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Why is Christophe LeMaitre so Damn Fast?
By: Bret Contreras

Christophe LeMaitre is one fast sumbitch. As a matter of fact, he's the fastest Caucasian in the history of track & field. At only 21 years of age, he's the only Caucasian to officially run 100 meters in less than 10 seconds (he actually did so at age 20). To date, 80 sprinters have broken the 10-second barrier, but only one of them is Caucasian. Christophe has run the 100m in 9.92 seconds and the 200m in 19.8 seconds, and he's faster than Asafa Powell and Tyson Gay (and possibly Usain Bolt) were when they were 20 years old.

Over the years, many theories have been proposed as to what limits acceleration, maximal speed, and 100m sprint performance. Is absolute force what's truly important, or does the direction of force application matter? Do increased vertical force and the generation of high levels of stiffness get you on and off the ground more quickly? Is horizontal force more important to help push you further down the track? Is the resultant ground reaction force vector (combination of vertical and horizontal forces) critical, or is it more complicated? Is the "force" portion of the power formula (P = FV) more important than the "velocity" portion, or vice versa? Do faster sprinters have lower contact times? What about stride lengths and stride rates? Do faster sprinters have higher body masses, thereby allowing them to produce greater force? Do they have longer limbs than their slower counterparts? What are the most important "sprint" muscles?

These are just some of the questions that sports scientists and track & field coaches are trying to figure out, and French researcher JB Morin is leading the way with some amazing research over the past several years.

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Mechanical Determinants of 100m Sprint Running Performance

Recently, Morin and colleagues decided to analyze LeMaitre and other sprinters in an attempt to figure out what makes LeMaitre faster than his competitors. Here's aLINK to the abstract. This study is one of the coolest studies I've ever read and I commend the researchers for putting together such a comprehensive study in order to advance our understanding of sprint biomechanics. Here's what they did:

Subjects:

The researchers examined 13 subjects. Nine of them were P.E. students who had been exercising regularly (including sprinting) over the past six months but were not sprint specialists. Three of them were National level sprinters in France. And one was Christophe LeMaitre; the fastest dude in all of Europe (in the world top 4 in 100 and 200m at the 2011 World Championships in Daegu). Though many studies in the literature have examined high-level sprinters, very few have experimentally studied a world-class sprinter, which makes this study highly valuable.

Methods:

1. Two main measurements were taken for each subject:
    1. A 100m sprint on a standard field track, and
    2. A 6-second sprint on a specialized torque treadmill (to date the only of this kind) that measured 3-dimensional forces, velocity, power, and other important variables of interest
2. In addition, anthropometric data was collected
3. The researchers collected a ton of data, both on the track and at their lab, and conducted an impressive number of analyses

Results:

This particular paper has contributed very heavily to the body of knowledge. In fact, it took me a few reads to adequately understand all of the findings due to the physics and mathematics involved in the paper. Since there were so many findings, I'll just list them in bullet-point fashion:

- Mean and peak propulsive power in the horizontal direction, as measured on the instrumented torque treadmill, were significantly correlated with maximum speed, 100m sprint time, and the distance covered over a 4-second interval. The latter were the most relevant and simple to understand acceleration and sprint performance variables considered by the group of scientists.

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- The researchers were able to create a force-velocity line by plotting the dots created by the horizontal force and corresponding velocity values averaged for each running contact phase, from the step at which max horizontal force during the sprint was produced (typically one of the first three steps), to that when maximum velocity was reached. By doing so, they were able to draw and study subjects' "force-velocity" profile (i.e. the overall incline of their individual force-velocity linear relationship), i.e. on what balance between these capabilities (force or velocity) does subjects' power output depend.

By extending the line to the vertical and horizontal axes, they were able to obtain theoretical maximums of horizontal force production (the hypothetical maximum amount of force production possible absent of time requirements) and velocity production (the hypothetical maximum velocity possible absent of external forces). These maxima are important as they characterize the mechanical limits of neuromuscular output in sprint running, and can not be reached in experimental conditions.

