How Fast Can a Human Run? − Bipedal vs. Quadrupedal Running

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Running head: Human quadrupedal running

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ABSTRACT

Background. Usain Bolt holds the current world record for a 100-m run, 9.58 s, and has been described as the best human sprinter in history. However, this raises questions concerning the maximum human running speed. Can the world's fastest men become faster still? The correct answer is likely "Yes".

Methods. We plotted the historical world records for bipedal and quadrupedal 100-m sprint times according to competition year. These historical records were plotted using several curve-fitting procedures.

Results. We found that the projected speeds intersected in 2052, when for the first time, the winning quadrupedal 100-m sprint time of 9.249 s was projected to be lower than the winning bipedal time of 9.350 s.

Conclusion. Quadrupedal running is not a new running style, and has been used by all humans. This running style simply awakens a human locomotive instinct from an enduring sleep.

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INTRODUCTION

Currently, Usain Bolt holds the world record of 9.58 s for a 100-m run. He has accordingly been described as the best human sprinter in history. However, this raises questions concerning whether humans can run faster, thus increasing this maximum speed. Over the past 50 years, many researchers have attempted to generate a model to explain the development of world record speeds. One interesting attempt was made to calculate the maximum running speed of Usain Bolt. Using rigorous mathematical evidence, Barrow (2012) predicted that Usain Bolt could achieve a faster running time (from 9.58 s to 9.45 s) with no extra effort on his part or improvement in his performance.

Let us consider future athletes. How fast might they run? Although all of us have experienced walking and running while using two arms and two legs, most of us eventually become bipedal. However, the existence of quadruped humans (Ledford, 2008;Ozceilk et al., 2008) was first publicized by a 2006 British television documentary about a Turkish family in which several adults walked on all four limbs. In addition to living on all fours, running on all fours has also been reported. One quadruped runner, or “monkey runner”, broke the Guinness world record for the 100-m sprint on November 13, 2014. The new world record time was 15.86 s (Lynch, 2014), a full second less than the previous world record. Surprisingly, world record times have been

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set on six occasions in 6 years and have improved by more than 2 s in the last 3 years. Accordingly, these rapid improvements in quadrupedal running world records might suggest a hypothesis that quadrupedal running will outpace bipedal running in the future.

In the present study, to obtain approximate estimates of future 100-m sprint world records, a trend extrapolation method was applied to the world record 100-m bipedal and quadrupedal sprint times by competition year. The historical progression of 100-m sprint times will likely be important to an understanding of the physiological determinants underlying this seemingly inexorable progression of record performance.

METHODS

Historical records and analysis

The bipedal (men's) and quadrupedal world record 100-m sprint times were obtained from the International Association of Athletics Federations (Progression of World Best Performances and Official IAAF World Records, 2011 edition, Monte-Carlo, Monaco, 2011) and the Guinness World Records (Lynch, 2014) (Table 1). Occasionally, a single individual recorded the world record time in multiple years; however, this analysis assumed that the individual data points were independent.

The historical race data were fitted with the Matlab algorithm (MathWorks, Natick,

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MA, USA), using several curve-fitting procedures, including linear, quadratic, cubic, logarithmic, inverse, power, and exponential curves. The standard error (SE) equation was used to calculate the 95% confidence intervals for the predicted 100-m sprint world records as follows:

$$SE = \sqrt{s_{t,y}^2\left(1 + \frac{1}{n} + \frac{(y - \bar{y})^2}{\sum (y - \bar{y})^2}\right)}$$

where *t* is the world record time and *y* is the year.

Kinematic parameters of human quadrupedal running

The participant in this study was a Japanese quadrupedal sprinter, Kenichi Ito (height = 162 cm, weight = 48 kg, age = 32 years), who holds the previous quadrupedal 100-m world record. The subject was fully informed about the experimental protocol and the purpose of the study and provided written informed consent to participate in the investigation. This study was approved by the Kanagawa University Ethics Review Committee for Research Involving Human Participants (2012-1). Data were collected during a competitive four-legged sprint race in 2013. The race was videotaped at 300 Hz with a high-speed camera (EXLIM PRO EX-F1, Casio Computer Co., Ltd., Tokyo, Japan) that was positioned perpendicular to the runway approximately 50 m from the starting line. Individual limb touchdowns and liftoffs were determined on a frame-by-frame basis. Videos were calibrated for distance by placing an object of known size in the field of view. The speed was measured by calculating the averages of the forward velocities of the parietal head and shoulder acromion.

