**Straight Line Motion, Acceleration.**

**Acceleration** We saw in the last section that velocity is a function of time, $v(t)$. The function which measures the rate of change of velocity is called the acceleration function and is often denoted by $a(t)$. We will start with average acceleration over a time interval.

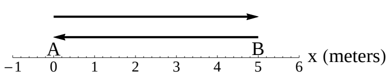
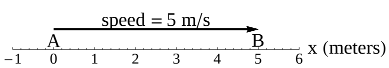
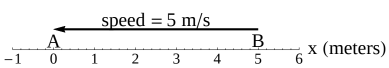
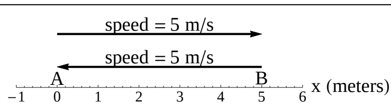
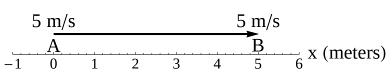
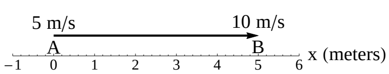
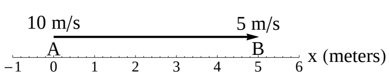
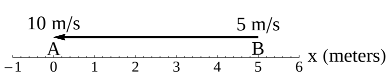
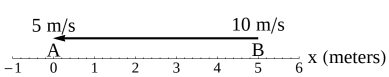
**Average Acceleration** Let $v(t)$ denote the velocity of an object moving in a straight line at time $t$. The average acceleration of the object on the time interval $[t_1, t_2]$ is given by

$$\text{average acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}} = \frac{\Delta v}{\Delta t} = \frac{v(t_2) - v(t_1)}{t_2 - t_1} \quad m/s^2.$$

**Example** An automobile is moving to the right along a straight highway, which we choose to be the positive $x$-axis. The initial velocity of the car observed at time $t = 0$ is 15 m/s. The driver applies the brakes and the velocity observed at time $t = 5$ seconds is $v(5) = 5$ m/s. What is the car's average acceleration in the time interval $[0, 5]$?

**Acceleration and speed** As with velocity, acceleration can be positive or negative and this leads to some confusion in its interpretation. In everyday language we use the term acceleration to indicate that an object is speeding up and deceleration to indicate that it is slowing down. However this is usually applied to objects moving in a single (positive) direction and we must be careful to include direction of movement in our analysis when interpreting positive and negative values for acceleration. The example below should highlight the differences. In general when velocity and acceleration (or velocity and displacement when talking about average quantities ) have the same sign the speed of the object is increasing, and when they have opposite signs the speed of the object is decreasing or the object is slowing down.

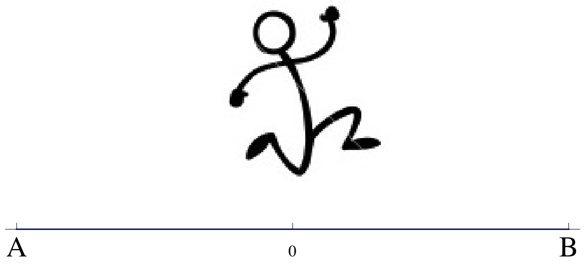
**Example** The examples below show the path of an object as it moves between a point $A$ to a point $B$ positioned 5 meters to the right of $A$. We will use a single axis with units in meters for reference with the origin at $A$ and the positive side to the right of $A$ (therefore a movement from $A$ to $B$ is considered to be a forward movement). In all of the schematic diagrams, the path of the object is represented by arrows. If there are two arrows, the top arrow represents the first half of the movement and the bottom one the second half. In the first 4 diagrams, the constant speeds are shown on the path of the object. In the last five schematic diagrams the speed of the object at the end points $A$ and $B$ are shown and the time taken for the movement is shown at the right of the diagram. In all cases the direction of movement is indicated by the direction of the arrow(s).
Fill in the column on the right with the appropriate measure and units for the entire movement.

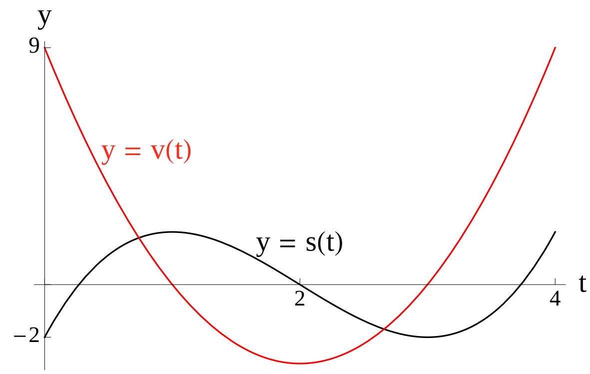
| Movement | | To Calculate | Answer |
|---|---|---|---|
|  | | Displacement (s) (for entire movement) = <br> Distance (d) (for entire movement) = | |
|  | | Average velocity ($\bar{v}$) = | |
|  | | Average velocity ($\bar{v}$) = | |
|  | | Average velocity ($\bar{v}$ for entire movement) = <br> Average speed ( for entire movement) = | |
|  | t = 2s | Average acceleration ($\bar{a}$) = | |
|  | t = 2s | Average acceleration ($\bar{a}$) = | |
|  | t = 2s | Average acceleration ($\bar{a}$) = | |
|  | t = 2s | Average acceleration ($\bar{a}$) = | |
|  | t = 2s | Average acceleration ($\bar{a}$) = | |

**Instantaneous Acceleration** If an object is moving in a straight line, with position function $s(t)$ and velocity function $v(t)$, we can define the instantaneous acceleration of the object at time $t$ (denoted $a(t)$) as the instantaneous rate of change of the velocity function at time $t$; i.e.

$$a(t) = \lim_{\Delta t \to 0} \frac{v(t + \Delta t) - v(t)}{\Delta t} = v'(t)$$

**Example** An athlete doing agility training starts at point A and runs to point B and then turns and runs back to point A and turns again and runs back to point B. The position function for the athlete at time $t$ is given by $s(t) = t^3 - 6t^2 + 9t - 2$. The graphs of the position function, $s(t)$, and the velocity function, $v(t)$, are shown below for $0 \le t \le 4$.