The theoretical maximum horizontal force that sprinters could produce was not correlated with any of the performance variables, whereas the theoretical maximum horizontal velocity that sprinters could achieve was significantly correlated with all performance variables. In other words, a velocity-oriented power profile seems critical to speed and 100m sprint performance, not a force-oriented power profile.

- The researchers calculated what they call an "index of force application/orientation technique" by plotting the dividend of the horizontal force and total force (they call this RF which stands for "ratio of force") from the second step of the sprint until maximum speed was reached and then creating a line-of-best fit, allowing them to calculate the slope. This gives an indication of the sprinter's ability to continue to create a forward-oriented total ground reaction force (GRF) at increasing speeds. This index is highly correlated with all measures of sprint performance; maximal speed, 100m sprint time, and 4-s distance. In fact, Christophe Lemaitre (the fastest runner in the group) had the highest index whereas the slowest runner had the lowest index.

- Low contact times, high step frequencies, and low swing times were significantly correlated with 100m sprint performance, which surprisingly was not the case with high step lengths and aerial times.

- Body mass index (BMI) and leg length ratio (leg length divided by total height) were not correlated with 100m sprint performance.

- Here are the correlations between the index of force application technique, horizontal GRF, vertical GRF, resultant GRF, maximum horizontal power output, average horizontal power output, theoretical maximal horizontal force, and theoretical maximal horizontal velocity with maximum speed, average 100m speed, and 4-second distance (significant correlations are shown in red):

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	Maximal Speed	**Mean 100m Speed**	**4s Distance**
Index of force application technique	**.875**	**.729**	**.683**
Horizontal GRF	**.773**	**.834**	**.773**
Vertical GRF	**.593**	.385	.404
Resultant GRF	**.611**	.402	.408
Maximum horizontal power output	**.863**	**.850**	**.892**
Average horizontal power output	**.810**	**.839**	**.903**
Theoretical maximum horizontal force	.560	.447	.432
Theoretical maximum velocity	**.819**	**.735**	**.841**

- As you can see, the index of force application technique is the highest correlate of maximal speed, followed by maximum horizontal power output. Average 100m speed is most related to measures of horizontal power and force. Distance covered over a 4s interval is most related to horizontal power output as well.
- Horizontal GRFs are much more related to sprint performance than vertical or resultant GRFs.

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- Theoretical maximum horizontal velocity is more related to sprint performance than theoretical maximum horizontal force. In fact, when comparing these two extremes between Lemaitre (fastest sprinter in the group) and the slowest sprinter in the group (he recorded a 15.03s 100m sprint), Lemaitre possessed a theoretical max horizontal velocity and theoretical max horizontal force of 14.0 m/s and 8.47 N/kg, respectively, whereas the slowest sprinter possessed a theoretical max horizontal velocity and theoretical max horizontal force of 8.28 m/s and 6.82 N/kg, respectively. So Lemaitre's theoretical max horizontal velocity is far superior (69% higher) to the slowest sprinter, whereas his theoretical horizontal force is only 24% higher than the slowest sprinter.

Correspondence With Morin

I was able to correspond with JB Morin and attain some very interesting information that cannot be found in the published study (including the detailed chart below).

- First, though the National sprinters along with Lemaitre did possess better vertical stiffness than the non-sprinters, leg stiffness did not vary between Lemaitre and the National sprinters and surprisingly the non-sprinters as well.
- Second, some of Lemaitre's results compared to his peers are quite startling. He achieved:
    - 2 standard deviations (5.5% faster) ahead of the National sprinters for the 100m sprint time
    - 2 standard deviations ahead of the National sprinters for maximum velocity power output
    - 3 standard deviations ahead of the National sprinters in theoretical maximal horizontal velocity (5 standard deviations ahead of non-sprinters)
    - 3 standard deviations ahead of the National sprinters in the slope of the force-velocity relationship
    - Higher step frequency, shorter ground contact time compared to his National peers
    - Much higher levels (11.8% higher and 1.56 standard deviations) of net relative horizontal force compared to his National peers
    - 10% higher relative horizontal power compared to his National peers and 40% higher (5.90 standard deviations) ahead of the non-sprinters
    - A 43% (3.21 standard deviations ahead) better index of force application than National level sprinters and 95% (3.47 standard deviations ahead) of the non-sprinters
    - 10% greater metabolic power than his National peers (even higher at the beginning of the 100m sprint)

