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JULY 9 — 12, 2014 | LAS VEGAS | PARIS HOTEL & CASINO

Horizontal Trumps Vertical for Acceleration and Speed Development

Bret Contreras, MA, CSCS

AUT UNIVERSITY

Disclaimer

"This is what I know today. It is subject to change tomorrow as I continue to advance my knowledge."

Professor John Cronin,
AUT University

The Great Debate:

What Limits Maximum Sprinting Speed?

Vertical Force

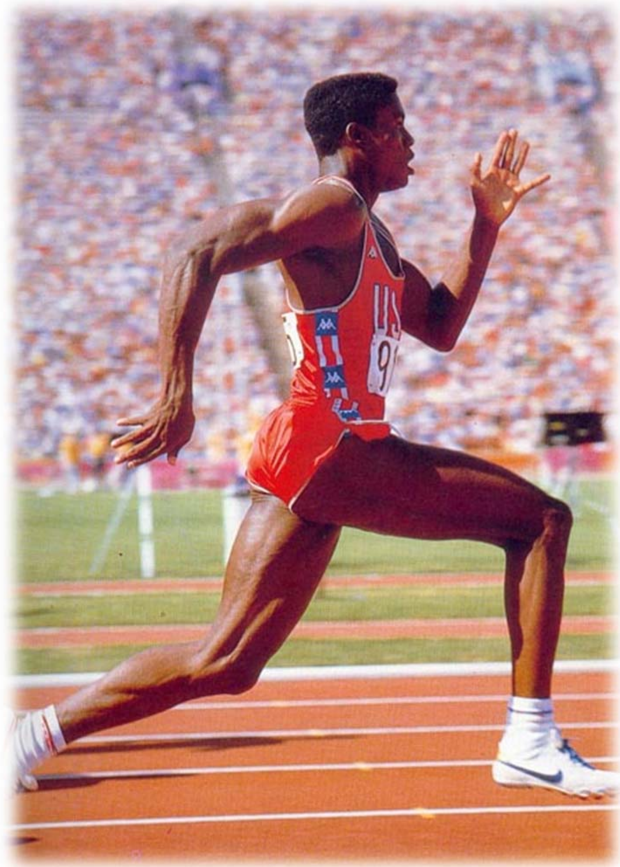
Horizontal Force

Why Does it Matter?

A better understanding of the mechanisms leads to more hypothesis to test and ultimately more effective methods for improving speed development

Before We Get Started…

- Sprinters are the only athletes who accelerate for 60 meters
- Most athletes top out at around 25 meters
- Ground sports are more about acceleration
- Acceleration mechanics in ground sports is more upright in posture



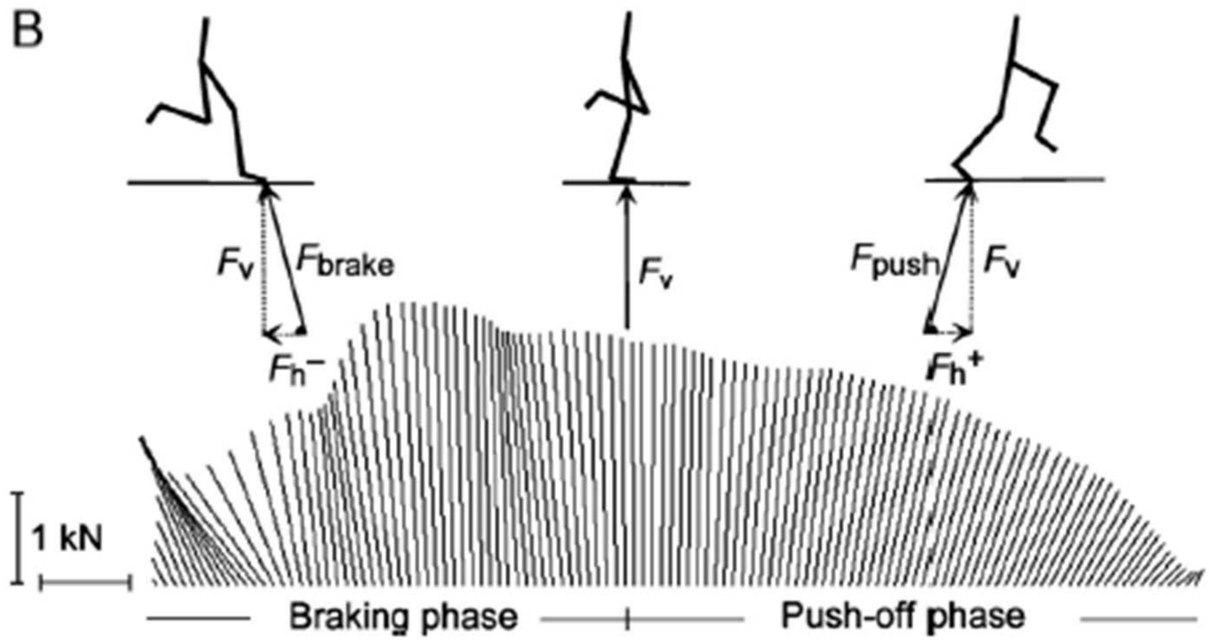
Evidence

- Sprinters reach top speed at around 60m, yet they don't maximally accelerate (faster speeds are seen in 50 & 60m sprints than same split times during 100m) [1, 2, 3]
- College American football players reach top speed at around 20m [5]
- 90% of all sprints in soccer [6] and 68% in rugby are shorter than 20m [4]
- 58% of sprints in rugby preceded by locomotion (24% by standing start) [4]

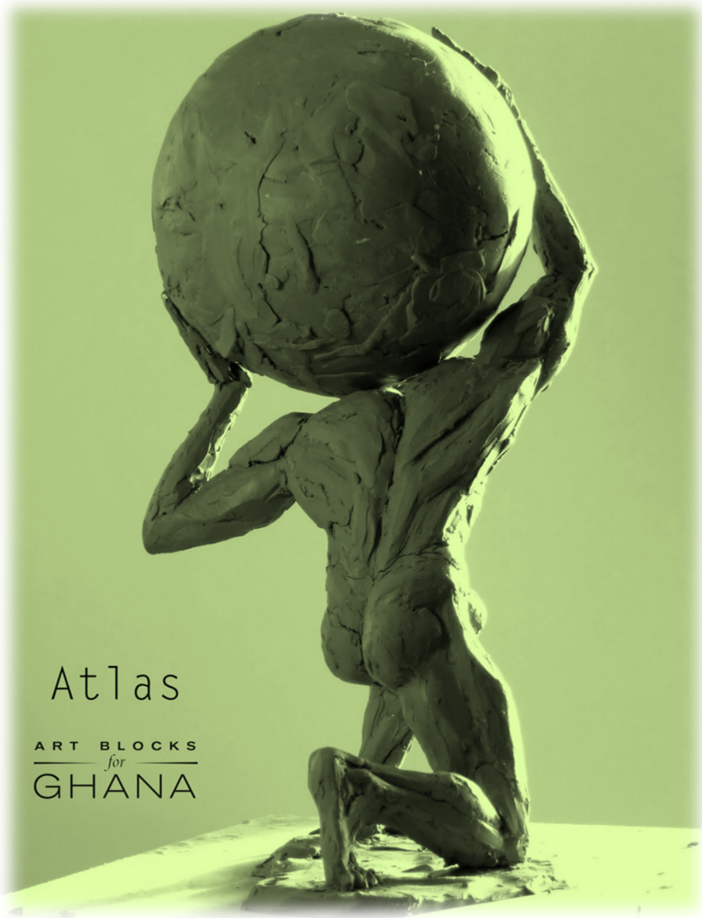
Nevertheless, the Debate Rages On!

