average value (Fig. 4).

In the leading hindlimb of Deep Impact, the angle between the palmer side of the metatarsal bone and the ground at the liftoff was significantly larger (Table 1). Furthermore, in leading forelimb, the angle at liftoff between the palmer side of the metacarpal bone and the ground, and the change of that angle at contacting with the ground and liftoff were significantly larger (Fig. 5 and Table 1). In the other limbs, however, these angles did not differ from the average values.

Discussion

The running speed of Deep Impact was the fastest of the 13 horses for which data could be measured. Running speed is the product of stride frequency and stride length. The balance between stride length and stride frequency differs for each horse. The running form of Deep Impact was in harmonious balance, because his stride frequency was the third greatest and his stride length was the longest.

The ace jockey of Deep Impact commented that,

Table 1. Angles between the palmer side of the metacarpal or metatarsal bone and ground surface on each limb at the point of contact with the ground and liftoff.

Variables		Deep Impact	Mean ± Standard deviation
Trailing Hind	Angle at ground contact (deg)	52.4	53.6 ± 5.1
	Angle at liftoff (deg)	130.5	129.0 ± 3.0
	Range of motion (deg)	78.1	75.3 ± 6.4
Laeding Hind	Angle at ground contact (deg)	50.2	47.7 ± 4.1
	Angle at liftoff (deg)	132.7*	127.8 ± 3.3
	Range of motion (deg)	82.5	80.1 ± 6.3
Trailing Fore	Angle at ground contact (deg)	59.3	58.8 ± 3.2
	Angle at liftoff (deg)	139.4	137.5 ± 2.9
	Range of motion (deg)	80.1	78.8 ± 4.1
Leading Fore	Angle at ground contact (deg)	51.9	55.6 ± 4.6
	Angle at liftoff (deg)	143.1*	137.0 ± 2.6
	Range of motion (deg)	91.2*	81.3 ± 6.4

*Significant difference (T-Score>60 or <40).

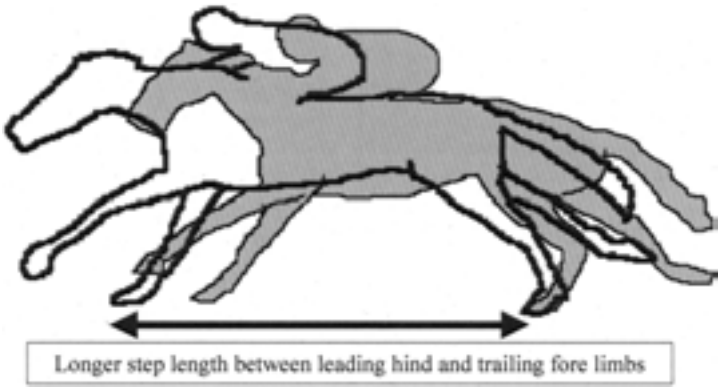

Fig. 6. Comparison of leading hind and trailing fore step lengths of Deep Impact (white) and other horses (gray) at about 100 m before the finishing post of the Kikuka Syo (Japanese St. Leger, 3,000 m, GI, Oct. 23, 2005).

when he rode Deep Impact in races, he felt that the horse was flying through the air. On the one hand, however, the airborne duration of Deep Impact (0.124 sec) was not longer than the average value (0.134 ± 0.016 sec). On the other hand, the airborne distance of Deep Impact was significantly longer. Because airborne distance is the product of running speed and airborne duration, it should increase in proportion to running speed if the airborne duration of each horse is the same. Because the running speed of Deep Impact was the fastest, the airborne distance was longer than the average value even though the airborne duration of Deep Impact was slightly shorter than the average value. Running like flying through the air should mean that the airborne duration is longer as compared with other horses. Thus, Deep Impact does not run as though he is flying.

The overlap time of Deep Impact was significantly shorter, especially between the hindlimbs and between the leading hindlimb and trailing forelimb (Figs. 2, 3). Pratt and O'Connor [9] reported that Secretariat, the famous triple crown horse in the United States, had the smallest overlap time and ratio-to-stride duration (0.081 s and 18.6%, respectively), and considered that these characteristics might provide the optimum gait to run faster. The ratio of overlap time to stride duration of Deep Impact (8.5%) was also smaller than the average value (16.9%). Thus, these characteristics are