We calculated the following kinematic parameters from these data: relative limb phase (fraction of a stride in which the left fore, right hind, and right fore foot touch-down followed the left hind foot touch-down at 0.0; (Hildebrand, 1976; 1980), stride length (distance travelled in one stride), relative stride length (stride length normalized by leg length), and stride frequency (number of strides taken per unit of time). Leg length was defined as the length from the femoral condyle to the medial malleolus and was calculated from the subject's height, as described by Winter (1990).

RESULTS

We plotted the 100-m sprint times of the bipedal and quadrupedal world records according to competition year. The r^2 values of the quadrupedal times ranged from 0.768 (sigmoid) to 0.968 (cubic), with a mean of 0.813. The r^2 values of the bipedal times ranged from 0.952 (linear) to 0.957 (cubic), with a mean of 0.953. There were no significant differences in r^2 values among the curve-fitting models. The winning time was fitted to a rational fraction curve for the quadruped records ($r^2 = 0.773$) and to a linear curve for the biped records ($r^2 = 0.952$) (Figure 1). A rational fraction function was adopted to consider the gradual maturation of the quadrupedal world record. This latter process (linear fitting for the bipedal record) was thought to be similar to that described in earlier literature (Tatem et al., 2004), in which a linear model was employed to extrapolate the 100-metre sprint time. There was no indication that either bipedal or quadrupedal athletes have reached a plateau in the 100-m sprint. The projected record times intersected in 2052, when for the first time, the projected winning quadrupedal 100-m sprint time of 9.249 s was expected to be lower than the bipedal winning time of 9.350 s. By the 2052 Olympic Games, the fastest human on the planet might be a quadrupedal runner if current trends continue.

A top speed of 5.40 $m \cdot s^{-1}$ (19.43 $km \cdot h^{-1}$) was recorded in the four-legged sprint competition race; this was approximately one-half of Bolt's record (Table 2). Ito had a stride length of 3.10 m, which was longer than that exhibited by Bolt. Notably, the stride length is inextricably linked to the stride frequency. Consequently, Ito's stride frequency was 2.25 strides/s, approximately 2 Hz lower than Bolt's stride frequency. Ito employed a transverse gallop at that speed (Figure 2). In a transverse gallop, the two hindfeet are placed in sequence. Placement of the second hind foot is followed by placement of the contralateral forefoot, followed by the remaining forefoot. The right-left or right-left sequence was the same in the forelimbs and hindlimbs. A suspended phase was observed after the forefeet were lifted, during which all four limbs were lifted from the ground and gathered under the body; this phase is called the gathered flight phase.

DISCUSSION

To date, our knowledge of the galloping gaits used by human quadruped runners is limited. This pattern is the fastest gait used by human quadrupeds, and thus a good understanding of this gait might be crucial to investigations of its speed limitations. Although galloping mechanics have been investigated in several mammals, the human gallop remains poorly understood.

Mammals that use four legs can make many movements that are impossible with two legs. Quadrupedal mammals move using sharply distinct speed-dependent gaits (Alexander, 1989). These gaits are commonly identified by their footfall patterns (Muybridge, 1957). Symmetrical gaits, such as trotting, are characterized by the even spacing over time of alternating footfalls of both feet in the same pair. In asymmetrical gaits, such as the two forms of galloping (transverse and rotary), at least one of the two pairs of feet is not commonly observed on the ground (Hildebrand, 1965; 1977). Many mammals employ galloping, particularly at high speeds, including human quadrupedal sprinters (Figure 2). A galloping gait is used only at high speeds for various reasons; for

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example, the greater the horizontal component of the center of mass velocity, the smaller the deflection angle required for each contact and, consequently, the smaller the proportion of momentum loss (Bertram et al., 2009).