Definitions

- Force
- Power
- Impulse
- Relative
- Absolute
- Net
- Horizontal
- Braking
- Propulsive
- Vertical
- Resultant (Total)
- Ratio of Forces
- Index of Force Application



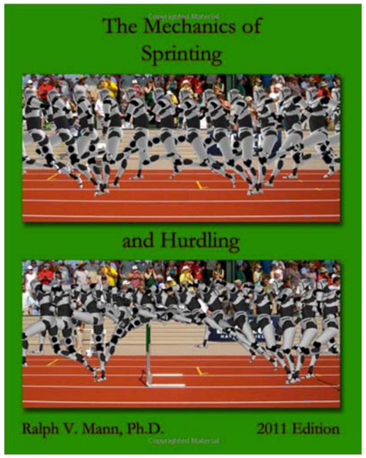
Arguments in Favor of Vertical Force



Argument #1

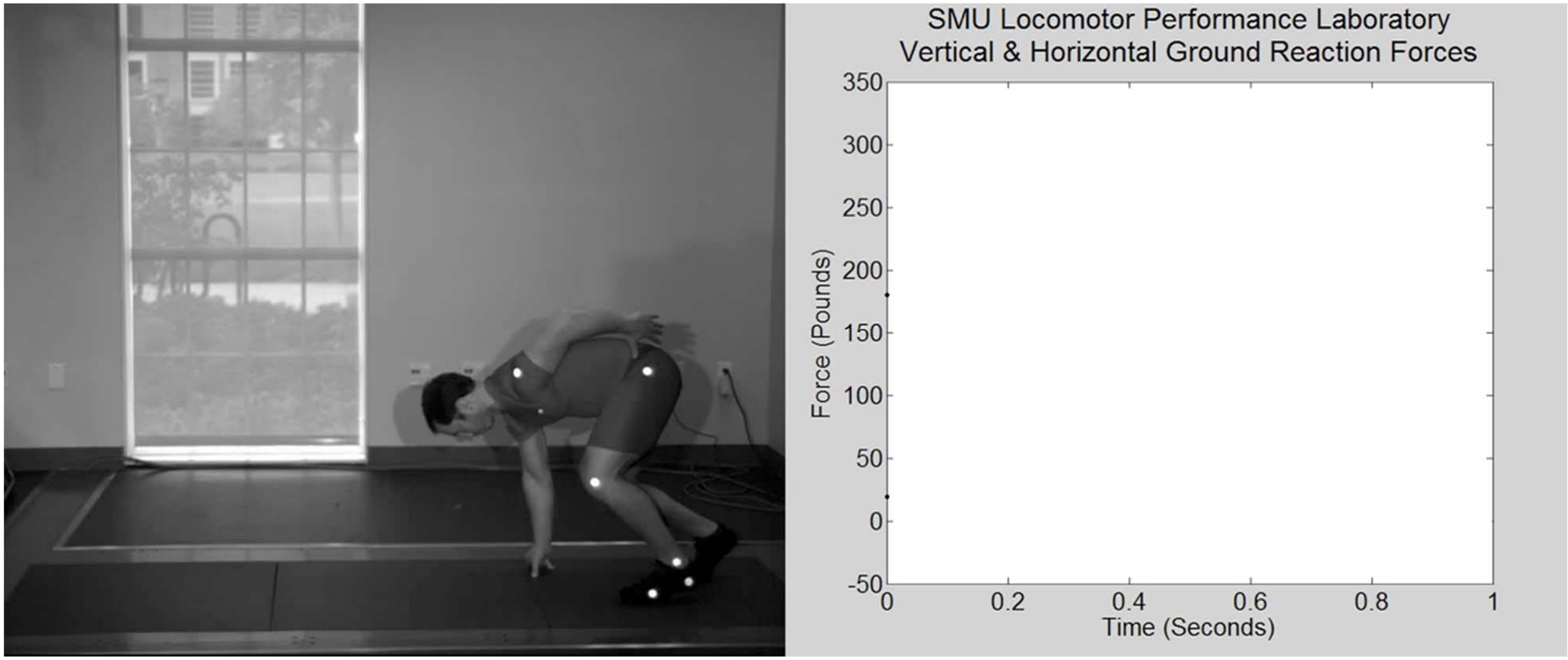
Throughout a Sprint, Vertical Force Rises and Net Horizontal Force Diminishes to Zero, so Vertical Force is More Important

- Weyand
- Mann



Force Discrepancy Throughout a Sprint

Acceleration: Forces are Similar



Sprint acceleration with vertical and horizontal force data.

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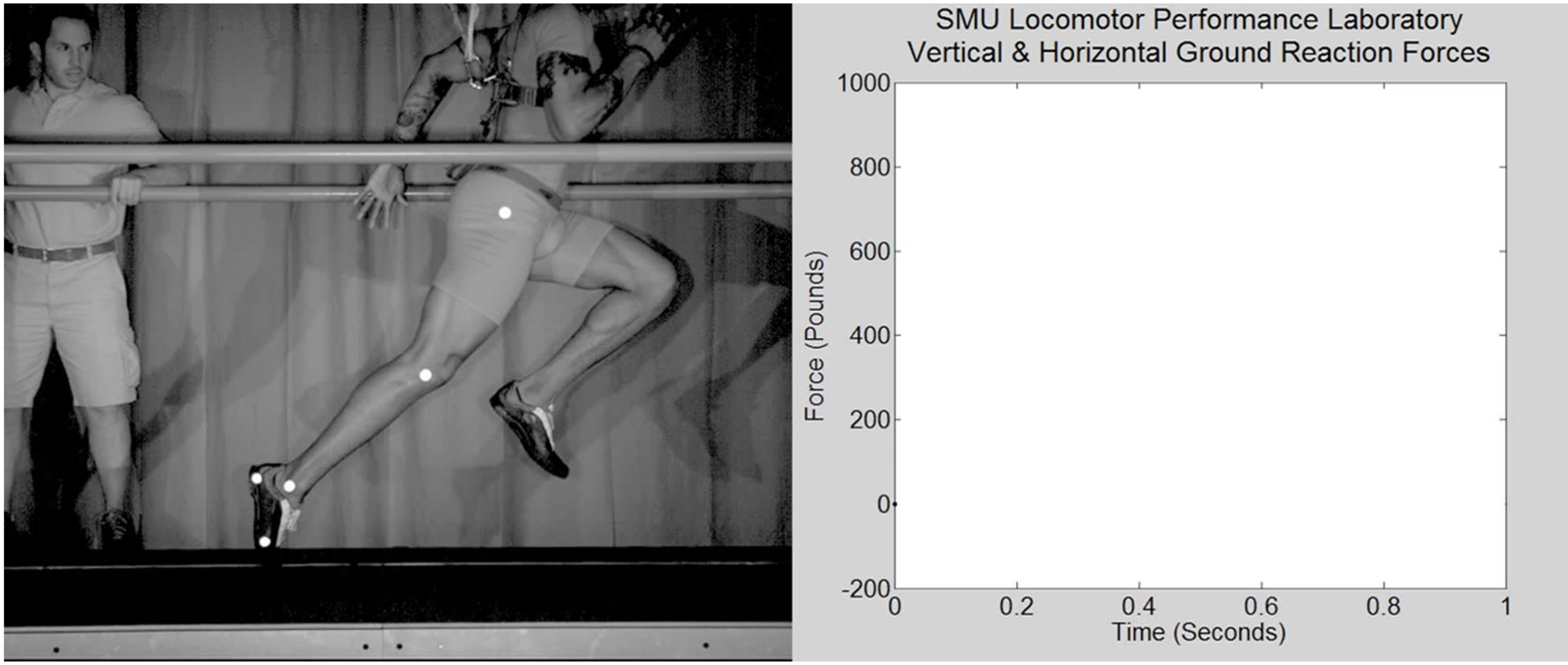
Force Discrepancy Throughout a Sprint

Max Speed: Forces are Dissimilar



Slow motion video of sprint trial with synchronized vertical and h...

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Counterargument #1

The fact that horizontal force diminishes so drastically might indicate that it's the more difficult of the two components to maintain as speed rises, and therefore the more critical for max speed

Counterargument #2

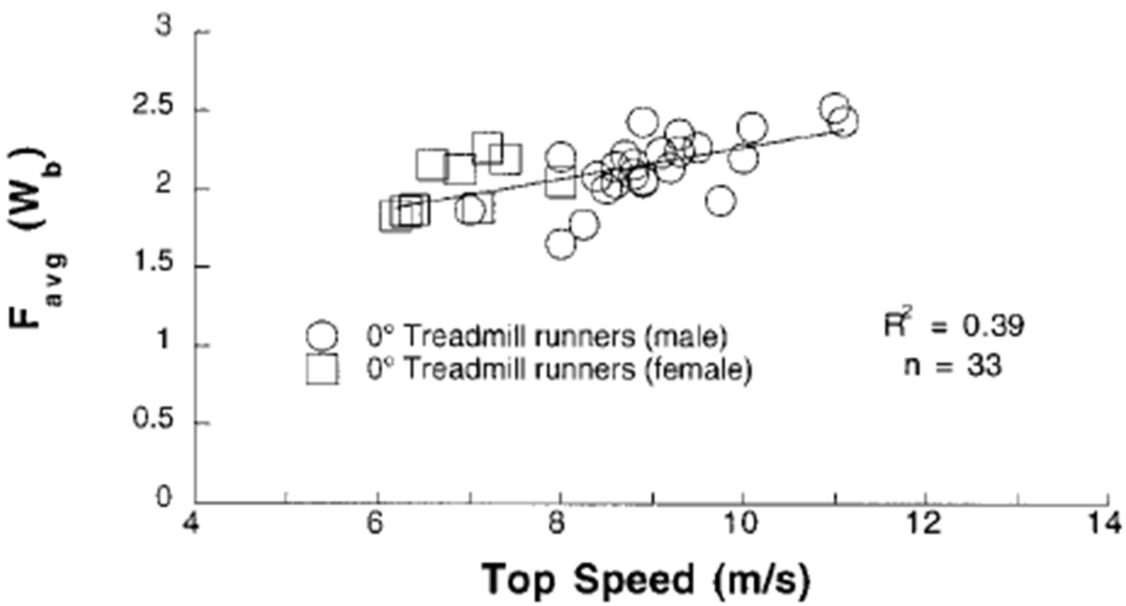
Need to examine running forces at a range of velocities to determine critical factors of increasing speed