common to both elite horses. However, the overlap time and the ratio of overlap time to stride duration of Deep Impact were smaller than those of Secretariat. Although the construction of dirt tracks in the United States was different from that in Japan, it is common that the surface of dirt track is soft cushion layer. Therefore, it is thought that the dirt track in United States might be slippery same as the Japanese dirt track which is found to slide forward during first half of stance phase compare to turf track from hoof acceleration analysis (unpublished data). In another high speed video analysis of running form of Deep Impact, overlap time and ratio-to-stride duration on slippery condition of turf track was bigger compare to those on firm condition (unpublished data). From these data, it seemed that difference of overlap time and ratio-to-stride duration in Deep Impact and Secretariat would be due to the type of track surface or in track conditions. However, because overlap time and ratio-to-stride duration still negatively correlated to running speed on slippery condition of turf track (unpublished data), smaller overlap time and ratio-to-stride duration were important to run faster.

By contrast, Leach *et al.* [7] reported that horses with moderate athletic ability had an average overlap time of 18.81% on dirt track, similar to that of Secretariat. They therefore thought that overlap time might not be related to stride efficiency. Their data were obtained at the beginning of the race, however, whereas the results of both this report and Secretariat were obtained at the end of race. Because it has been reported that overlap time increases at the end of race owing to fatigue [6], it may be common for faster horses to maintain a smaller overlap time at the end of race. Furthermore, the overlap time significantly correlated with running speed negatively in this report ($r=-0.8813$, $p<0.0001$). Therefore, faster horses had short overlap time, whereas the tired and slower horses had long overlap time. High performance ability may be shown from the fact that Deep Impact and Secretariat kept short overlap time and faster running speed at the end of race.

Smaller overlap time between the leading hindlimb and trailing forelimb of Deep Impact than the average value means that the time of contact of the trailing forelimb with the ground tended to be later (T-score 59.7) (Fig. 3). According to this delay in contact with the ground of the trailing forelimb, Deep Impact might extend his body and achieve a longer step length between the leading hindlimb and trailing forelimb (Fig. 6) [5, 9]. Moreover, it might be related to contract the extended body with longer diagonal step length to bend forward the leading hindlimb at the liftoff (Table 1).

The stride length of Deep impact was 7.54 m. The stride length of Secretariat has been reported as 7.38 m [9], whereas the mean value of ordinary Thoroughbred race horses has been reported as 6.66 m [3] or in the range of 6.1–7.7 m [8].

To increase running speed, either the stride frequency or stride length, or both, needs to be increased. Lengthening the stride may be particularly important to increase running speed, however, because the upper limits of stride frequency reported previously were about 2.5 strides/sec [2, 3], and the maximum stride frequency in this report (2.4 strides/sec) was near this upper limit. In another report [7], the maximum stride frequency was found to be about 3.0 strides/sec, however, the time point of the measurement (at the start of race) differed from that in this report [1].

Among the elements constituting stride length, the airborne distance becomes longer if the airborne duration becomes longer. A longer airborne duration, however, may decrease running speed, because air resistance acts on the body to reduce speed during airborne phase. Furthermore, a horse must fly higher during the airborne phase to increase airborne duration. An up-down movement is thought to be inefficient during running.

In the leading forelimb of Deep Impact, the angle between the palmer side of the metacarpal bone and the ground at liftoff, as well as the change in this angle at contacting the ground and liftoff, were significantly larger. This indicates that Deep Impact bent the leading forelimb more forward at liftoff, therefore the range of angle change in leading forelimb had become larger. We think that these characteristics are related to effective running form with little up-down motion of the body.

The reason why the natural wearing of Deep Impact's hindlimb shoes was smaller was assumed that his hind hoof did not slide during producing propulsion force. Therefore, Deep Impact might run efficiently without a loss of energy by sliding hind hoof. However, it was too difficult to measure the length of hoof slide from high speed video analysis in this study, as it was assumed that a hoof slides only several centimeters during stance phase from analysis of hoof acceleration data (unpublished data).

In conclusion, although it has been thought that Deep Impact runs as though he is flying through the air, he does not 'fly' in respect of time because he has a shorter airborne duration as compared to the average value. The longer airborne distance of Deep Impact is related to his current fastest running speed. The characteristics of the running form of Deep Impact are shorter overlap time, extended diagonal step length, and bending more forward at liftoff in the leading forelimb. A shorter overlap time may be especially important because this characteristic is common to Secretariat, the famous superior horse in the United States and it correlated to running speed. Thus, these characteristics may be related to effective running form in elite horses.

Manufacturer's addresses

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2: Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2005.
3: JMP 5.0.1a, SAS Institute Inc., Cary, North Carolina, USA

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