The Deceleration Paradox and the Mechanical Constraints of Agility

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Lecture handouts, worksheets, and papers available here

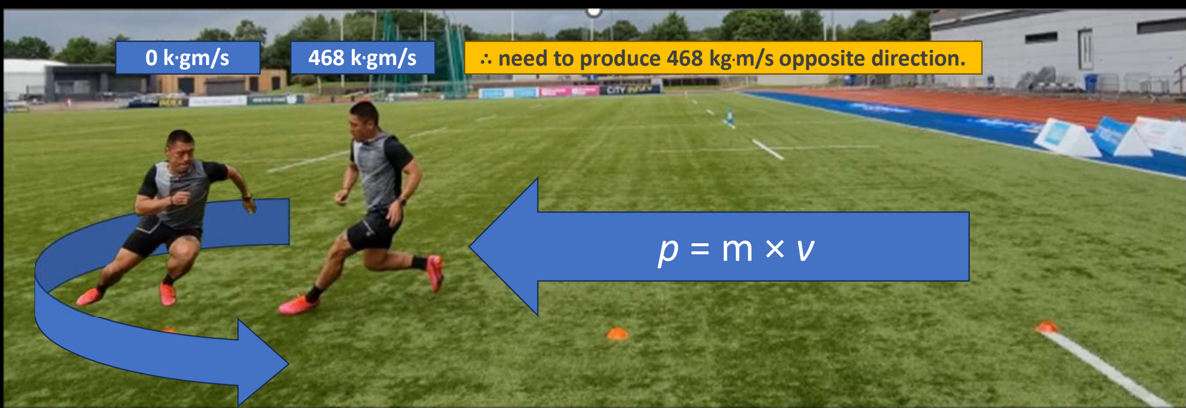
Presentation Outline

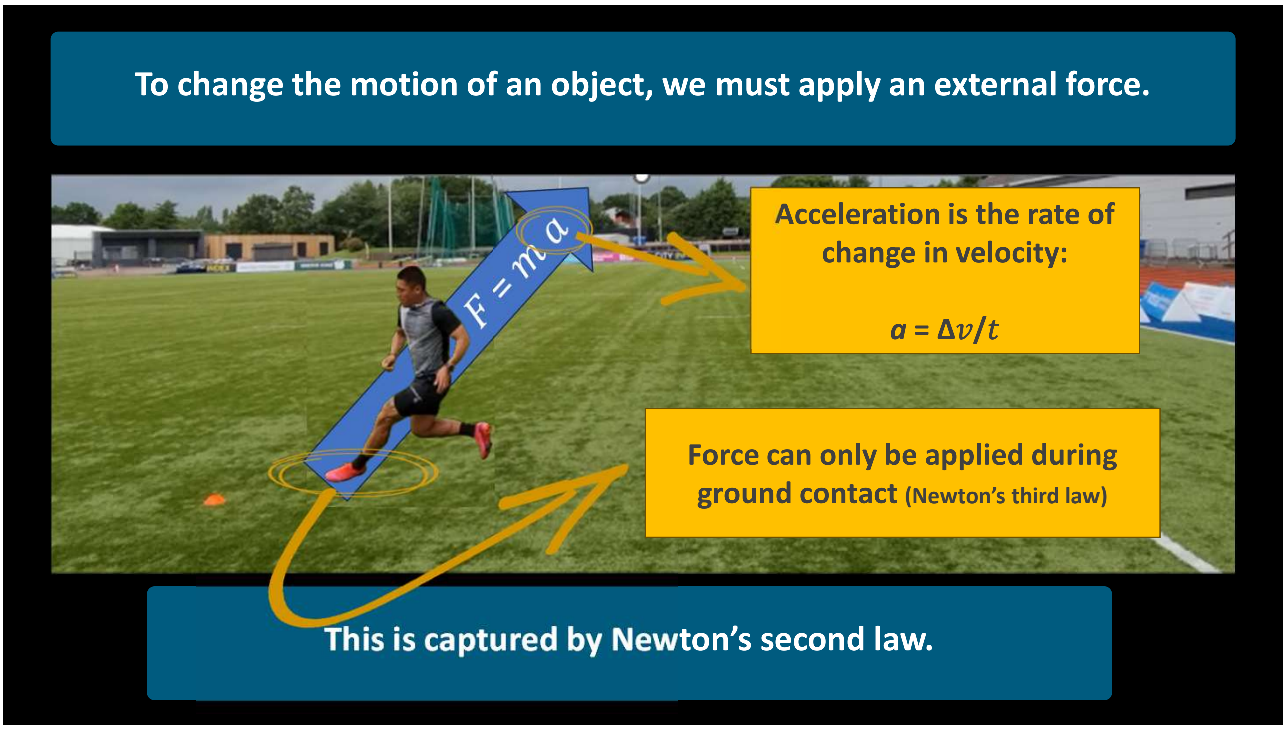
1. Underpinning mechanics
2. How to TEST it
3. How to TRAIN it