- Belli [36]
- Brughelli [10]
- Kyrolainen [31, 32]
- Kuitunen [35]
- Munro [34]
- Nummela [30]

Argument #2

Faster Runners Produce More Force

1.8-fold increase in max velocity, 1.26-fold increase in vGRF [7]



Morin et al. (2011) [9]

TABLE 2. Correlations between mechanical variables (rows) and 100-m performance variables (columns).

	Maximal Speed ($m \cdot s^{-1}$)	Mean 100-m Speed ($m \cdot s^{-1}$)	4-s Distance (m)
Maximal value of RF (%)	0.013 (0.97)	−0.018 (0.96)	−0.217 (0.96)
Mean 4-s RF (%)	**0.695 (<0.01)**	**0.773 (<0.01)**	**0.689 (<0.05)**
Index of force application technique (D_{RF})	**0.735 (<0.01)**	**0.779 (<0.01)**	**0.745 (<0.01)**
F_H (BW)	**0.775 (<0.01)**	**0.736 (<0.01)**	**0.621 (<0.05)**
F_V (BW)	0.501 (0.10)	0.390 (0.22)	0.466 (0.13)
F_{Tot} (BW)	0.520 (0.08)	0.411 (0.19)	0.471 (0.13)
F_V at top speed (BW)	**0.612 (<0.05)**	0.507 (0.09)	0.498 (0.10)
P_P ($W \cdot kg^{-1}$)	**0.891 (<0.001)**	**0.862 (<0.001)**	**0.715 (<0.01)**

F_H, F_V, F_{Tot}, and P_P are mean values for the acceleration phase. Values are presented as Pearson correlation coefficient (P values). Significant correlations are reported in bold.

Morin et al. (2012) [8]

Table 3 Correlations between mechanical variables of sprint kinetics measured during treadmill sprints (rows) and 100-m performance variables (columns)

	Maximal speed ($m\ s^{-1}$)	Mean 100-m speed ($m\ s^{-1}$)	4-s distance (m)
Index of force application technique D_{RF}	**0.875** (*<0.01*)	**0.729** (*<0.05*)	**0.683** (*<0.05*)
Horizontal GRF	**0.773** (*<0.01*)	**0.834** (*<0.01*)	**0.773** (*<0.05*)
Vertical GRF	**0.593** (*<0.05*)	0.385 (*0.18*)	0.404 (*0.16*)
Resultant GRF	**0.611** (*<0.05*)	0.402 (*0.16*)	0.408 (*0.16*)

Significant correlations are reported in bold. Horizontal, vertical and resultant GRF data are averaged values for the entire acceleration phase. Values are presented as Pearson's correlation coefficient (*P* values in italics)

Counterargument #1

Horizontal force more correlated than vertical force or resultant (total) force – the Weyand study only examined vertical

- Of studies that examine both, 13 show that horizontal is more correlated to speed/acceleration, whereas only 1 shows that vertical is more correlated (example below [10])

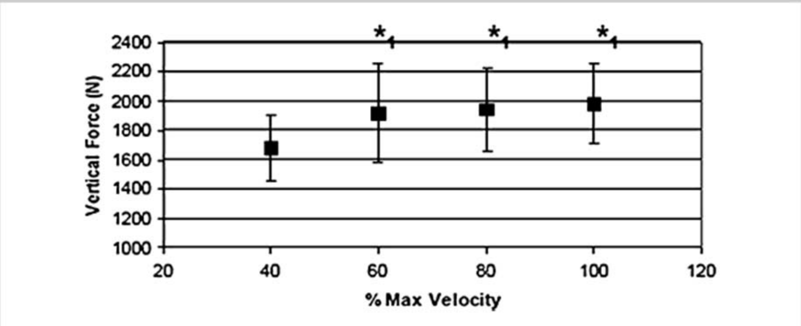


Figure 1. Effects of running velocity on vertical force production. *$p < 0.05$; *1 = significantly different from 40%.

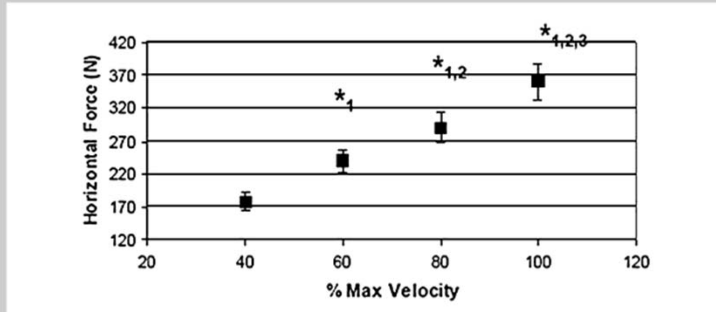


Figure 2. Effects of running velocity on horizontal force production. *$p < 0.05$; *1 = significantly different from 40%; *2 = significantly different from 60%; and *3 = significantly different from 80%.

Counterargument #2

- Vertical force production isn't maximized when sprinting [11]

BIOLOGICAL LIMITS TO RUNNING SPEED 951

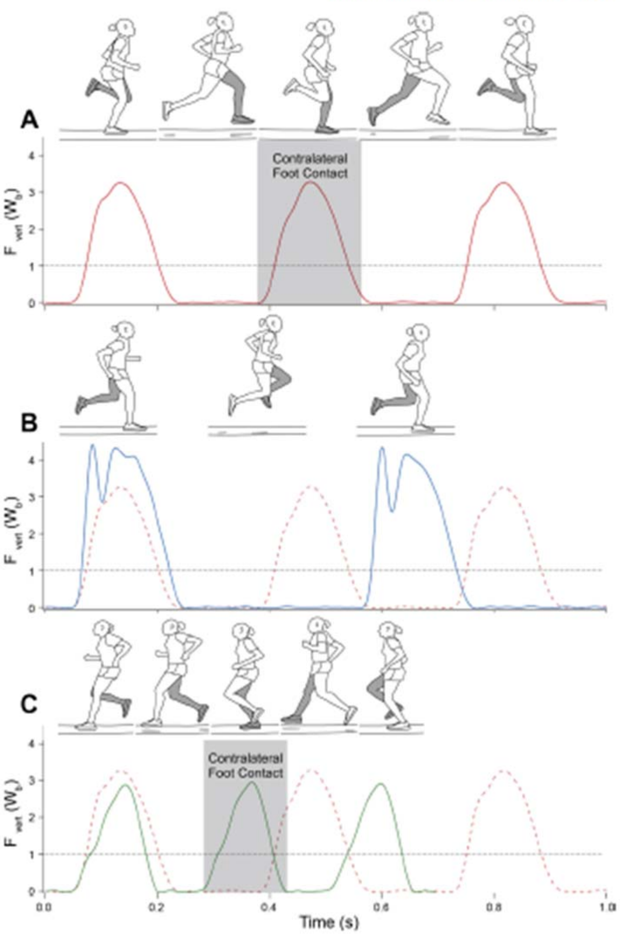


Fig. 1. Vertical ground reaction forces and contact and aerial periods of the step cycle vs. time for forward running (*A*), one-legged hopping (*B*), and backward running (*C*) for a representative subject at the same speed for all three gaits (5.0 m/s). The ground reaction forces for forward running from *A* are reproduced in *B* and *C* (dashed curves) to allow comparisons of the ground reaction forces and contact and aerial phase durations of these gaits with forward running. Note that the durations of the contact, aerial, and swing phases are appreciably shorter at top forward running speed.

Counterargument #3

- Any excess vertical motion in sprinting will slow the sprinter down [12, 13, 14]

TOTAL BODY VERTICAL SPEED (TOTAL BODY RESULT)

Although the performer must project the body vertically (upward) during the sprint, excessive vertical motion is not wanted. Figure 3 shows good, average, and poor levels of vertical speed for all of the male 100 meter elite athletes analyzed to date. The better sprinters tend to produce just enough vertical speed to allow time to complete leg recovery and prepare for the next ground contact, while directing more effort toward maintaining horizontal speed.

