© by IAAF
27:4; 57-62, 2012

How fast can a human run?

by Jeremy Richmond

ABSTRACT

As sprinters challenge each other to win major championships and run faster we are naturally curious if there is a limit to how far the 100m world record can fall. Predictions about how fast humans can run have been made in the past using mathematical curve fitting based on previous record-breaking performances, metabolic factors and thermodynamic principles and, particularly in the case of the 100m, information about phosphagen energy stores. In this study, the author presents a projection of the limits of human performance in the 100m based on known physiological measurements and recorded observations, many of which are recent findings. It is assumed that ground contact time limits maximum running velocity and that force production times are similar between sprinters running under 10 sec today and in recent years. From the evidence available it seems plausible that humans could reach a velocity of 12.75 m/sec compared to the 12.34 m/sec achieved by Usain Bolt (JAM) in his 9.58 sec world record race. Assuming similar velocity relationships across all phases of the race and the same start reaction time recorded for Bolt, it is suggested that the human limit for the 100m may be close to 9.27 sec.

AUTHORS

Jeremy Richmond is an exercise physiologist and personal trainer in Australia and the founder of the Australian Institute of Speed and Agility. He holds a Bachelors degree in Applied Science-Physics and a Masters degree in Exercise and Sports Science.

Introduction

It is universally agreed that the fastest human ever is Usain Bolt (JAM), the 100m world record holder with a time of 9.58 sec. In establishing that mark in the final of the 2009 IAAF World Championships in Athletics, Bolt broke his own record of a 9.69 sec, set a year earlier at the Olympic Games, and was challenged by Tyson Gay (USA) who ran 9.71 sec to became the second fastest ever. Gay later ran 9.69 sec himself, a mark that was subsequently matched by Bolt's countryman Yohan Blake.

It is reported that Bolt reached a maximal velocity of 12.34 m/sec at about the 68m point of the record race and that Gay achieved a maximal velocity of 12.20 m/sec[1] Although it is not necessarily the case, it is not unreasonable to suggest that both Gay and Blake could have reached 12.20 m/sec or faster when running their 9.69 sec races.

As sprinters challenge each other to win major championships and run faster we are naturally curious as to whether there is a limit on how much the world record will fall eventually. Of course, predictions as to how fast humans can run have been made in the past. The methods used include mathematical curve fitting based on previous record-breaking performances[2,3], metabolic factors and thermodynamic principles[4,5,6] and, particularly in the case of the 100m, information about phosphagen energy stores[7].

This study differs from previous papers in that we have based a prediction of human running speed limits in the 100m on known physiological measurements and recorded observations, many of which have come to light since the publication of the studies mentioned above.

Recent discussions of human running speed limitations have focused on two aspects: vertical force production[8] and the ground contact time needed to apply large mass specific forces[9]. It seems, however that vertical force production might not be the limiting factor for fast running. Data from one study shows that vertical force production remains the same above velocities greater than approximately 7 m/sec, although, it must be acknowledged that the study observed endurance runners[10]. However, the finding is supported by data from a study of sprinters and other athletes, some of whom could reach velocities greater than 10 m/sec, that showed that there is no relationship between maximum vertical force and running velocity[11] (see Figure 1).

Turning to ground contact time, many studies show it to be limited to around 80 milliseconds[12,13] although other researchers have recorded results down to 70 ms within the limitation of their measurement criteria[14]. If ground contact time is indeed the limiting factor for human running velocity, it would be of interest to ascertain the relationship between the known limits and the running velocity of sprinters so as to provide an estimate of human running capacity.