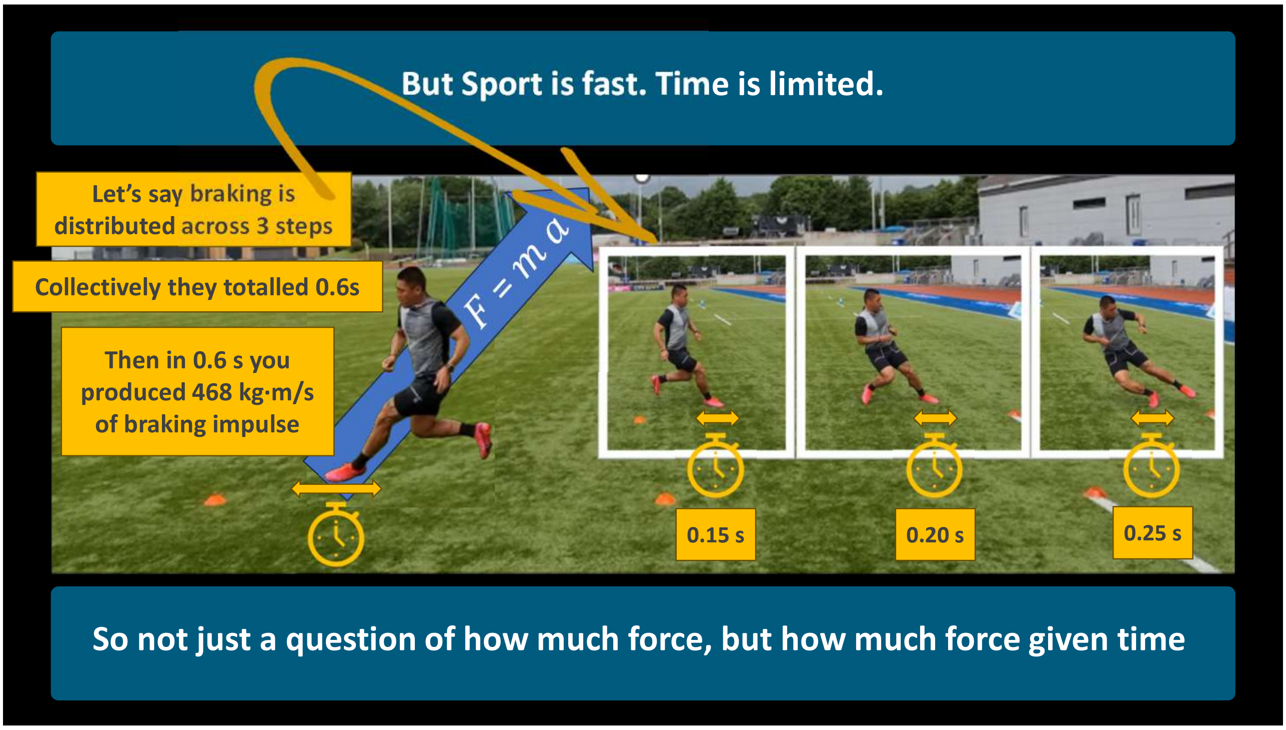
Changing direction is changing momentum.