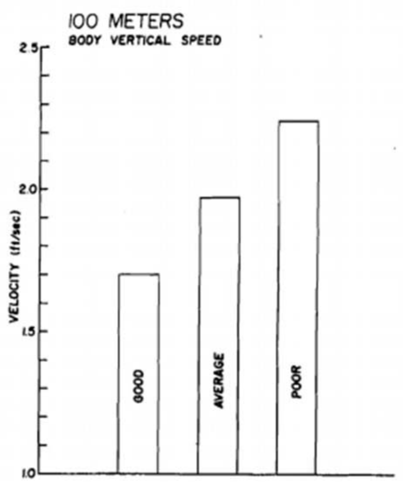


Figure 3. Total body maximum vertical speed trends generated by male, elite athlete 100 meter sprinters.

tended to produce only moderate magnitudes of relative vertical impulse. We speculated that, during the acceleration phase, the most favorable magnitude of relative vertical impulse is one that creates a flight time just long enough to allow repositioning of the lower limbs; all other strength reserves should be directed horizontally. Further research is required to see if braking, propulsive, and vertical impulses

Table 5. Pre- and post-test results for biomechanical variables recorded at 8 m from the start during the 10-m sprint test for heavy and light groups.

Variable	Heavy group (n = 10) Pretest	Heavy group (n = 10) Posttest	Light group (n = 11) Pretest	Light group (n = 11) Posttest	Interaction P value
Sagittal-plane video data					
Step frequency (Hz)	4.02 ± 0.40	4.33 ± 0.36*	4.06 ± 0.31	4.11 ± 0.37	0.160
Step length (m)	1.68 ± 0.13	1.72 ± 0.15	1.64 ± 0.09	1.72 ± 0.14*	0.390
Ground reaction force data					
Relative resultant impulse ($m \cdot s^{-1}$)	2.51 ± 0.22	2.39 ± 0.11*	2.45 ± 0.15	2.49 ± 0.18	0.023†
Relative vertical impulse ($m \cdot s^{-1}$)	0.92 ± 0.14	0.80 ± 0.06*	0.81 ± 0.11	0.82 ± 0.14	0.020†
Relative net horizontal impulse ($m \cdot s^{-1}$)	0.39 ± 0.06	0.41 ± 0.05	0.37 ± 0.06	0.37 ± 0.08	0.439
Relative braking impulse ($m \cdot s^{-1}$)	-0.06 ± 0.02	-0.06 ± 0.02	-0.07 ± 0.02	-0.08 ± 0.02	0.254
Relative propulsive impulse ($m \cdot s^{-1}$)	0.45 ± 0.05	0.47 ± 0.04	0.44 ± 0.06	0.45 ± 0.07	0.812

*Significant difference from pretest at $P < 0.05$; †significant group × time interaction at $P < 0.05$

Momentum Explanation

Sprinting is akin to a bouncy ball or skipping a stone – momentum is built up and it continues on it's own

Counterargument #1

- Each stride, losses of 1.4-4.8% of horizontal velocity occur during the braking phase and around 2% in flight [15, 16, 17, 18]
- Sprinter must reproduce this or deceleration occurs

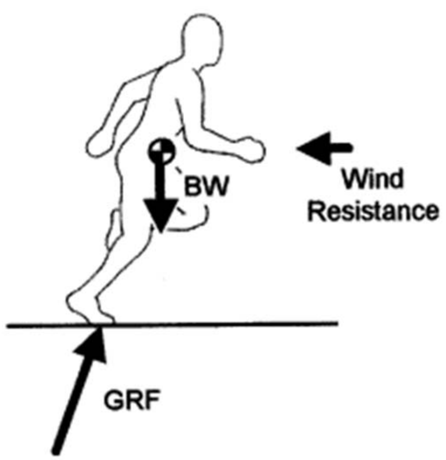


Figure 1 — The three external forces that determine the acceleration of a sprinter's center of mass: ground reaction force (GRF), gravitational force (equivalent to body weight, BW), and wind resistance.

Counterargument #2

- Bouncing balls and skipping stones slow down and come to a stop
- That's not what we want in sprinting!

Arguments in Favor of Horizontal Force

Relationships & Correlations with Force, Power, and Impulse

- Horizontal variables are correlated with acceleration, vertical and total (resultant) are not
- Horizontal variables are correlated with maximum velocity to a higher degree than vertical variables
- Horizontal power is always highly correlated with maximum speed and acceleration

- Morin (3) [8, 9, 19]
- Brughelli [10]
- Mero [15]
- Nummela [30]
- Kyrolainen (2) [31, 32]
- Hunter [13]
- Kugler & Janshen [33]
- Munro [34]
- Kuitunen [35]
- Belli [36]
- Randell (thesis) [37]
- Fukuda & Ito [38]
- Kawamori [39]
- Mangine [40]
- Funato [41]
- Lockie [42]

Net Horizontal Force as Speed Rises

- Faster sprinters are able to keep producing positive net horizontal force at increasingly faster speeds with shorter contact times [19]

Morin et al. (2014) [19]

Variable	Starting-Blocks	0-20 m phase	20-40 m phase	Entire 40-m
Resultant impulse (N.s)	450 (53)	201 (23)	166 (18)	189 (21)
Vertical impulse (N.s)	361 (51)	188 (22)	167 (18)	181 (21)
Net horizontal impulse (N.s)	268 (35)	64.1 (9.03)	10.6 (2.9)	46.0 (6.5)
Braking horizontal impulse (N.s)	0.00 (0.00)	-3.79 (1.27)	-11.7 (1.7)	-6.45 (1.31)
Propulsive horizontal impulse (N.s)	268 (35)	67.8 (9.6)	22.2 (3.8)	52.3 (7.2)

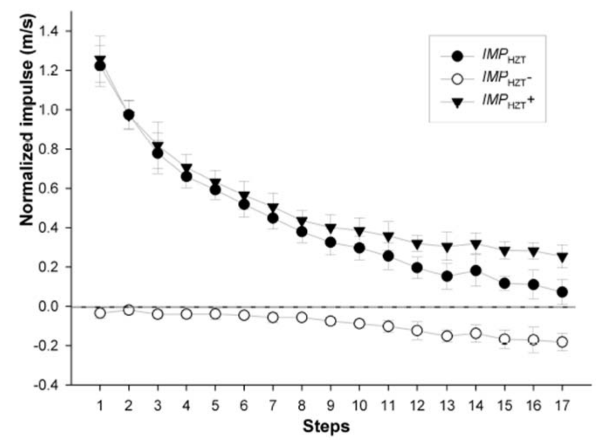
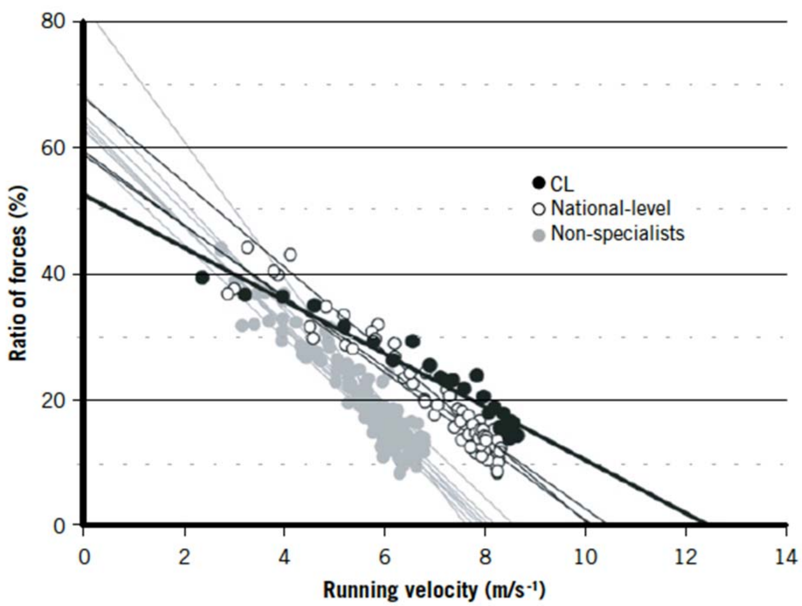


Figure 1 – Net (filled circles), propulsive (triangles) and braking (empty circles) relative impulses for the 17 steps analyzed over the 40-m sprints. Starting-blocks push-off data are not presented.