(a) Identify the time intervals on which the acceleration is positive and the time intervals on which the acceleration is negative.

(b) Identify the time intervals on which the athlete is speeding up and the intervals on which the athlete is slowing down.

(c) Sketch the acceleration function using the graph of $v(t)$ shown above.

(d) Calculate a formula for the acceleration function using the formula for the position function $s(t)$ given above.

(e) The velocity of the athlete at times $t = 1$ and $t = 3$ is 0. Find the acceleration of the athlete at these times, i.e. find $a(1)$ and $a(3)$.

Two **common misconceptions about the relationship between acceleration and velocity** are addressed by these questions;
(a) If the velocity of an object is zero, does it mean that the acceleration is zero?
(b) If the acceleration is zero does it mean that the velocity is zero?

The answer to question (a) can be seen to be "No" from part (e) of the previous example. Also if one thinks of a car which starts moving at time $t = 0$, it has initial velocity $v_0 = 0$, but obviously the initial acceleration must be non-zero since the velocity is changing.

The answer to (b) is also "No", since a car(or any object) moving with constant velocity has acceleration equal to 0.

**Approximating acceleration from data** We can use the central distance method to estimate acceleration at time $t$ from a set of velocity data. Namely given two consecutive time intervals of the same length, $[t_1, t_2]$ and $[t_2, t_3]$, we can estimate velocity at time $t_2$ using the formula

$$a(t_2) \approx \frac{v(t_3) - v(t_1)}{t_3 - t_1}.$$

Consider our data from the last lesson. Use the method described above to estimate acceleration from the already estimated velocity.

**Example** Consider our data from the last lesson. We have already estimated velocity using the central distance method. Use the estimates for velocity to estimate acceleration. The following is a set of Position-Time data showing the vertical position of an object moving downwards in a straight line collected from 11 video frames collected at 60 frames per second.

| Frame | Time (s) | Vertical Position (m) | Approx. (inst.) velocity $v$ m/s | Approx. (inst.) acceleration |
|---|---|---|---|---|
| 1 | 0.000 | 0.00 | 0.000 | |
| 2 | 0.0167 | 0.10 | 6.29 m/s | |
| 3 | 0.0334 | 0.21 | 4.79 m/s | |
| 4 | 0.0501 | 0.26 | 3.29 m/s | |
| 5 | 0.0668 | 0.32 | -4.79 m/s | |
| 6 | 0.0835 | 0.10 | -9.58 m/s | |
| 7 | 0.1002 | 0.00 | 2.99 m/s | |
| 8 | 0.1169 | 0.20 | 7.78 m/s | |
| 9 | 0.1336 | 0.26 | 4.19 m/s | |
| 10 | 0.1503 | 0.34 | -6.59 m/s | |
| 11 | 0.1670 | 0.04 | | |

## How can we use this information?

**Collecting and using data: How do we record the speed of a runner?** The data shown directly below gives split times for Usain Bolt's 100 record race in the Berlin World Championships. It is based on a video tape analysis and 10m increment markers or with electronic "eyes" set every 10m.

| Berlin World Championships | | | | |
|---|---|---|---|---|
| **Distance** | **Time (sec.)** | **Split (sec.)** | **10m Velocity** | **10m Accel** |
| **Reaction time** | 0.146 s | | | |
| **10m** | 1.85 s | 1.704 s | | |
| **20m** | 2.89 s | 1.04 s | | |
| **30m** | 3.78 s | 0.89 s | | |
| **40m** | 4.64 s | 0.86 s | | |
| **50m** | 5.49 s | 0.85 s | | |
| **60m** | 6.31 s | 0.82 s | | |
| **70m** | 7.11 s | 0.80 s | | |
| **80m** | 7.92 s | 0.81 s | | |
| **90m** | 8.74 s | 0.82 s | | |
| **100m** | 9.58 s | 0.84 s | | |

From this one might calculate approximations for acceleration are averages based on average velocities, they are much less accurate than averages based on instantaneous velocities.

The data on the next page was collected with a laser gun by scientists working on a biomechanics analysis project for the IAAF show the instantaneous velocity data collected for Usain Bolt's 100 record smashing run. The gun collected data at a rate of 100 frames per second, however the variation in velocity (shown in blue) throughout each stride make it difficult to interpret the velocities. To overcome this difficulty, the researchers used a computer to apply statistical methods to find the best fitting velocity curve to the data (shown in red). So despite the advantages of having instantaneous velocity readings at their fingertips, the scientists report average velocities for the 10 meter intervals to compare the performance of Bolt and Powell and use the curve (based on statistical averages) to calculate maximum speed. Because of these difficulties in deciding what the most useful measure of maximum velocity might be and because of differences in the accuracy of and timing in the usage of measuring instruments, the reported split times vary for the race (note the split times from this analysis are different from those recorded above).