Sagittal spine movements are important during asymmetrical gaits, particularly in small mammals and larger cursorial species wherein cyclic flexion and extension of the spine help to increase the stride length (Hildebrand, 1959; Schilling & Hackert, 2006). In a gallop, faster speeds are achieved by taking longer strides, although the stride frequency remains almost constant (Biewener, 2003). Thus, longer legs represent one way to achieve higher speeds. Fortunately, in human quadrupeds, the distal segment of the leg usually lengthens more than the proximal segment (Winter, 1990), yielding not only longer legs but also a longer moment arm for the distal segment. Thus, relatively larger ground forces can be applied, which reduce the limb contact time and increase the flight time (Weyand, 2000). Human spinal flexion and extension are largely confined to the lumbosacral junction (Haussler, 2001), although in humans, an increase in sagittal spinal movement might lead to an extended stride, an adaptation that could allow for higher speeds. From a different point of view, a minority of the world's quadrupedal athletes and individuals who have walked on all fours throughout their lives have experienced increasing opportunities to participate in sports and train at a competitive level.

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Use of a formula or statistical model to accurately predict future athletic performances is challenging (Hilbe 2008). Fitted linear models should be treated with some caution. The use of linear regression for world record modeling would yield a continued decline that would eventually become negative, thus suggesting there are no limits to athletic running performances. Further, examinations of 100-m performances feature a number of confounding variables, including the move from handheld to electronic timing devices and technological advancements, such as improved track surfaces in the mid-1960s. It must also be noted that quadrupedal world records did not exist before 2008. This relatively recent involvement of quadrupedal running results in a somewhat tenuous comparison of world record times. Nevertheless, a rational fraction approximation might provide a rationale for a limitation of the human quadrupedal 100-m running time, which converges at approximately 3 s (approximate average speed at 30 m s^{-1}). This appears to be consistent with the top speed of the cheetah (Jones & Lindstedt, 1993), the fastest land animal on Earth.

It is worth questioning why the top speeds of quadrupedal human athletes are expected to improve more rapidly than those of bipedal human athletes. To answer this question, we used video analysis to demonstrate the gait and kinematic patterns in during human quadrupedal competition races. Our team has made progress with a biomechanical analysis, and detailed results will appear in a future publication.

Currently, human quadrupedal locomotion is thought to be poorly understood, although quadruped mechanics have often been investigated in mammals (Biancardi & Minetti, 2012).

In summary, in the future, the fastest human on the planet might be a quadrupedal runner at the 2052 Olympics. Quadrupedal running is not a new running style, and has been experienced by all humans. Rather, this running style simply awakens a human locomotive instinct from an enduring sleep.

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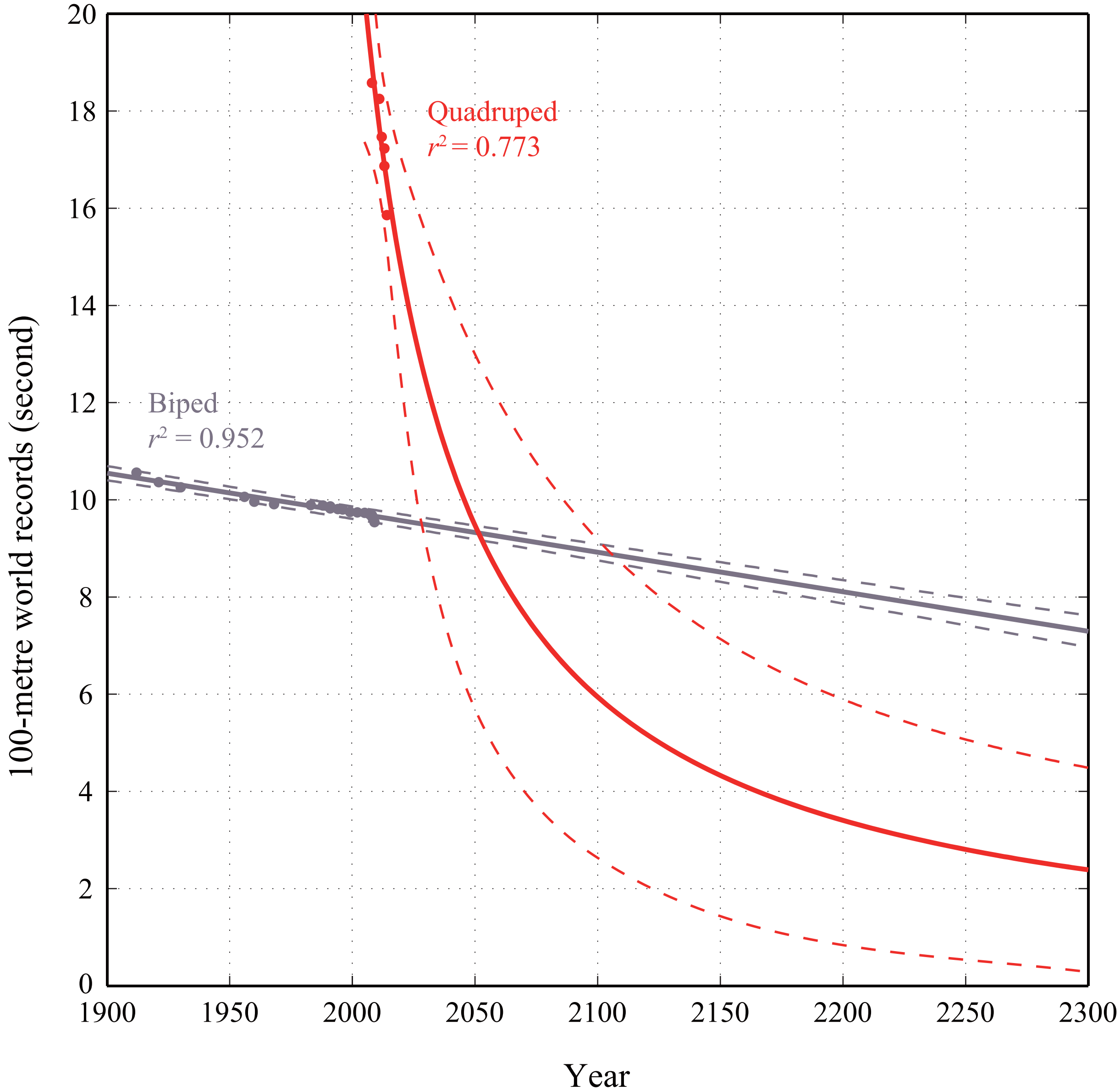
FIGURE LEGENDS