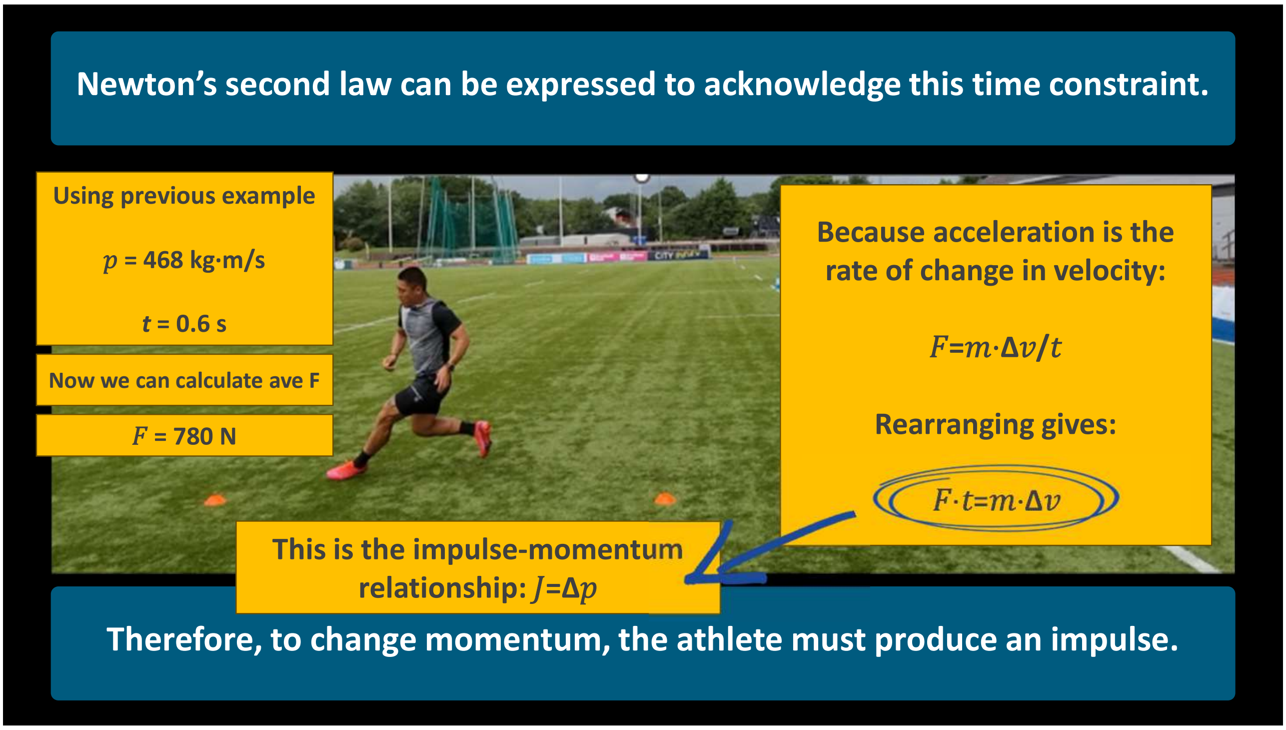
Let's first address agility as a mechanical problem.