Another issue with collecting kinematic data for runners is that ideally when recording the position and velocity of a runner, one would record the position and speed of the center of gravity. However the position of the center of gravity will vary over the course of the race and it is not the center of gravity which crosses the line first at the end of the race.

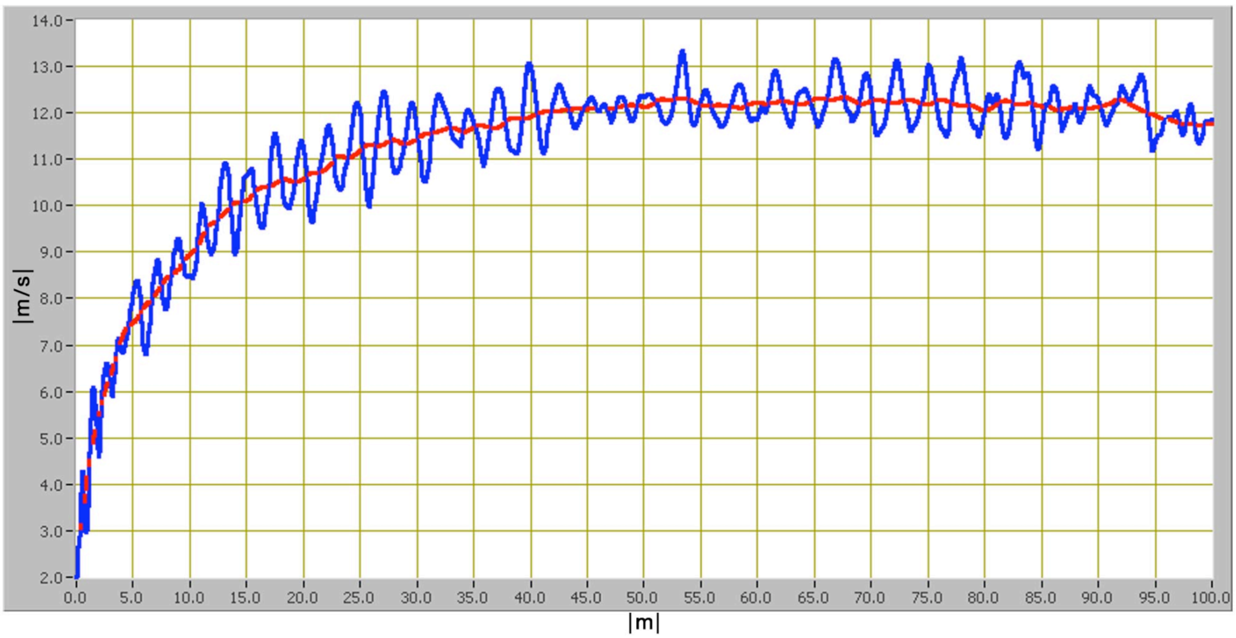
**Example** Use the velocities shown in the graph below (red line) to compare average acceleration on the intervals 0 - 30 m. , 30 - 60 m., 60-80 m. and 80-100 m. (Not that the graph has distance on the horizontal axis and velocity on the vertical axis).

berlin 2009 August 15–23 · 12th IAAF World Championships in Athletics

**Scientific Research Project**

Deutscher Leichtathletik-Verband · IAT Institut für Angewandte Trainingswissenschaft · Olympiastützpunkte Berlin, Hessen, Rheinland · MLU Halle-Wittenberg

## Biomechanical analysis
## 12th IAAF World Championships in Athletics • Berlin, 15.–23.08.2009
## 100m men final: Usain BOLT (JAM) 9,58s – WR




Race distribution: LAVEG measurement curve (blue) and average speed (red)

**Split times [s]**

| | Reaction time | t10 | t20 | t30 | t40 | t50 | t60 | t70 | t80 | t90 | t100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bolt | 0,146 | 1,89 | 2,88 | 3,78 | 4,64 | 5,47 | 6,29 | 7,10 | 7,92 | 8,75 | 9,58 |
| Powell | 0,134 | 1,87 | 2,90 | 3,82 | 4,70 | 5,55 | 6,39 | 7,23 | 8,08 | 8,94 | 9,84 |

**Average velocities at 10m, 20m, ... 100m [m/s]**

| | V10 | V20 | V30 | V40 | V50 | V60 | V70 | V80 | V90 | V100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bolt | 5,29 | 10,10 | 11,11 | 11,63 | 12,05 | 12,20 | 12,35 | 12,20 | 12,05 | 12,05 |
| Powell | 5,35 | 9,71 | 10,87 | 11,36 | 11,76 | 11,90 | 11,90 | 11,76 | 11,63 | 11,11 |

| Vmx | at m | V99% | at m |
|---|---|---|---|
| 12,27 | 65,03 | 12,15 | 48,18 |

Vmax is the maximual velocity of 12,27m/s, reached at 65m

V99 is 99% of the maximal velocity, reached at 48,18m

## How Fast is Fast? Can Usain Bolt's record be beaten?

The shattering of the world record for the 100 m. in Berlin led to much speculation on where the limit on human speed is and whether this record time could be reduced even further. The article by John Barrow[1] included in the previous lecture argues that Usain Bolt could take his time down to 9.4 s. by reducing reaction time, running with a higher tailwind speed and running at a higher altitude. The following table, taken from Blazevich[2], uses statistics from Bolt's performance in Berlin to measure the maximum speed and acceleration for humans and compares it to the top recorded speed for some of the fastest land animals.