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- Third, some of Lemaitre's results were on par with his National peers. He achieved:
  - Similar levels of theoretical maximal horizontal force
  - Similar levels of aerial time, swing time, and step length
  - Similar levels of vertical and total force production per unit of bodyweight (vertical force only 3.24% higher and total force only 3.68% higher)
  - Similar levels of BMI (actually slightly lower) and L/H ratio
  - Forth, at every single sprint velocity, Lemaitre is able to produce more horizontal force than the National sprinters, who are able to produce more horizontal force at every sprint velocity than the non-sprinters, despite the fact that each group's theoretical maximal horizontal forces were similar (8.54 N/kg for Lemaitre, 9.28 N/kg for Nationals, 8.40 N/kg for non-sprinters).
  - 17.3% higher horizontal rate of force development (3.02 standard deviations) than his National peers (obtained by dividing net horizontal force by contact time), but only 6.45% greater vertical rate of force development (1.2 standard deviations) than his National peers. However, the horizontal and vertical RFDs were much higher in the National sprinters than the non-sprinters.
  - Based on these data, it can be deduced that what's important is not the maximum amount of horizontal force capabilities, but the relative (per bodyweight) horizontal force at any given velocity (and especially at higher velocities).

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TABLE 1. Main field performance, running mechanics and metabolic power variables for the elite sprinter tested and the national-level peers (n = 3) and non-specialists (n = 9) groups compared.

	CL	National-level peers	% difference with CL	Non-specialists	% difference with CL
Field 100-m performance variables					
t_{100} (s)	10.35	10.92 *(0.20)*	5.51*	13.60 *(0.70)*	31.4***
S-max (m.s^{-1})	11.21	10.78 *(0.37)*	-3.83	8.63 *(0.39)*	-23.0***
S_{100} (m.s^{-1})	9.66	9.16 *(0.17)*	-5.18*	7.36 *(0.38)*	-23.8***
Treadmill running velocity, power output and F-V characteristics					
V (m.s^{-1})	7.08	6.77 *(0.21)*	-4.35	5.50 *(0.40)*	-22.3**
V-max (m.s^{-1})	8.67	8.13 *(0.18)*	-6.23**	6.50 *(0.38)*	-25.0***
P (W.kg^{-1})	25.5	22.7 *(1.67)*	-11.0	15.7 *(2.31)*	-38.4***
P-max (W.kg^{-1})	31.9	28.5 *(1.16)*	-10.7*	19.8 *(2.05)*	-37.9***
F_H0 (N.kg^{-1})	8.54	9.28 *(0.42)*	8.67	8.40 *(1.22)*	-1.64
$V0$ (m.s^{-1})	13.1	11.3 *(0.31)*	-13.7***	8.91 *(0.61)*	-32.0***
$S_{F\text{-}V}$ (N.s.m^{-1}.kg^{-1})	-0.655	-0.821 *(0.050)*	25.3**	-0.951 *(0.192)*	45.2
Running kinematics					
tc (s)	0.121	0.129 *(0.003)*	6.61*	0.156 *(0.015)*	28.9*
ta (s)	0.095	0.097 *(0.003)*	2.11	0.093 *(0.014)*	-2.11
t_{swing} (s)	0.309	0.311 *(0.012)*	0.65	0.338 *(0.025)*	9.39
SF (Hz)	4.64	4.39 *(0.093)*	-5.39*	4.05 *(0.20)*	-12.7*
SL (m)	1.53	1.54 *(0.010)*	0.65	1.36 *(0.16)*	-11.1
Running kinetics and spring-mass behaviour					
F_H (BW)	0.398	0.351 *(0.030)*	-11.8	0.310 *(0.052)*	-22.1
F_V (BW)	1.85	1.79 *(0.06)*	-3.24	1.60 *(0.12)*	-13.5*
F_{Tot} (BW)	1.90	1.83 *(0.06)*	-3.68	1.63 *(0.13)*	-14.2*
$F_{V\text{-}Vmax}$ (BW)	1.97	1.99 *(0.06)*	1.02	1.78 *(0.12)*	-9.64
D_{RF}	-0.042	-0.060 *(0.006)*	-42.9**	-0.082 *(0.007)*	-95.2**
k_{leg} (kN.m^{-1})	15.1	15.9 *(1.11)*	5.30	15.1 *(3.97)*	0.00
k_{vert} (kN.m^{-1})	103	102 *(3.8)*	-0.97	68.4 *(12.1)*	-33.6*
Metabolic power					
P_{met}-100 (W.kg^{-1})	54.3	48.5 *(3.52)*	-10.7	33.1 *(2.49)*	-39.0***
P_{met}-max (W.kg^{-1})	108	99.3 *(3.85)*	-8.06*	51.7 *(5.59)*	-52.1***
P_{met}-4s (W.kg^{-1})	77.1	69.5 *(3.34)*	-9.86*	43.6 *(3.74)*	-43.4***