Ratio of Forces & Index of Force Application

- Christophe Lemaitre [8]



Morin (2013) [20]

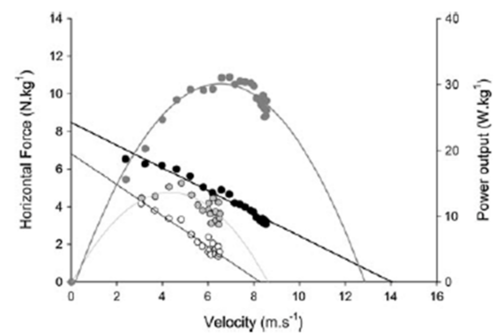
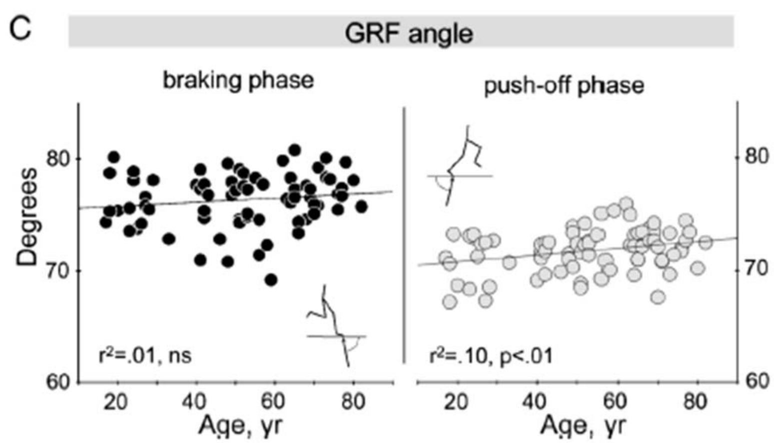


Fig. 1 Typical linear force–velocity and 2nd degree polynomial power–velocity relationships obtained from instrumented treadmill sprint data for the fastest (100-m best time: 9.92 s, 100-m time of 10.35 s during the study: *black and dark grey circles*) and slowest (100-m time of 15.03 s during the study: *white and light grey circles*) subjects of this study. All linear and 2nd degree polynomial regressions were significant ($r^2 > 0.878$; all $P < 0.001$)

Losses in Sprinting Forces Associated With Aging

- We lose more hGRF than vGRF as we age [21, 22]

Korhonen et al. (2009) [21]



Korhonen et al. (2010) [22]

Table 1 The components of the GRFs and temporal-spatial stride parameters of sprint running for the dominant and nondominant sides, and the symmetry indices (SI, ASI) in young and older subjects

	Young Runners 9.50 ± 0.42 m/s				Older Runners 7.30 ± 0.57 m/s			
	Dominant	Nondominant	SI %	ASI %	Dominant	Nondominant	SI %	ASI %
Vertical force								
LR_{max} (bw/s)	418 ± 58	418 ± 56	–0.6 ± 15.4	11.8 ± 9.9	338 ± 121	339 ± 112	0.6 ± 20.4	18.1 ± 11.3
LR_{ave} (bw/s)ᵃ	211 ± 32	206 ± 26	1.7 ± 15.9	11.2 ± 11.0	193 ± 59	195 ± 60	–1.3 ± 25.6	18.8 ± 16.8
Fz_{impact} (bw)ᵃ	2.01 ± 0.79	2.12 ± 0.72	–5.4 ± 15.4	13.5 ± 8.5	3.20 ± 0.64	3.29 ± 0.69	–2.6 ± 16.7	10.1 ± 13.4
Fz_{max} (bw)	3.34 ± 0.25	3.35 ± 0.26	–0.3 ± 6.8	**3.8 ± 2.6**	2.82 ± 0.34	2.83 ± 0.33	–0.3 ± 4.0	**2.2 ± 1.6***
$F_{z\,ave}$ (bw)	2.07 ± 0.13	2.02 ± 0.10	2.0 ± 4.5	3.8 ± 3.1	1.85 ± 0.19	1.85 ± 0.20	0.5 ± 4.8	4.1 ± 2.7
Horizontal force								
$Fy_{brake\text{-}max}$ (bw)	1.42 ± 0.17	1.43 ± 0.24	0.6 ± 15.8	13.7 ± 7.8	0.88 ± 0.20	0.91 ± 0.26	–2.0 ± 22.6	18.3 ± 14.3
$Fy_{brake\text{-}ave}$ (bw)	0.40 ± 0.04	0.41 ± 0.06	–0.3 ± 17.0	14.3 ± 9.8	0.31 ± 0.04	0.32 ± 0.05	–1.9 ± 22.1	17.4 ± 15.2
$Fy_{push\text{-}max}$ (bw)	0.74 ± 0.09	0.73 ± 0.08	3.0 ± 7.9	6.5 ± 5.2	0.50 ± 0.07	0.50 ± 0.07	2.7 ± 6.8	6.5 ± 3.7
$Fy_{push\text{-}ave}$ (bw)	0.41 ± 0.03	0.40 ± 0.04	2.9 ± 11.3	10.1 ± 5.7	0.29 ± 0.04	0.28 ± 0.03	2.1 ± 11.1	9.7 ± 6.5
Resultant force								
$Fr_{brake\text{-}max}$ (bw)	3.76 ± 0.63	3.52 ± 0.38	5.6 ± 11.0	9.6 ± 7.7	3.29 ± 0.50	3.26 ± 0.57	1.5 ± 8.6	6.1 ± 6.5
$Fr_{brake\text{-}ave}$ (bw)	2.70 ± 0.25	2.62 ± 0.17	2.8 ± 6.7	5.8 ± 4.4	2.40 ± 0.29	2.39 ± 0.30	0.7 ± 4.7	4.1 ± 2.7
$Fr_{push\text{-}max}$ (bw)	3.08 ± 0.21	3.05 ± 0.25	0.5 ± 6.5	4.2 ± 4.4	2.74 ± 0.31	2.74 ± 0.31	–0.2 ± 5.6	4.8 ± 3.0
$Fr_{push\text{-}ave}$ (bw)	1.90 ± 0.15	1.87 ± 0.17	0.4 ± 6.6	3.9 ± 4.3	1.61 ± 0.19	1.62 ± 0.18	–0.3 ± 6.8	5.9 ± 3.5
Temporal-spatial parameters								
$t_{contact}$ (ms)	102 ± 7	101 ± 7	1.4 ± 4.7	4.0 ± 2.9	129 ± 16	127 ± 16	1.5 ± 3.6	3.3 ± 2.1
t_{aerial} (ms)	129 ± 11	123 ± 9	**5.0 ± 8.1**	8.0 ± 5.2	116 ± 9	117 ± 12	**–0.6 ± 8.7***	7.3 ± 5.0
$Freq_{step}$ (Hz)	4.34 ± 0.25	4.49 ± 0.25	–3.6 ± 5.8	5.7 ± 3.8	4.14 ± 0.27	4.16 ± 0.30	–0.4 ± 5.0	4.0 ± 3.1
L_{step} (m)	2.16 ± 0.07	2.13 ± 0.07	1.7 ± 3.2	2.7 ± 2.3	1.77 ± 0.10	1.77 ± 0.12	–0.2 ± 3.0	2.6 ± 1.6

Note. Values are group means ± *SD*. Number of subjects = 18 young and 25 older subjects (ᵃ these variables could be determined only for the midfoot strikers, *n* = 13 young and 18 older runners). *Significantly different ($P < .05$) from the corresponding value in the young group (indicated by **bold** numbers). bw = body weight. See text and Figure 1 for description of the parameters.

Fatigue Affects on Sprinting Forces

- We lose more hGRF than vGRF in repeated sprints [23]

Table 1
Changes in performance variables, force production and force application technique variables between the first two (pre-RS) and the last two (post-RS) sprints of the multiple-set repeated sprint series. All changes reported are significant.

	Pre-RS		Post-RS		t-Test P values	Pre–post % change		Effect size
S (m s^{-1})	4.55	(0.29)	3.83	(0.36)	<0.001	−15.7	(5.4)	2.30 (very large)
S-max (m s^{-1})	5.47	(0.40)	4.53	(0.42)	<0.001	−17.2	(5.7)	2.39 (very large)
F_H (N)	309	(25)	267	(35)	<0.001	−13.9	(8.5)	1.41 (very large)
F_H (BW)	0.416	(0.033)	0.359	(0.050)	<0.001	−13.9	(8.5)	1.41 (very large)
F_V (N)	1074	(97)	1023	(103)	<0.05	−5.12	(5.88)	0.66 (medium)
F_V (BW)	1.44	(0.10)	1.37	(0.12)	<0.05	−5.12	(5.88)	0.66 (medium)
F_{Tot} (N)	1121	(99)	1060	(106)	<0.001	−5.81	(5.76)	0.78 (large)
F_{Tot} (BW)	1.51	(0.11)	1.42	(0.13)	<0.001	−5.81	(5.76)	0.78 (large)
RF (%)	27.7	(1.1)	25.6	(2.6)	<0.001	−7.74	(8.13)	1.10 (very large)
RF-max (%)	42.1	(2.6)	38.4	(3.2)	<0.01	−8.41	(9.48)	1.33 (very large)
D_{RF}	−0.069	(0.007)	−0.081	(0.013)	<0.001	−19.2	(20.9)	1.20 (very large)

Values are mean (SD).