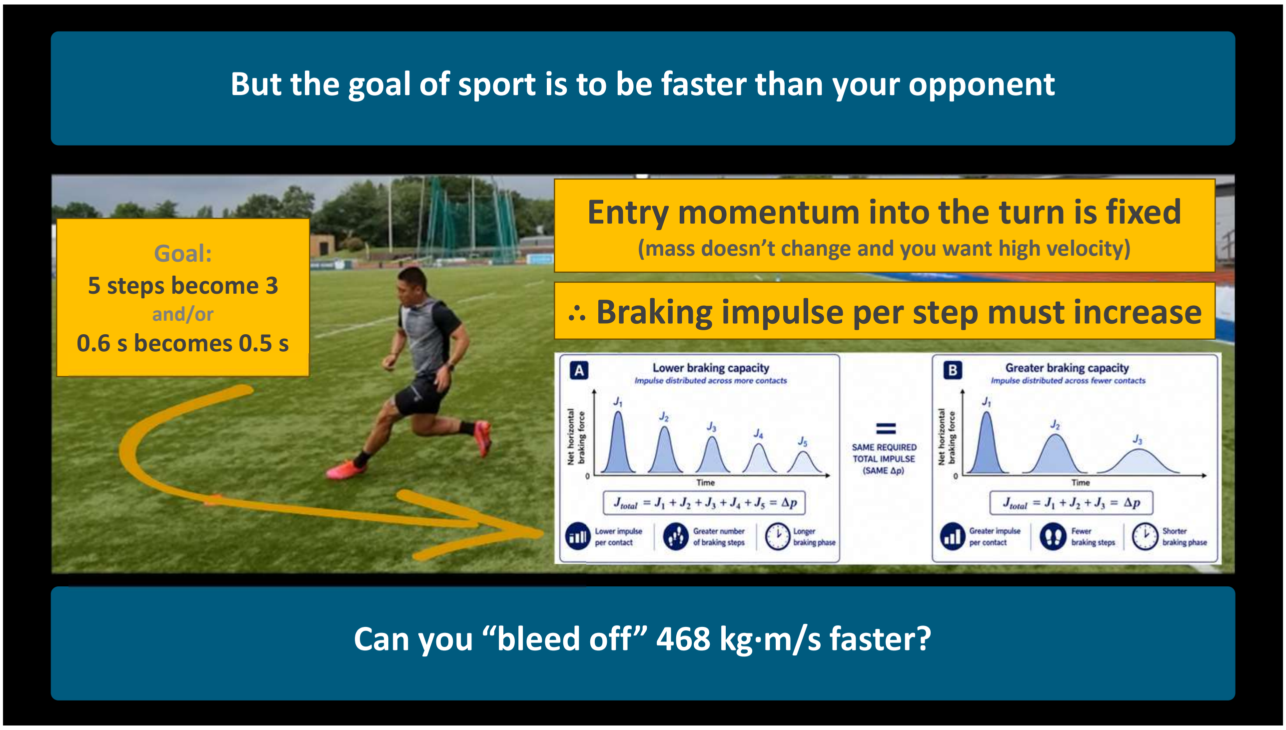
If m = 78 kg and v = 6 m/s, then p = 468 kg·m/s