**BOX 1.3 HOW FAST IS FAST?**

Sometimes, when we see numbers, it is difficult to imagine how big or fast or small they are. By way of comparison, the table below shows the estimated top speeds and accelerations of some of the fastest land animals.

| *Animal* | *Speed* ($m \cdot s^{-1}$) | *Speed* ($km \cdot h^{-1}$) | *Animal* | *Acceleration* ($m \cdot s^{-2}$) |
|---|---|---|---|---|
| Human[a] | 12.3 | 44.3 | Human[a] | 5.1 |
| Cheetah | 29 | 104.5 | Lion[b] | 9.5 |
| Lion | 22 | 80 | Gazelle[b] | 4.5 |
| Gazelle | 22 | 80 | | |
| Hunting dog | 20 | 72 | | |
| Ostrich | 18 | 64 | | |
| Domestic cat | 13 | 48 | | |
| Elephant | 11 | 40 | | |

Data adapted from: *Natural History* magazine, Copyright Natural History Magazine, Inc., 1974.
a Data of Usain Bolt measured by Radar in the World Championships 100 m, Berlin, 2009.
b Data from Elliott et al., 1977, In: Alexander, R.M. *Principles of Animal Locomotion*, Princeton University Press.

In an interesting exercise (shown on the next page), Blazevich[2] takes the **fastest split times** on record for 100 m. for men and women and **strings them together** which allows us to compare top performances for men and women on each segment and also leads us to speculate that if a single runner were to match the top performance recorded on each segment, the world record could be reduced for 100m.

[1]Mathletics, *John D. Barrow*, Norton, 2012.
[2]Sports Biomechanics, The Basics; 2nd Edition, *Anthony J. Blazevich*, A&C Black, 2010.

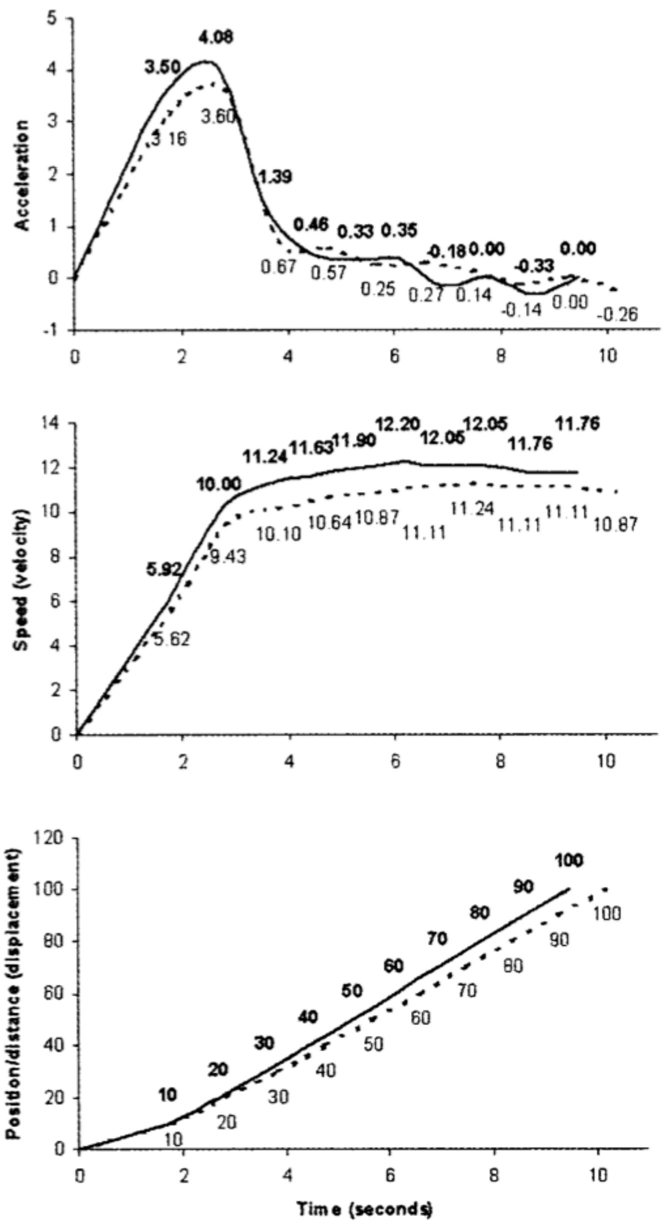



**FIG. 1.5** The above graphs are drawn from data representing the fastest 10 m split times for a world-class male (dark bold lines and numbers) and female (dashed lines and lighter numbers) sprinter. The athletes' reaction times are not included. As usual, the acceleration graph varies greatly, with the variation being less for speed and less again for position/distance. It can also be seen that the female sprinter accelerated similarly to the male early (up to 10 m or 20 m), but attained a lower top speed, which they both seem to hold equally well. The greater top speed allows the man to reach each 10 m point sooner than the woman, ultimately leading to him finishing the 100 m much faster. Of interest is that these graphs show that if you took the fastest segments run by either runner and put them together, the 100 m could be completed in 9.46 s by the man and in 10.20 s by the woman. With a reaction time of 0.1 s (the fastest legal reaction time under current IAAF regulations), it seems the man (9.56 s) and woman (10.30 s) are currently capable of running the 100 m faster than the current (2009/10) world records of 9.58 s and 10.54 s, for men and women respectively. As a side issue, the units for position/distance, speed and acceleration are not included on the graphs … what units should be used and what abbreviations are common for these?