Force Losses With Hamstring Injury

- Hamstring injuries affect hGRF more than vGRF
- Restored in 2 months

TABLE 1. Mean (± *SD*) for leg asymmetries in Australian Rules football players during running at 80% Vmax.

	Injured group (IG)		Imbalance (%)	Noninjured Group (NIG)		Imbalance (%)
	Injured leg	Noninjured leg		Right leg	Left leg	
Vertical force (N)	1905 ± 253	1,887 ± 153	1.0	1,905 ± 314	1,892 ± 329	1.6
Horizontal force (N)	175 ± 30*†‡	324 ± 44†‡	45.9	261 ± 43	252 ± 51	4.9
Vertical stiffness (kN/m)	48.8 ± 11.9	45.1 ± 10.9	7.6	50.3 ± 9.7	47.2 ± 10.4	6.5
Leg stiffness (kN/m)	7.2 ± 1.0	7.6 ± 0.9	5.3	8.0 ± 0.9	7.2 ± 0.9	4.2
CM displacement (cm)	3.9 ± 0.9	4.18 ± 0.8	6.7	3.8 ± 0.7	4.0 ± 0.8	5.0
Contact time (s)	0.211 ± 0.03	0.214 ± 0.03	1.9	0.226 ± 0.02	0.214 ± 0.03	3.5
Impulse (J)	222 ± 2.1	217 ± 2.1	4.0	230 ± 2.1	222 ± 1.9	4.2
Positive work (J)	260 ± 2.3	245 ± 2.3	6.9	281 ± 1.9	255 ± 2.7	10.7

*Significantly different ($p < 0.01$) from noninjured leg (Injured Group).
†Significantly different ($p < 0.05$) from dominant leg (Noninjured Group).
‡Significantly different ($p < 0.05$) from nondominant leg (Noninjured Group).

	Non-injured T1 (n=14)	Injured T1 (n=14)	Injured T2 (n=11)
Body mass (kg)	69.3±5.9	72.4±7.1	71.2±5.8
Height (m)	1.75±0.05	1.73±0.05	1.73±0.05
BMI (kg/m²)	22.7±1.5	24.1±2.4	23.9±1.6
5-m (s)	1.4±0.05	1.5±0.12	1.4±0.07
10-m (s)	2.2±0.07	2.3±0.17	2.2±0.11
40-m (s)	5.9±0.18	6.1±0.32	6.0±0.26
Top Speed (km/h)	30.5±1.1	29.8±0.9	29.8±1.3
V_0 (km/h)	31.9±1.31	31.4±0.91	31.0±1.45
F_{H0} (N/kg)	6.8±0.56	6.1±1.04	6.9±0.84
Pmax (W/kg)	15.0±1.44	13.1±2.39	14.9±2.15

Brughelli et al. (2010) [24]

Mendiguchia et al. (2014) [25]

Barefoot Forces versus Spikes

- Spikes increase hGRF but not vGRF (not significant, but possible type II error? [26]

Despite faster sprinting velocities for the sprint spike trials, there was no difference (*p* = .671) in peak vertical forces with mean values of 2184.9 N ± 263.2 N and 2169.8 N ± 216.0 N for the barefoot and sprint spike conditions respectively. Mean horizontal propulsive forces were slightly greater for the sprint spike conditions than the barefoot conditions with peak values of 622.0 N ± 158.0 N and 570.8 N ± 154.1 N respectively, although the difference was

Forces With Transtibial Amputees

- Oscar Pistorius – lower vertical and braking forces but similar propulsive forces

Brüggemann et al. (2008) [27]

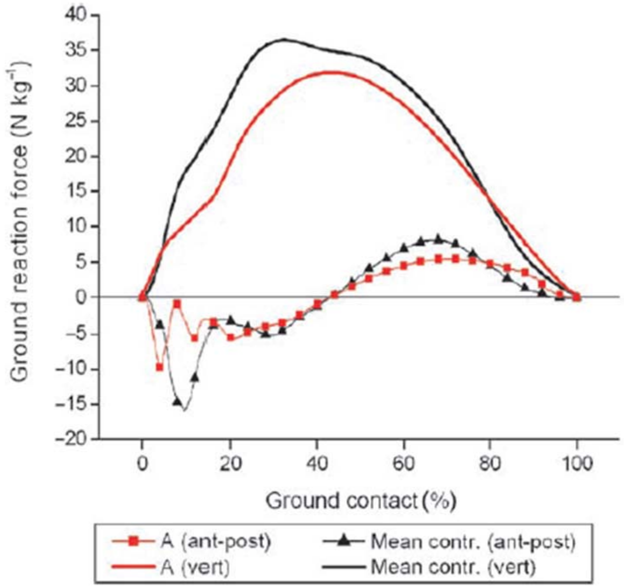
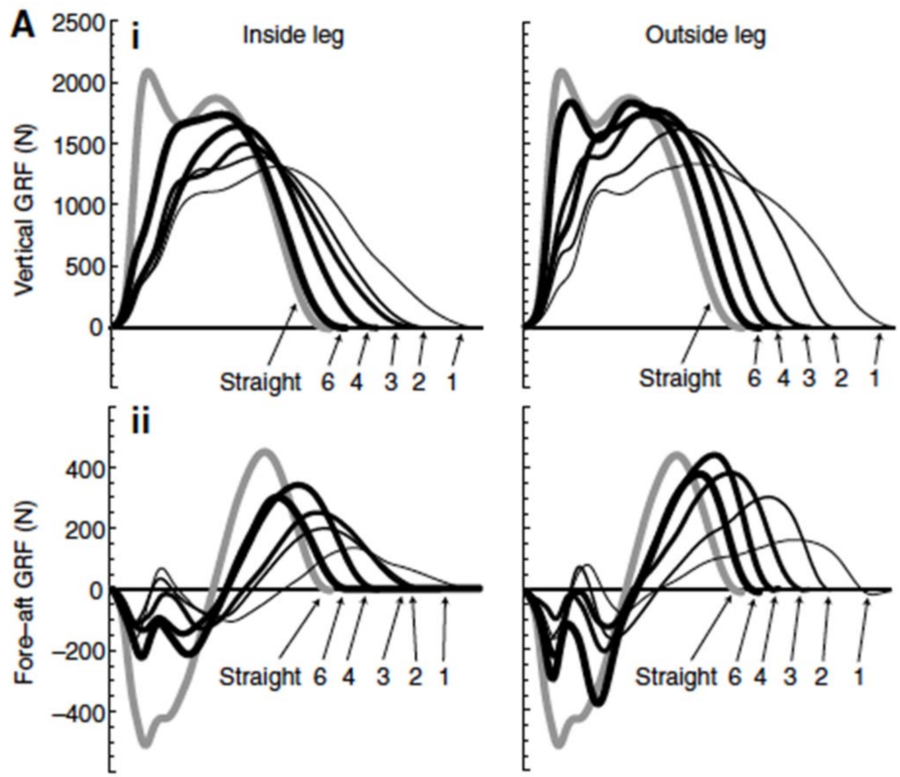


Figure 3. Mean ground reaction forces (vertical and anteroposterior) while sprinting at 9.2–9.5 ms^{-1}. Forces are normalized to body mass and the time (%) is normalized to the stance phase. Data of the transtibial athlete is shown in red, and the forces of the able-bodied controls are in black.