Values are mean *(SD)*
*: difference higher than 2SD
**: differences higher than 3SD
***: difference higher than 4SD

*Metabolic power was estimated following the methods proposed by di Prampero in 2005.
Click HERE for a link to that paper.

Limitations

The only main limitation of the study is that it was conducted on a torque treadmill. This type of treadmill does have a different "feel" to it compared to sprinting on a track, as it involves more forward lean. However, treadmill sprint times and 100-m performances were significantly correlated to track field times (the fastest runners on the track appear to be the fastest runners on the treadmill, and the slowest on the track appear to be the slowest on the treadmill). Moreover, the treadmill allows for the collection of highly meaningful data including the GRFs over the entire sprint run (records GRFs for every single step).

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This data collection allows for the calculation of RFs and the index of force application, which seems to be the most highly correlated factor relating to maximal speed. This is currently the only way to get such data, until fully instrumented 100-m tracks are made available…

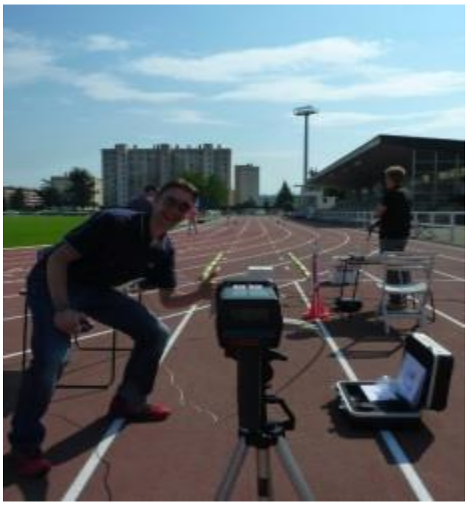
What Future Research Needs to Determine

Like all excellent studies, this paper should lead to further research for various questions, including:

- What training methods best produce horizontal force and power during sprint running?
- What muscle groups are the most concerned? JB Morin and his group are currently testing the hypothesis that the hip extensors (glutes and hamstrings) play an important role in this forward orientation of the resultant force.
- Does each sprinter have an optimal force/velocity profile, as recently shown for vertical jump performance by researcher Pierre Samozino (Click HERE for a link to that abstract)?
- What are the best cues for sprinting to allow them to increase horizontal force and power?
- If Lemaitre continues to get faster over time, what variable changes will help him achieve his speed increases (for example, increased resultant force capability, increased BMI)?

Conclusion

What makes Christophe Lemaitre so damn fast? It isn’t vertical force, total force, resultant force, stiffness, step length, or theoretical maximum horizontal force. His effectiveness of force application onto the ground (quantified through Morin et al.’s index of force application: the slope of the line of best fit formed with the plots of the ratio of horizontal to total force for each step of the sprint) is much higher than his peers. He produces much higher relative net horizontal force and power throughout the sprint. The velocity component of his force-velocity profile is much higher than his peers. And his step rate is higher and contact time is lower than his peers. This shows that throughout the race and especially at high speeds, he continues to produce high levels of net horizontal force.



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