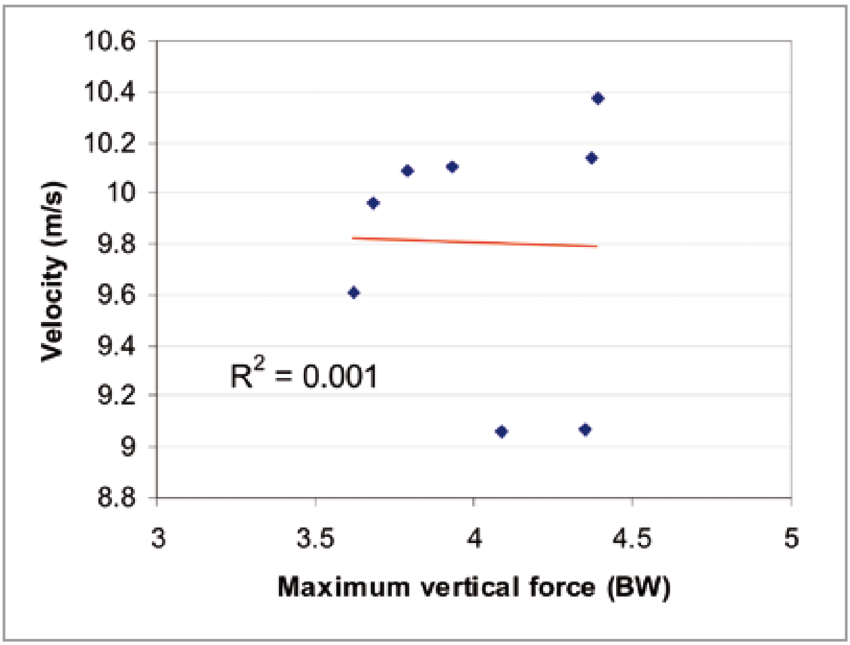

Figure 1: The relationship between maximal vertical force and running velocity (adapted from BEZODIS [10])

Method

For the present study data was gathered from various earlier studies of sprinters[15,16,17] and tabulated in Table 1.

Using software (Microsoft Office Professional Edition 2003) the strength of the relationship between ground contact time and running velocity was calculated. From this relationship an equation was formulated from the gradient and intercept. The results are highlighted in Figure 2.

Table 1: data used to determine a relationship between ground contact time and velocity

Studies	MERO & KOMI [15]	COH[16]	RICHMOND[17]
Ground contact times and velocities	101 ms at 9.59 m/sec	178 ms at 4.88 m/sec 179 ms at 5.25 m/sec 129 ms at 6.33 m/sec 130 ms at 6.98 m/sec 129 ms at 7.63 m/sec 130 ms at 7.76 m/sec 117 ms at 8.42 m/sec 111 ms at 8.29 m/sec 98 ms at 9.38 m/sec 105 ms at 9.12 m/sec 104 ms at 9.95 m/sec	124.5 ms at 8.71 m/sec 95.5 ms at 10.47 m/sec 86.0 ms at 11.14 m/sec 83.75 ms at 11.50 m/sec 81.5 ms at 11.67 m/sec 81.0 ms at 11.80 m/sec

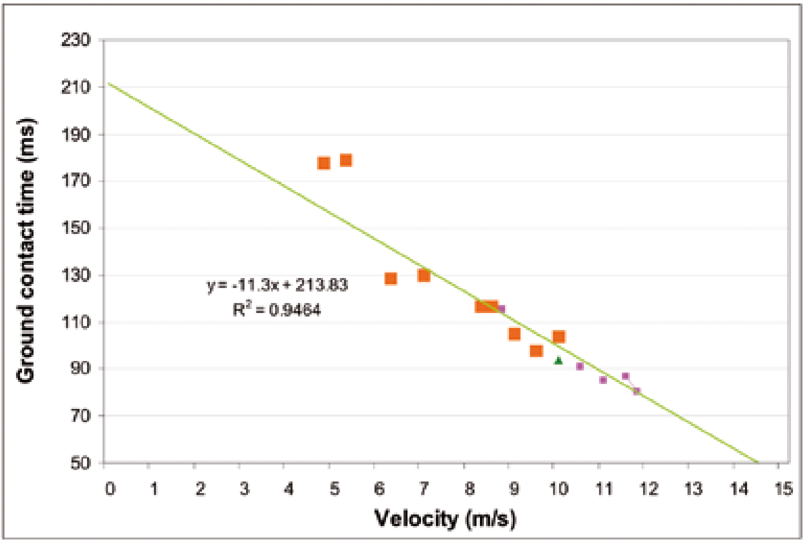

Figure 2: The relationship between ground contact time and running velocity of sprinters (data from MERO & KOMI[15], COH[16], RICHMOND[17])

Interpretation of Correlation Coefficients

0.0 to 0.2	very weak, negligible
0.2 to 0.4	weak, low
0.4 to 0.7	moderate
0.7 to 0.9	strong, high, marked
0.9 to 1.0	very strong, very high

(Courtesy of: Rowntree, Derek. Statistics without tears (2000), Penguin Books.)