Figure 1. The 100-m world records for quadrupedal (red points) and bipedal (grey points) human athletes with superimposed best-fit lines and coefficients of determination. The lines were extrapolated, and the available points have been used to superimpose 95% confidence intervals (dotted lines). The projections intersect in 2052, when the quadrupedal 100-m sprint world record of 9.249 s will be lower than the bipedal world record of 9.350 s.

Figure 2. A. Phase relationships in human quadrupedal running. The numbers on the feet demonstrate when each particular foot hits the ground as a fraction of a complete cycle. **B.** Stance timing during strides. Coloured bars represent the stance periods for each limb during a complete stride.



100-metre world records (second)
Year
Quadruped
$r^2 = 0.773$
Biped
$r^2 = 0.952$
0
2
4
6
8
10
12
14
16
18
20
1900
1950
2000
2050
2100
2150
2200
2250
2300

Figure 1

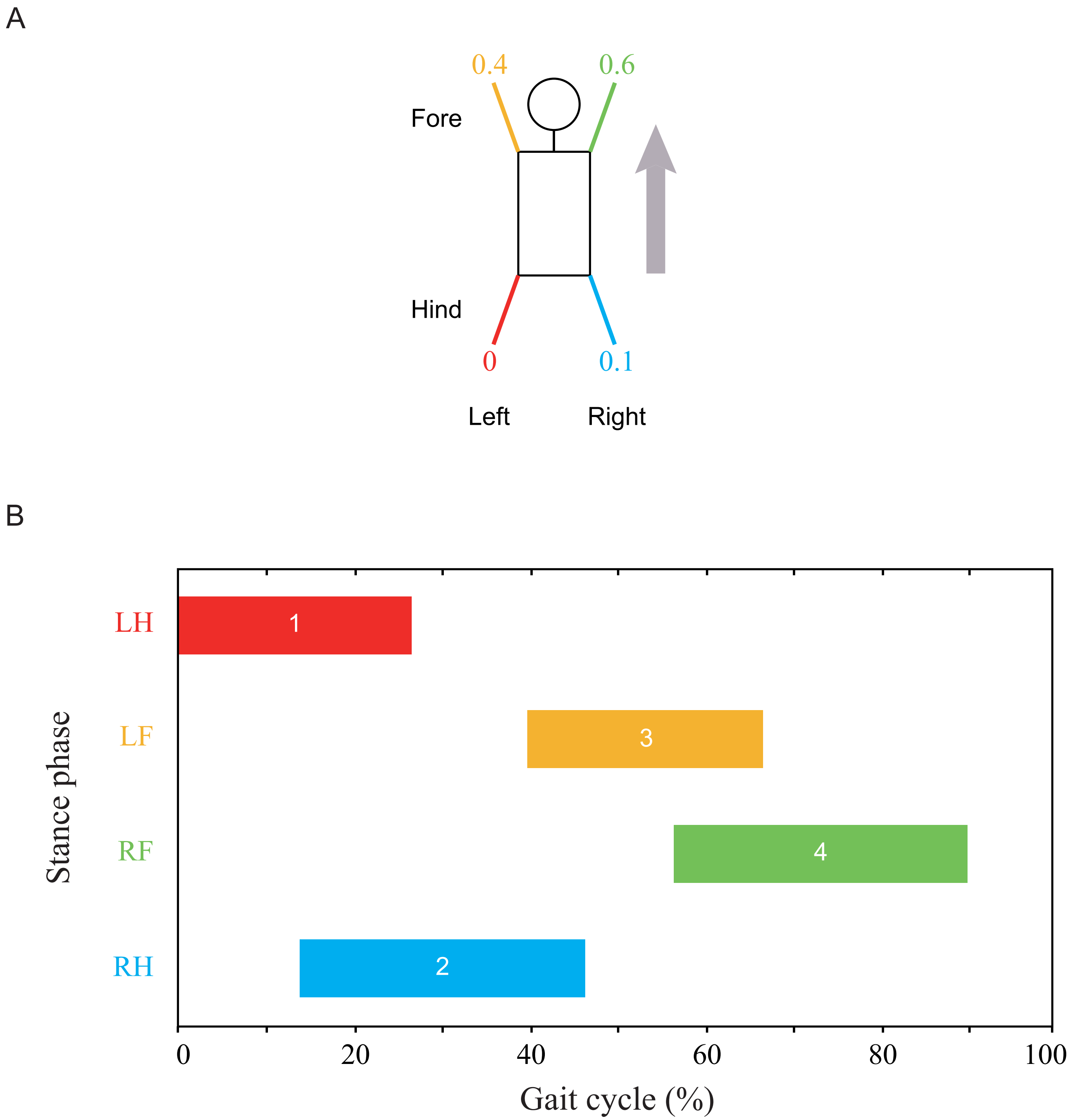

A
0.4
0.6
Fore
Hind
0
0.1
Left
Right
B
LH
LF
RF
RH
1
3
4
2
Stance phase
0
20
40
60
80
100
Gait cycle (%)

Figure 2

Table 1. Bipedal and quadrupedal world record 100-m sprint times from 1912.

Year	100-m world records (s)	
	Bipedal [1)]	Quadrupedal