**How do we Identify Factors affecting performance in a race?**

**Characteristics of the velocity curve** Your textbook shows a picture of Hill's proposed mathematical model for a sprint race velocity curve, to which the performance of most sprinters conforms. Most sprinters accelerate rapidly at the beginning of the race and then maintain a constant velocity (zero acceleration) in the middle of the race, with velocity decreasing (negative acceleration) at the end of the race as the runner tires. The winner of the race is usually the person whose velocity decreases the least at the end of the race.

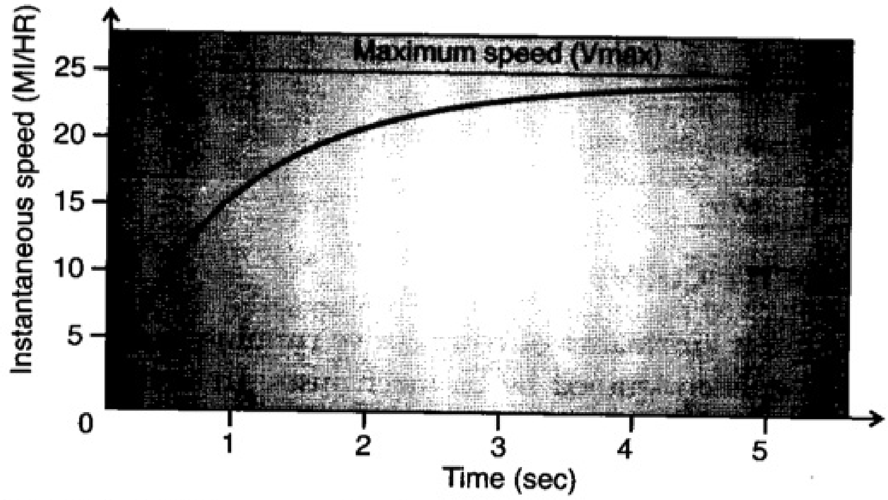
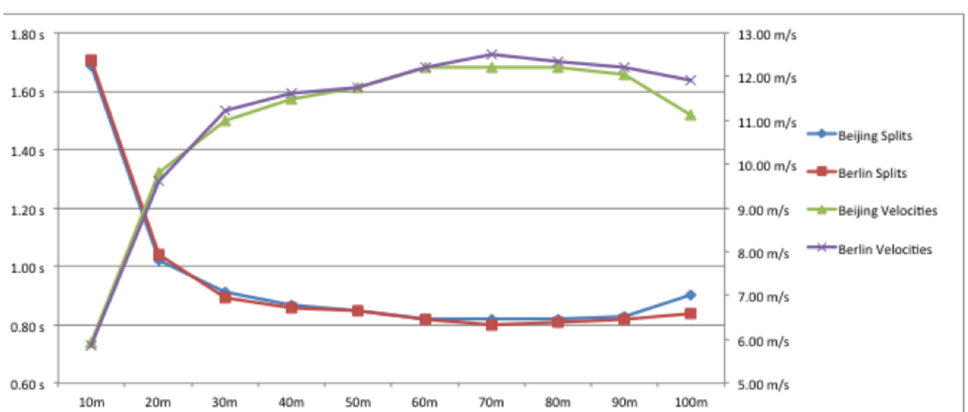
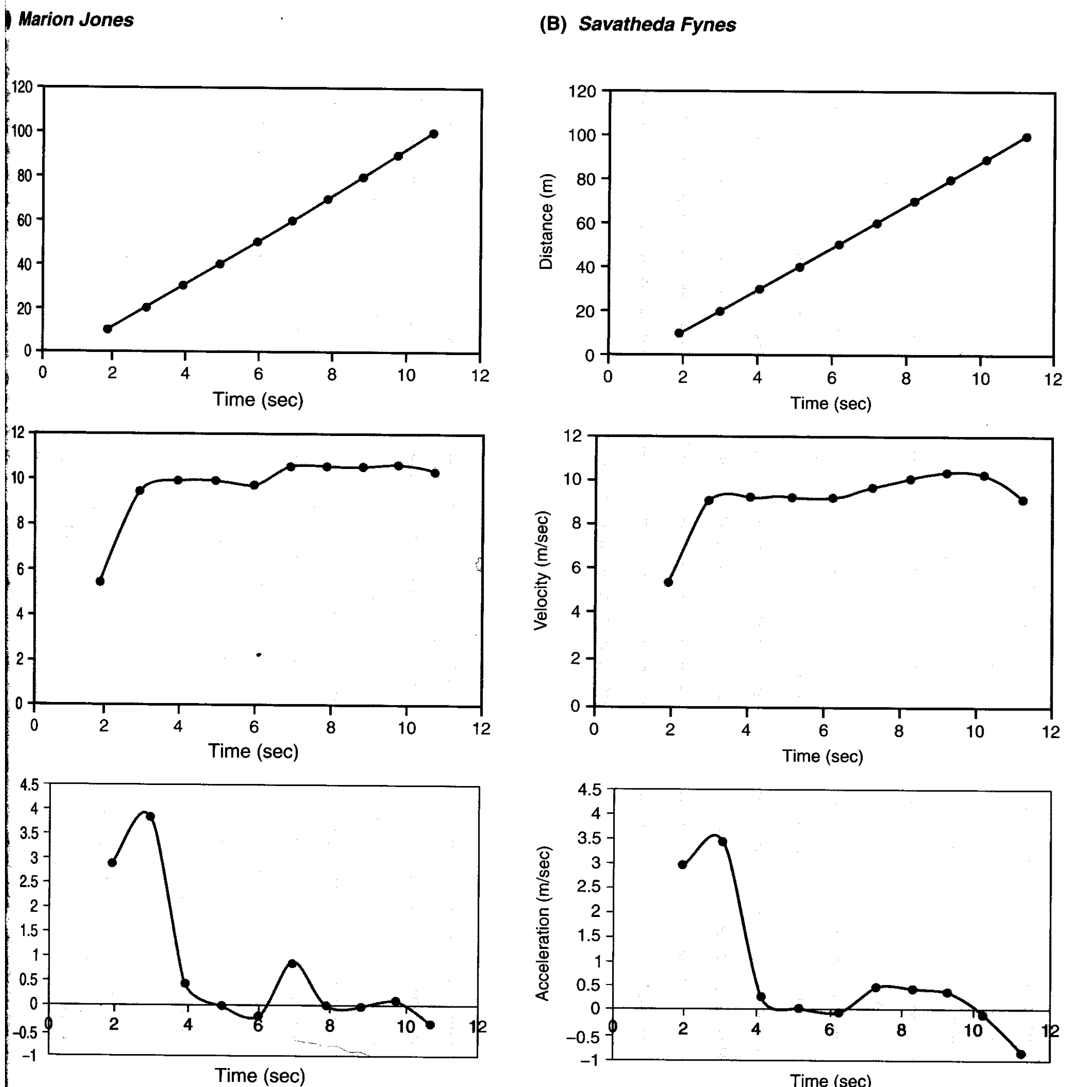