Forces Around Curves

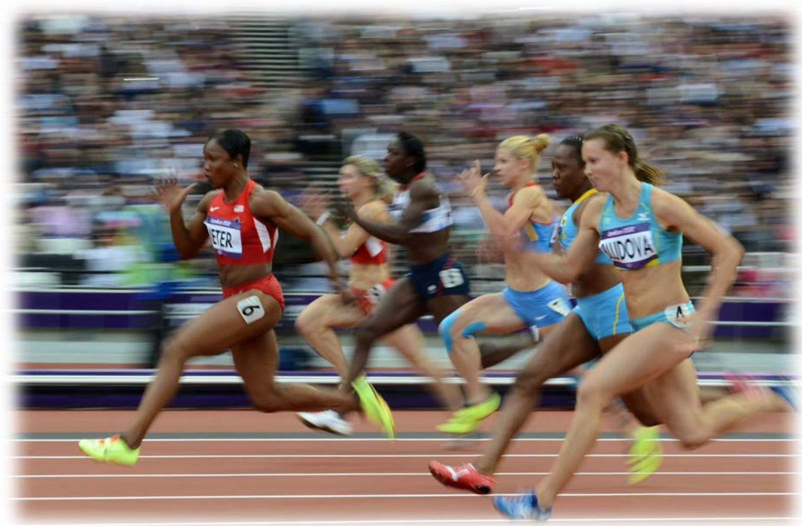
- Horizontal force affected more than vertical around curves

Chang et al. (2007) [28]



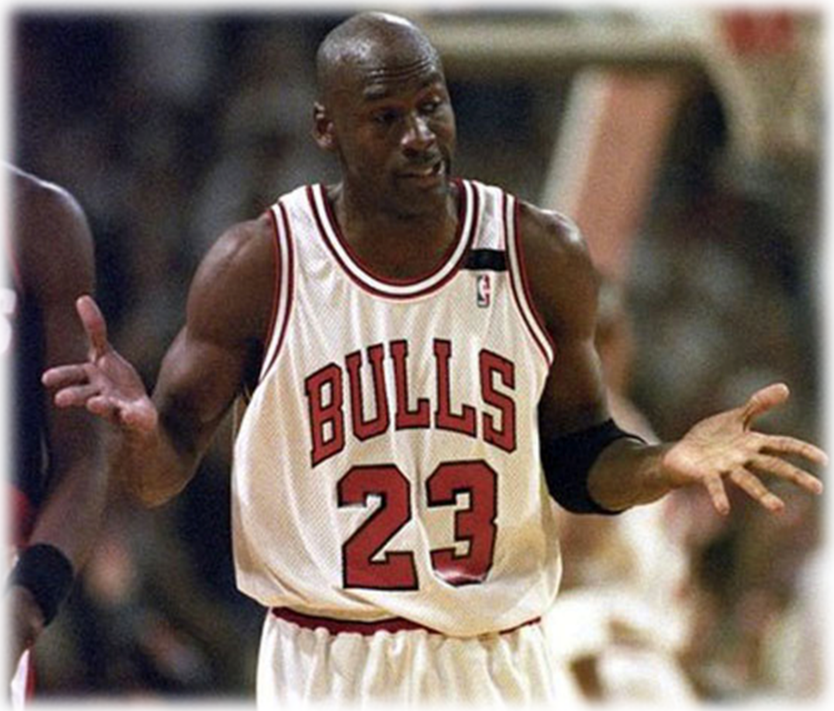
Verdict

- Vertical force is important for maximum speed
- Horizontal force is more important, and also much more related to acceleration



Practical Applications

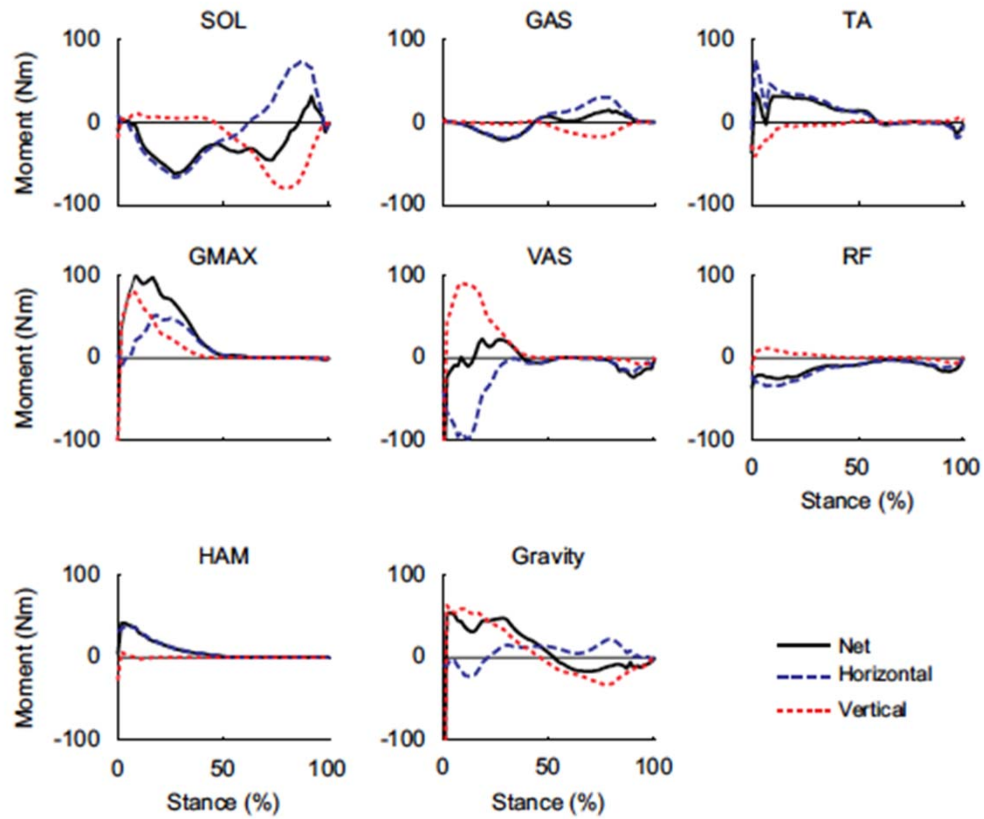
How Do We Increase Horizontal Force, Impulse, and Power?



Horizontal Force Production Requirements versus Vertical Force Production Requirements

- Muscles have unique responsibilities

Neptune et al. (2011) [29]



Keep in Mind…

- When considering the force-velocity curve for sprinting, pay more attention to the velocity side of the curve than the force side
- Rapid knee flexion and hip extension torque production are critical
- Hamstrings are more important in the air, glutes on the ground
- Increased hip flexion ROM + hip extensor angular velocity + knee flexion angular velocity during swing = decreased braking forces
- Ankles transmit power into ground
- Not just about stronger muscles; there's a huge technical aspect

Some Possibilities…

- Sprints & Towing
- Bounding & Horizontal Plyos
- Eccentric & Long-Length Hamstring Exercises
- End-Range Hip Extension Glute Exercises
- Explosive Lifts & Vertical Plyos
- Hip Flexion Exercises

More Research is Needed

- More acute studies to better understand mechanisms of interventions (force, impulse, power, ratio of forces, EMG)
  - Bounding/hopping/stepping/sprinting, towing, sleds, vests [43, 44, 45]
- More longitudinal (training) studies to determine mechanical factors involved in acceleration & speed improvements
- More longitudinal (training) studies to determine effects of various interventions (changes in force production, changes in architectural factors, changes in neural factors)
  - Heavy versus light sled [46]
- Not all training studies show improvements…
  - Hip thrust + eccentric ham + sled + sprint [47]

Thank You for Attending!

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References

1. Koyama, H., Mochida, T., Hoga-Miura, K., Shibayama, K., Hirosuke, K., Hiroki, T. (2011). Biomechanics Analysis of the Men's 100 Meters Sprint during the IAAF World Championships, Daegu 2011. *Biomechanics Research Project in the IAAF World Championships Daegu 2011.* 13-23.
2. Dick, F. W. (1989). Development of maximum sprinting speed. *Reprinted from Track Technique. Disponível em: www. trackandfieldsnews. com/tecnique/109. Acesso em*, *8*.
3. Brown, T. D., & Vescovi, J. D. (2012). Maximum speed: Misconceptions of sprinting. *Strength & Conditioning Journal*, *34*(2), 37-41.
4. Gabbett, T. J. (2012). Sprinting patterns of national rugby league competition.*The Journal of Strength & Conditioning Research*, *26*(1), 121-130.
5. Brechue, W. F., Mayhew, J. L., & Piper, F. C. (2010). Characteristics of sprint performance in college football players. *The Journal of Strength & Conditioning Research*, *24*(5), 1169-1178.
6. Vigne, G., Gaudino, C., Rogowski, I., Alloatti, G., & Hautier, C. (2010). Activity profile in elite Italian soccer team. *International journal of sports medicine*,*31*(05), 304-310.
7. Weyand, P. G., Sternlight, D. B., Bellizzi, 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*(5), 1991-1999.
8. Morin, J. B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P., & Lacour, J. R. (2012). Mechanical determinants of 100-m sprint running performance. *European journal of applied physiology*, *112*(11), 3921-3930.
9. Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and science in sports and exercise*, *43*(9), 1680-1688.
10. Brughelli, M., Cronin, J., & Chaouachi, A. (2011). Effects of running velocity on running kinetics and kinematics. *The Journal of Strength & Conditioning Research*, *25*(4), 933-939.