Discussion

This relationship between ground contact time and running velocity can be described as very strong (see Box) and from the ensuing equation of the line of best fit, y = -11.3x + 213.83, we can estimate the running velocity at various ground contact times. The relationship that describes how the velocity changes relative to ground contact time is a reasonable estimate; empirical studies report ground contact times for former Olympic Champion and 100m world record holder Donovan Bailey (CAN) of 80 ms[13] with maximal running velocities of 12.03 m/sec[18], which fits in well with the relationship described here (Figure 2).

Using the equation for the line of best fit, we can see that if the observed 70 ms contact time[14] were replicable by sprinters it would produce a running velocity of 12.75 m/sec. Compare this to Bolt's 12.34 m/sec maximal velocity in his world record race.

In fact, a ground contact time of 70 ms[14] is physiologically possible. Scientists have measured human fast-twitch fibres with single twitches of 55-88 ms[20], although the probability of a single twitch producing sufficient forces for sprinting is not likely. However, others have measured quadriceps contraction time to be as low as 71 ms in marathon runners[19] and it would seem plausible that sprint trained atletes could produce contraction times equal to, if not shorter than, such a figure.

Whether a method can be devised produce sufficient force in such short muscle contraction times is worthy of investigation[21]. However, sprinters demonstrate a significant pre-activation of muscle prior to foot strike[22,23] of 50 to 70% of maximum contact levels[24], which may circumvent the ground contact time limitations and allows for more scope to reach quicker ground contact times than are being produced by today's sprinters.

Can we predict the 100m time from maximal speed of 12.75 m/s?

Bolt's top velocity of 12.34 m/sec in the world record race was 1.1% faster that that achieved by Gay in the same race. We will take a conservative view that there is a consistent differential equal to the ratio of maximal velocity (Table 3) that exists throughout the race as compared to the measured average differential of 1.27% determined from interval times (see Table 2). The assumption of a consistent velocity relationship across the entire race has been previously demonstrated whereby faster 100m runners showed consistent speed advantages even from the first few steps[25].

Conclusion

Given the relationship between ground contact time and running velocity and a ground contact time limited to 70 ms, which is the lowest figure recorded, we predict a human running velocity limit of 12.75 m/sec or 45.9 kph. From this speed limit we estimate that with the same reaction time as Usain Bolt during the world record performance of 9.58 seconds, the human limit for 100m under the same conditions would be 9.27 sec.

If scientists and coaches can develop a training method to further shorten muscle contraction time and produce sufficient force for fast running then it seems plausible that human beings could run even faster.

Table 2: interval times and differential for 100m performances at the World Athletics Championship in Berlin 2009 (modified from GRAUBNER & NIXDORF [1])

	Usain Bolt[1]	Tyson Gay[1]	Differential
10m	1.88	1.91	1.6%
20m	2.88	2.88	1.74%
30m	3.78	3.84	1.59%
40m	4.64	4.70	1.29%
50m	5.47	5.54	1.28%
60m	6.29	6.36	1.11%
70m	7.10	7.19	1.27%
80m	7.92	8.02	1.26%
90m	8.74	8.86	1.37%
100m	9.58	9.71	1.36%
Average			1.27%

Table 3: Hypothetical limit times are calculated from the ratio of top speeds

	Usain Bolt (Berlin 2009) [1]	Hypothetical Human Limit
10m	1.88	1.82
20m	2.88	2.79
30m	3.78	3.66
40m	4.64	4.49
50m	5.47	5.29
60m	6.29	6.09
70m	7.10	6.87
80m	7.92	7.67
90m	8.74	8.46
100m	9.58	9.27

Please send all correspondence to:
Jeremy Richmond
jeremyrichmond@hotmail.com

REFERENCES

1. GRAUBNER, R, & NIXDORF, E. (2011) Biomechanical analysis of the sprint and hurdle events at the 2009 IAAF World Championships in Athletics. New Studies in Athletics 26(1/2): 19-53.