**FIGURE 8-29** Hill's proposed mathematical model of a sprint race velocity curve. (Adapted from Brancazio, P. J. [1984]. *Sport Science*. New York: Simon & Schuster.)

The following graph of the split time data for Usain Bolt's 100 m. finals in Berlin and Beijing also bear out this hypothesis.




Your text also has graphs showing the split times and corresponding average velocities and accelerations for the 100 m. runs of Marion Jones and Samantha Fynes in the Sydney Olympics in 2000. Certainly in this data we see that Jones' loss of speed at the end was much less than that of Fynes, bearing out the hypothesis above.




**RE 8-30** Distance **(top)**, velocity **(middle)**, and acceleration **(bottom)** curves for the 2000 Olympics nen's 100-m final performance of Marion Jones **(A)** and Savatheda Fynes **(B)**. (Source of split times: ://sydney2000.nbcolympics.com/).

**Correlations** The following study (the full paper is included at the end of this lecture) used data collected with a laser gun for top male sprinters in the races shown to test for correlations between performance times and certain variables. It also bears out the above hypothesis.

**Table 1: Speed data of the top sprinters in the men's 100 meter at the World Championships.**

| Name | WC | Rank/ Rd. | React Time (sec) | Final Time (sec) | Max. S. (m/s) | Avg. S. (m/s) 80m-100m | S 80m-100m /Max S(%) | Reduc. (%)of S btw 80m-100m |
|---|---|---|---|---|---|---|---|---|
| T. Gay (USA) | 07 | 1/F | 0.143 | 9.85 | 11.83 | 11.63 | 98.31 | 1.69 |
| D.ATKINS (BAH) | 07 | 2/F | 0.137 | 9.91 | 11.74 | 11.56 | 98.47 | 1.53 |
| A.POWELL (JAM) | 07 | 3/F | 0.145 | 9.96 | 11.79 | 11.11 | 94.23 | 5.77 |
| C.MARTINA (AHO) | 07 | 5/F | 0.180 | 10.08 | 11.67 | 11.49 | 98.46 | 1.54 |
| M.DEVONISH (GBR) | 07 | 6/F | 0.149 | 10.14 | 11.48 | 11.24 | 97.91 | 2.09 |
| U. BOLT (JAM) | 11 | 1/1R | 0.153 | 10.10 | 11.64 | 10.53 | 90.46 | 9.54 |
| U. BOLT (JAM) | 11 | 1/SF | 0.164 | 10.05 | 11.74 | 10.65 | 90.72 | 9.28 |
| M.FRATER (JAM) | 11 | 1/1R | 0.149 | 10.26 | 11.42 | 10.53 | 92.21 | 7.79 |
| N.CARTER (JAM) | 11 | 1/1R | 0.164 | 10.26 | 11.31 | 10.42 | 92.13 | 7.87 |
| Y.BLAKE (JAM) | 11 | 1/F | 0.174 | 9.92 | 11.75 | 11.39 | 96.94 | 3.06 |
| U. BOLT (JAM) | 09 | 1/F | 0.146 | 9.58* | 12.27 | 12.04 | 98.13 | 1.87 |
| Mean | | | 0.155 | 10.01 | 11.69 | 11.14 | 95.27 | 4.73 |
| SD | | | 0.014 | 0.197 | 0.25 | 0.54 | 3.34 | 3.34 |

* World record of men's 100 meter, 07: Osaka, 09: Berlin, 11: Daegu, S: speed, 2007 Osaka WC data is adapted from JAAF (2007) report

Table 2 shows the Pearson correlation coefficients between performance time and variables. The results indicated that the performance time of the sprinters is negatively correlated with maximum speed and an average speed between 80 meters and 100 meters ($p < 0.01$). Furthermore, the performance time of the sprinters is positively correlated with speed reduction between 80 meters to 100 meters with respect to their maximum speed (R=0.567, $p < 0.05$). However, there was no significant correlation between performance time and reaction time of the sprinters.