References cont.

11. Weyand, P. G., Sandell, R. F., Prime, D. N., & Bundle, M. W. (2010). The biological limits to running speed are imposed from the ground up. *Journal of applied physiology*, *108*(4), 950-961.
12. Mann, R., Kotmel, J., Herman, J., Johnson, B., & Schultz, C. (2008, March). Kinematic trends in elite sprinters. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).
13. Hunter, J. P., Marshall, R. N., & McNair, P. J. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomech*, *21*(1), 31-43.
14. Kawamori, N., Newton, R. U., Hori, N., & Nosaka, K. (2013). Effects of weighted sled towing with heavy versus light load on sprint acceleration ability. *The Journal of Strength & Conditioning Research*, ahead of print.
15. Mero, A. (1988). Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Research Quarterly for Exercise and Sport*, *59*(2), 94-98.
16. Choh, M., Dolenec, A., & Jošt, B. (1999). Kinematic, kinetic and electromyographic characteristics of the sprinting stride of top female sprinters. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).
17. Cavanagh, P. R., & Lafortune, M. A. (1980). Ground reaction forces in distance running. *Journal of biomechanics*, *13*(5), 397-406.
18. Hunter, J. P., Marshall, R. N., & McNair, P. J. (2004). Interaction of step length and step rate during sprint running. *Medicine and science in sports and exercise*, *36*(2), 261-271.
19. Morin, J.B., Dorel, S., Slawinski, J., Saez De Villareal, E., Rabita, G. (2014). Impulse and acceleration capability in elite sprinters: push more, brake less? Manuscript in preparation.
20. Morin, J.B. (2013). Sprint Running Mechanics: New technology, new concepts, new perspectives. *Aspetar Sports Medicine Journal, 2*(3), 326-332.
21. Korhonen, M. T., Mero, A. A., AlEN, M., Sipilä, S. A. R. I. A. N. N. A., Häkkinen, K. E. I. J. O., Liikavainio, T., ... & Suominen, H. (2009). Biomechanical and skeletal muscle determinants of maximum running speed with aging. *Medicine and science in sports and exercise*, *41*(4), 844-856.

References

22. Korhonen, M. T., Suominen, H., Viitasalo, J. T., Liikavainio, T., Alen, M., & Mero, A. A. (2010). Variability and symmetry of force platform variables in maximum-speed running in young and older athletes. *Journal of applied biomechanics*, *26*(3), 357-366.
23. Morin, J. B., Samozino, P., Edouard, P., & Tomazin, K. (2011). Effect of fatigue on force production and force application technique during repeated sprints. *Journal of biomechanics*, *44*(15), 2719-2723.
24. Brughelli, M., Cronin, J., Mendiguchia, J., Kinsella, D., & Nosaka, K. (2010). Contralateral leg deficits in kinetic and kinematic variables during running in Australian rules football players with previous hamstring injuries. *The Journal of Strength & Conditioning Research*, *24*(9), 2539-2544.
25. Mendiguchia, J., Samozino, P., Martinez-Ruiz, E., Brughelli, M., Schmikli, S., Morin, J. B., & Mendez-Villanueva, A. (2014). Progression of Mechanical Properties during On-field Sprint Running after Returning to Sports from a Hamstring Muscle Injury in Soccer Players. *International journal of sports medicine*, (EFirst).
26. Smith, G., Lake, M., & Lees, A. (2013). Metatarsophalangeal Joint Function During Sprinting: A Comparison of Barefoot and Sprint Spike Shod Foot Conditions. *Journal of applied biomechanics*.
27. Brüggemann, G. P., Arampatzis, A., Emrich, F., & Potthast, W. (2008). Biomechanics of double transtibial amputee sprinting using dedicated sprinting prostheses. *Sports Technology*, *1*(4-5), 220-227.
28. Chang, Y. H., & Kram, R. (2007). Limitations to maximum running speed on flat curves. *Journal of Experimental Biology*, *210*(6), 971-982.
29. Neptune, R. R., & McGowan, C. P. (2011). Muscle contributions to whole-body sagittal plane angular momentum during walking. *Journal of biomechanics*,*44*(1), 6-12.
30. Nummela, A., Rusko, H. E. I. K. K. I., & Mero, A. N. T. T. I. (1994). EMG activities and ground reaction forces during fatigued and nonfatigued sprinting.*Medicine and science in sports and exercise*, *26*(5), 605-609.
31. Kyröläinen, H., Avela, J., & Komi, P. V. (2005). Changes in muscle activity with increasing running speed. *Journal of sports sciences*, *23*(10), 1101-1109.

References cont.

32. KYRÖLÄINEN, H., KOMI, P. V., & BELLI, A. (1999). Changes in muscle activity patterns and kinetics with increasing running speed. *The Journal of Strength & Conditioning Research*, *13*(4), 400-406.
33. Kugler, F., & Janshen, L. (2010). Body position determines propulsive forces in accelerated running. *Journal of biomechanics*, *43*(2), 343-348.
34. Munro, C. F., Miller, D. I., & Fuglevand, A. J. (1987). Ground reaction forces in running: a reexamination. *Journal of biomechanics*, *20*(2), 147-155.
35. Kuitunen, S., Komi, P. V., & Kyrolainen, H. (2002). Knee and ankle joint stiffness in sprint running. *Medicine and science in sports and exercise*, *34*(1), 166-173.
36. Belli, A., Kyröläinen, H., & Komi, P. V. (2002). Moment and power of lower limb joints in running. *International journal of sports medicine*, *23*(02), 136-141.
37. Randell, A. D. (2011). *Optimising transference of strength and power adaptation to sports specific performance* (Doctoral dissertation, Auckland University of Technology).
38. Ito, A., Fukuda, K., & Kijima, K. (2008). Mid-phase movements of Tyson Gay and Asafa Powell in the 100 metres at the 2007 World Championships in Athletics. *New Stud Athl*, *23*(2), 39-43.
39. Kawamori, N., Nosaka, K., & Newton, R. U. (2013). Relationships between ground reaction impulse and sprint acceleration performance in team sport athletes. *The Journal of Strength & Conditioning Research*, *27*(3), 568-573.
40. Mangine, G. T., Hoffman, J. R., Gonzalez, A. M., Wells, A. J., Townsend, J. R., Jajtner, A. R., ... & Stout, J. R. (2013). SPEED, FORCE AND POWER VALUES PRODUCED FROM A NON-MOTORIZED TREADMILL TEST ARE RELATED TO SPRINTING PERFORMANCE. *Journal of strength and conditioning research.*
41. Funato, K., Yanagiya, T., & Fukunaga, T. (2001). Ergometry for estimation of mechanical power output in sprinting in humans using a newly developed self-driven treadmill. *European journal of applied physiology*, *84*(3), 169-173.

References cont.

42. Lockie, R. G., Murphy, A. J., Schultz, A. B., Jeffriess, M. D., & Callaghan, S. J. (2013). Influence of sprint acceleration stance kinetics on velocity and step kinematics in field sport athletes. *The Journal of Strength & Conditioning Research*, *27*(9), 2494-2503.
43. Mero, A., & Komi, P. V. (1994). EMG, force, and power analysis of sprint-specific strength exercises. *Journal of Applied Biomechanics*, *10*, 1-1.
44. Kawamori, N., Newton, R., & Nosaka, K. (2014). Effects of weighted sled towing on ground reaction force during the acceleration phase of sprint running.*Journal of sports sciences, 12,* 1139–1145.
45. Cross, M. R., Brughelli, M. E., & Cronin, J. B. (2014). Effects of vest loading on sprint kinetics and kinematics. *Journal of strength and conditioning research / National Strength & Conditioning Association, 7,* 1867–1874.
46. Kawamori, N., Newton, R. U., Hori, N., & Nosaka, K. (2013). Effects of weighted sled towing with heavy versus light load on sprint acceleration ability.*Journal of strength and conditioning research / National Strength & Conditioning Association, Ahead of print.*
47. Mediguchia, J., Martinez-Ruiz, E., Morin, J.B., Samozino, P., Edouard, P. Alcaraz, P., Esparza, F., Mendez-Villanueva, A. (2014). Effects of hamstring-emphasized neuromuscular training on strength and sprinting mechanics in football players. *Scandinavian Journal of Medicine and Science in Sports.* Manuscript in review.