2. RUMBALL, W.M, & COLEMAN, C. E. (1970). Analysis of running and the prediction of ultimate performance. Nature 228: 184-185.

3. RYDER, W.H.; CARR, H.J, & HERGET, P. (1976). Future performance in foot racing. Scientific American 234: 109-119.

4. MORTON, H.R. (1986). A three component model of human bioenergetics. Journal of Maths and Biology 24: 451-466.

5. PERONNET, F. & THIBAULT, G. (1989). Mathematical analysis of running performance and world running records. Journal of Applied Physiology 67: 453-465.

6. WARD-SMITH, A. J. (1985), A mathematical theory of running, based on the first law of thermodynamics, and its application to the performance of world-class athletes. Journal of Biomechanics 18: 337-349.

7. SUMMERS, R.L. (1997). Physiology and biophysics of the 100-m sprint. News in Physiological Sciences 12: 131-136.

8. WEYAND, P.G.; STERNLIGHT, D.B.; BELLEZZI, M.J. & WRIGHT, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. Journal of Applied Physiology 89: 1991-1999.

9. WEYAND, P.G.; SANDELL, R.F.; PRIME, D.N.L. & BUNDLE, M.W. (2010). The biological limits to running speed are imposed from the ground up. Journal of Applied Physiology 108: 950-961.

10. NUMMELA, A.; KERANEN, T. & MIKKELSSON, L.O. (2007). Factors related to top running speed and economy. International Journal of Sports Medicine 28(8): 655-662.

11. BEZODIS, I.; SALO, A. & KERWIN, D. (2007). Joint kinetics in maximum velocity sprint running. XXV ISBS Symposium 2007; 59-62.

12. BRUGGEMANN, G.-P. & GLAD, B. (Eds) (1990). Scientific Research Project at the games of the XXXIV Olympiad- Seoul 1988: Final Report. Monaco: International Athletic Foundation.

13. KIVI, D. (1999). Sprint kinematics of the world's fastest human. XVII ISB Congress.

14. KUNZ, H. & KAUFMANN, D.A. (1981), Biomechanical analysis of sprinting: decathletes versus champions. British Journal of Sports Medicine 15(3): 177- 181.

15. MERO, A. & KOMI, P.V. (1994). EMG, force, and power analysis of sprint-specific strength exercises. Journal of Applied Biomechanics 10: 1-13.

16. COH, M.; TOMAZIN, K. & STUHEC, S. (2006). The biomechanical model of the sprint start and block acceleration. Facta Universitatis - Series: Physical Education and Sport 4(2): 103 -114.

17. RICHMOND, J. (2011). Modellng a sub-10 second sprint using Newton's equations of motion. New Studies in Athletics 26(1/2): 69-77.

18. ROWBOTTOM, M. (2008). The big question: as the 100m world record falls again, how much faster can humans run? The Independent 03 June 2008.

19. PLACE, N.; LEPERS, R.; DELEY, G, & MILLET. G.Y. (2004). Time course of neuromuscular alterations during a prolonged running exercise. Medicine and Science in Sports and Exercise 36(8): 1347-1356.

20. EBERSTEIN, A. & GOODGOLD, J. (1968). Slow and fast twitch fibers in human skeletal muscle. American Journal of Physiology 215(3): 535-41.

21. RICHMOND J. (2011). In search of the 70 kph human: challenging the limits of human muscle contraction time. Hypothesis 9(1): 1-10.

22. DIETZ, V.; SCHMIDTBLEICHER, D. & NOTH, J. (1979). Neuronal mechanisms of human locomotion. Journal of Neurophysiology 42(5): 1212- 1222.

23. KYROLAINEN, H.; KOMI, P.V. & BELLI, A. (1999). Changes in muscle activity patterns and kinetics with increasing running speed. Journal of Strength and Conditioning Research 13(4): 400-6.

24. MERO, A,; KOMI, P.V, & GREGOR, R.J. (1992). Biomechanics of sprint running. A review. Sports Medicine 13 (6): 376-392.

25. MERO, A.; LUHTANEN, P. & KOMI, P. V. (1983). A biomechanical study of the sprint start. Scandinavian Journal of Sports Science 5(1): 20-28.