**Table 2: Pearson's correlations coefficients (R) between performance time and variables.**

| N=11 | Reaction time (sec) | Maximum Speed (m/sec) | Avgage Speed btw 80m-100m | Speed Reduction btw Max Speed & 80m-100m |
|---|---|---|---|---|
| Performane Time (sec) | 0.307 | -0.967** | -0.843** | 0.567* |

One tail test, **$p$<0.01, * $p$<0.05

---

**Analysis of stride** Other significant factors in correlated with performance time studied by Professor Peter Weyand from Southern Methodist University, striking the ground with greater force and for less time significantly improves performance. This makes sense in light of the variation in velocity during a single stride ( the more force applied to the ground, the greater the resulting velocity in the latter half of the stride and the higher the overall average speed will be). This variation is obvious in the velocity curve shown above collected from Usain Bolt's record breaking run in Berlin. Applying greater force in a horizontal direction will also lead to longer strides. Weyand notes that in Usain Bolt's record breaking run, he took 41 strides, whereas most sprinters take 44 strides to complete 100 meters. It is noted in your text that when walking, there is always at least one foot on the ground, whereas when running, a person does not always have a foot on the ground, an airborne phase is followed by alternating single support phases. It has also been noted that during the 9.58 seconds it took Bolt to finish the 100 m. in Berlin, he spent 5.29 seconds not touching the ground at all.

# SPRINTING SPEED OF ELITE SPRINTERS AT THE WORLD CHAMPIONSHIPS

**Jiseon Ryu[1] Sukhoon Yoon[1] Sang-Kyoon Park[1] Tae-Sam Kim[1] Hojong Gil[1]**
**Si-Hyun Yoo[1] Gyesan Lee[2] Hiroyuki Koyama[3] and Takashi Mochida[4]**

**Biomechanics Laboratory, Korea National Sport University[1], Seoul, Korea, Kwandong University, Korea[1] Kwandong University[2], Korea, Kyoto University of Education[3], Yokohama Sports Association[4], Japan**

The purpose of this study was to analyze the sprinting speed of the sprinters during the men's 100 m events at the IAAF World Championships (WC) in order to provide important information to track and field coaches and athletes. Sprinting speed of the sprinters was collected by using laser guns (Laveg Sport, Jenoptik, Germany) during the World Championships in Daegu 2011. Then, data from Osaka 2007 WC and Berline 2009 WC were included in the analysis. The findings indicated that a reduction of a sprinter's maximum speed is correlated with their performance time ($p$<0.05). Three top sprinters showed less than 2% reduction of thier maximum speed. Therefore, how the sprinters maintain their maximum speed until the end of the race is important for best performance.

**KEY WORDS:** sprinting speed, Laveg system, maximum speed, speed reduction.

**INTRODUCTION:** The measurement of reliable running speed is important for the analysis of sprinting events but some biomechanical applications such as the method of video digitization are costly and time consuming. Currently, laser systems developed for measuring vehicle speed has been used for meauring running speed in track and field evnets (Harrison et al., 2004). A previous study suggested that sprinting should be divided into three phases: acceleration, maximum speed, and deceleration (Murase et al., 1976). However, in world class elite sprinting events, sprinters complete the race within ten seconds and almost without a deceleration phase. Therefore, the purpose of this study was to investigate sprinting speeds of world class sprinters in recent WCs, especially focused on how performance time is related to characteristics of sprinting speed.

**METHODS:** Three laser speed guns (LAVEG Sport, Jenoptik, Germany) were used to measure sprinting speed. The calibration process of the LAVEG system was done by two individuals in the 100 meter lane (Figure 1). The system measured an instant performance time at a given distance. Therefore, an instant speed of the sprinter was calculated by dividing the distance by time. Data was sampled with a frequency of 100 frames per second and filtered with a low pass filter (cutoff frequency: 0.5). Four top sprinters at the WC in Daegu 2011 were selected for the measurement of sprinting speed. Then, speed date for the six sprinters in the recent WCs (2007 Osaka WC and 2009 Berlin WC) were included in the analysis. Pearson's correlation coefficients were calculated to investigate the relationship between performance time and speed characteristics at an alpha level of 0.05 using SPSS version 17.0 program.

**RESULTS:** Table 1 shows speed data for the top sprinters in the men's 100 meter at the recent WCs between 2007 and 2011. Their average performance time is 10.01 seconds (SD: 0.197) with a reaction time of 0.155 seconds (SD: 0.014). Also, the average maximum speed between the races is 11.69 seconds (SD: 0.25) with a range from 11.31 to 12.27 seconds. In addition, the reduction of speed between 80 meters and 100 meters with respect to the maximum speed was 4.73 % (SD: 3.34) with a range from 1.69 % to 9.54 %. The three top sprinters among the eleven selected sprinters show less than a two percent reduction of their maximum speed between 80 meters and 100 meters.