1912	10.6	
1921	10.4	
1930	10.3	
1956	10.1	
1960	10.0	
1968	9.95	
1983	9.93	
1988	9.92	
1991	9.90	
1991	9.86	
1994	9.85	
1996	9.84	
1999	9.79	
2002	9.78	
2005	9.77	
2007	9.74	
2008	9.72	18.58
2008	9.69	
2009	9.58	
2011		18.25
2012		17.47
2013		17.23
2013		16.87
2014		15.86 [2)]

Source: [1)] International Association of Athletics Federations. Progression of World Best Performance and Official IAAF World Records, 2011 edition (Monte Carlo, Monaco, 2011).

[2)] Guiness World Records. Fastest 100 m running on all fours. http://www.guinnessworldrecords.com/news/2014/11/gwr-day-2014-katsumi-tamakoshi-beats-kenichi-ito-to-take-fastest-100-m-running-on-all-fours-record-61825/

Table 2. Kinematic parametres of human bipedal and quadrupedal running.

Kinematic parametres	Usain Bolt (Bipedal)	Kenichi Ito (Quadrupedal)
Speed (m s^{-1})	10.44 [1)]	5.40
Stride length (m)	2.47 [1)]	3.10
Stride frequency (Hz)	4.23 [1)]	2.25
Estimated leg length	0.56	0.46
Relative stride length	4.42	6.72

Source: [1)] Usain Bolt, World Championships Berlin 2009. Maćkała Krzysztof & Antti Mero. A Kinematic Analysis of Three Best 100 M Performance Ever. Journal of Human Kinetics 36, 146-160, 2013.