**Figure 1: Measurements of sprinting speed (Left: Laveg system, Middle: Calibration process, Right: Sprinting speed of Yohan Blake's 100 meter final at 2011 WC in Daegu). Figure is adapted from Ryu et al. (2011).**

**Table 1: Speed data of the top sprinters in the men's 100 meter at the World Championships.**

| Name | WC | Rank/ Rd. | React Time (sec) | Final Time (sec) | Max. S. (m/s) | Avg. S. (m/s) 80m-100m | S 80m-100m /Max S(%) | Reduc. (%)of S btw 80m-100m |
|---|---|---|---|---|---|---|---|---|
| T. Gay (USA) | 07 | 1/F | 0.143 | 9.85 | 11.83 | 11.63 | 98.31 | 1.69 |
| D.ATKINS (BAH) | 07 | 2/F | 0.137 | 9.91 | 11.74 | 11.56 | 98.47 | 1.53 |
| A.POWELL (JAM) | 07 | 3/F | 0.145 | 9.96 | 11.79 | 11.11 | 94.23 | 5.77 |
| C.MARTINA (AHO) | 07 | 5/F | 0.180 | 10.08 | 11.67 | 11.49 | 98.46 | 1.54 |
| M.DEVONISH (GBR) | 07 | 6/F | 0.149 | 10.14 | 11.48 | 11.24 | 97.91 | 2.09 |
| U. BOLT (JAM) | 11 | 1/1R | 0.153 | 10.10 | 11.64 | 10.53 | 90.46 | 9.54 |
| U. BOLT (JAM) | 11 | 1/SF | 0.164 | 10.05 | 11.74 | 10.65 | 90.72 | 9.28 |
| M.FRATER (JAM) | 11 | 1/1R | 0.149 | 10.26 | 11.42 | 10.53 | 92.21 | 7.79 |
| N.CARTER (JAM) | 11 | 1/1R | 0.164 | 10.26 | 11.31 | 10.42 | 92.13 | 7.87 |
| Y.BLAKE (JAM) | 11 | 1/F | 0.174 | 9.92 | 11.75 | 11.39 | 96.94 | 3.06 |
| U. BOLT (JAM) | 09 | 1/F | 0.146 | 9.58* | 12.27 | 12.04 | 98.13 | 1.87 |
| Mean | | | 0.155 | 10.01 | 11.69 | 11.14 | 95.27 | 4.73 |
| SD | | | 0.014 | 0.197 | 0.25 | 0.54 | 3.34 | 3.34 |

* World record of men's 100 meter, 07: Osaka, 09: Berlin, 11: Daegu, S: speed, 2007 Osaka WC data is adapted from JAAF (2007) report

Table 2 shows the pearson correlation coefficients between performance time and variables. The results indicated that the performance time of the sprinters is negaively correlated with maximum speed and an average speed between 80 meters and 100 meters ($p$<0.01). Furthermore, the performance time of the sprinters is positively correlated with speed reduction between 80 meters to 100 meters with respect to their maximum speed (R=0.567, $p$<0.05). However, there was no significant correlation between performance time and reaction time of the sprinters.

**Table 2: Pearson's correlations coefficients (R) between performance time and variables.**

| N=11 | Reaction time (sec) | Maximum Speed (m/sec) | Avgage Speed btw 80m-100m | Speed Reduction btw Max Speed & 80m-100m |
|---|---|---|---|---|
| Performane Time (sec) | 0.307 | -0.967** | -0.843** | 0.567* |

One tail test, **$p$<0.01, * $p$<0.05

Figure 2 shows the linear relationship between performance time and speed characteristics. There was a tendency to show a significant correlation between the sprinters' performance time and a maximum speed as well as reduction of maximum speed.

**Figure 2: Correlation coefficients between the performance time and Maximum speed (left), and Speed reduction (right).**

**DISCUSSION:** It is critical for the sprinters to perform a maximum speed during the race to show the best performance. How sprinters can reach a high sprinting speed and maintain a maximum speed have been the interestof much bimoechanics research. Ito et al. (2007) suggested that knee flex in the swing leg has a positive impact on maximum speed. Also, their correlation analysis indicated that greater hip extension velocity and smaller knee flexion velocity of the support leg are positively related to maximum speed. In addition, maintaining maxium speed throughout the race to the finish line is as important as reaching a high level of sprinting speed. The sprinters somehow experience a deceleration phase after their maximum speed. When Usain Bolt set the world record for the men's 100 meter race, 9.58 seconds, his maximum speed was 12.27 m/sec at a distance of 65 meters. Then, he continued to maintain that speed throughout the race as there was only a 1.87% reduction of maximum speed between 80 meters and 100 meters. Also, Tyson Gay, who won in 2007 Osaka WC and Derrick Atkins, who second place showed a reduction of 1.69 % and 1.53 %, respectively. Therefore, how the sprinters maintain their maximum speed throughout the race is an important topic to understand the sprinting mechanics of today's top male sprinters.

**CONCLUSION:** The findings indicated that increasing the maximum speed with a minimum reduction of maximum speed over time are important factors that affect sprinters' performance time. Therefore, how sprinters achieve and maintain their maximum speed until the end of the race is requried for further biomechanical investigation.

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