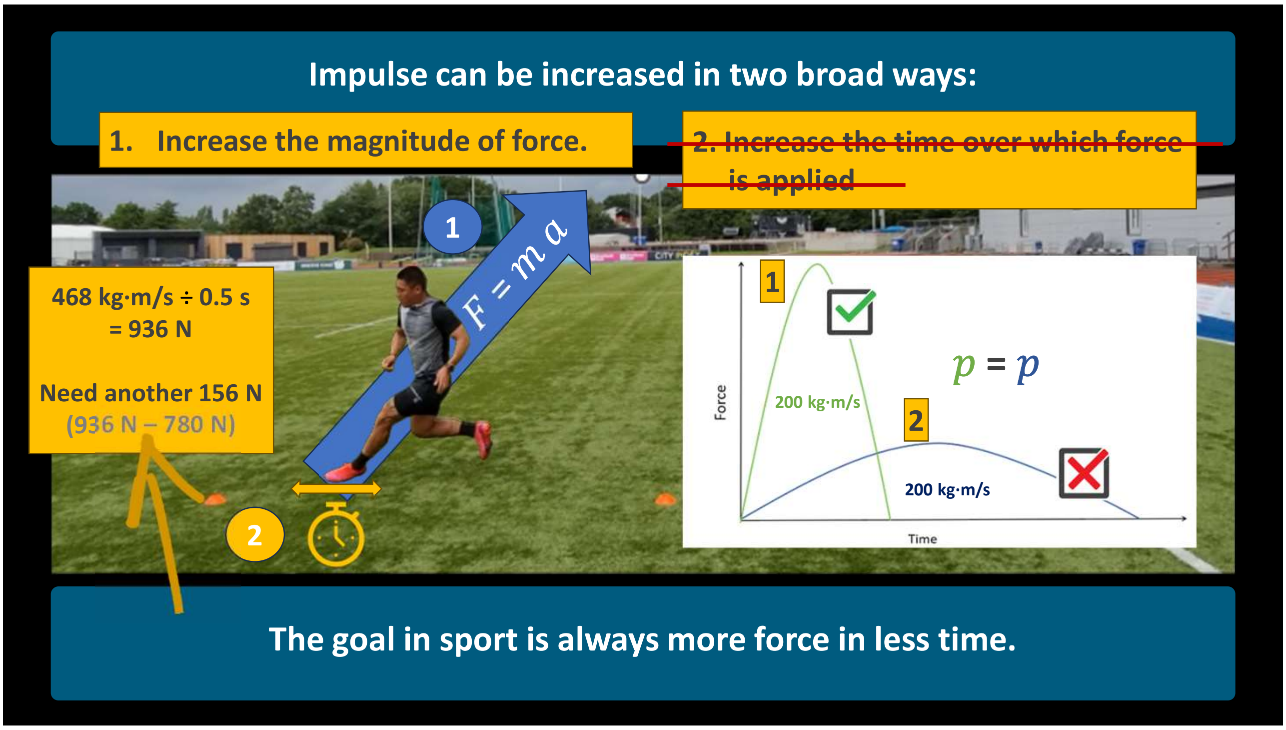


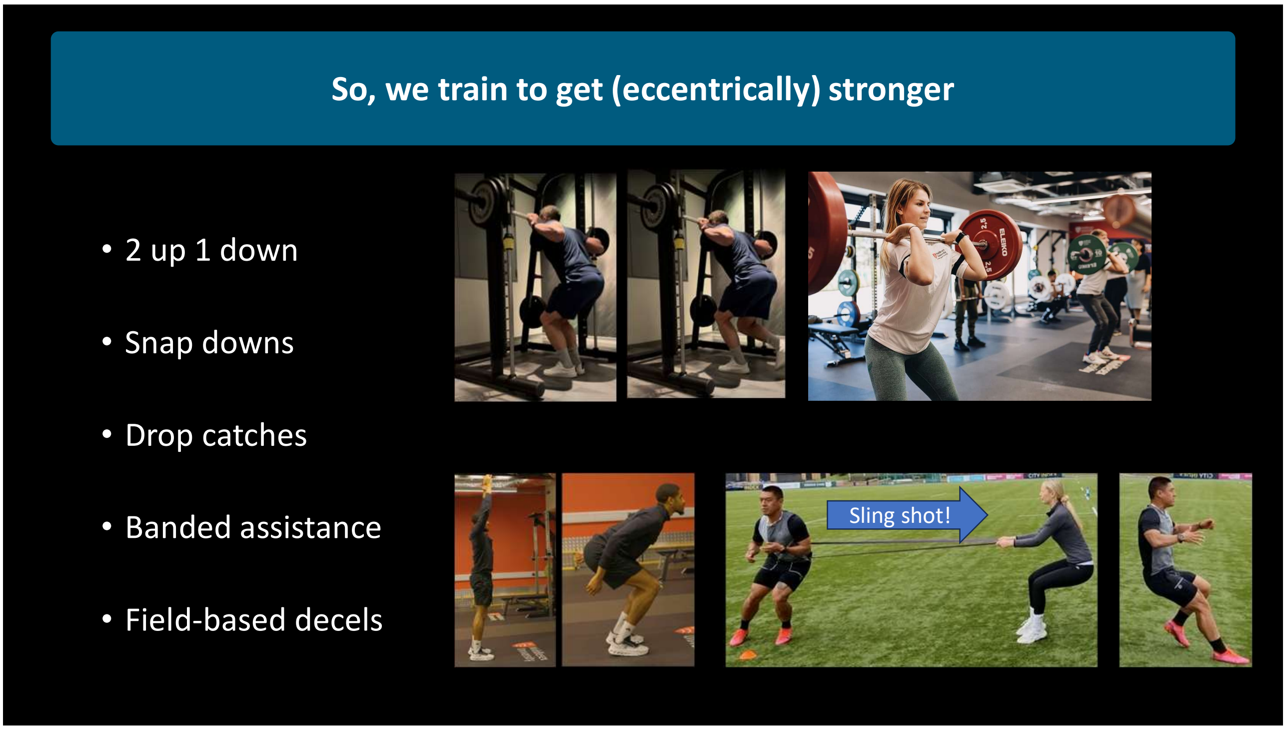

To change the motion of an object, we must apply an external force.
F = m a
Acceleration is the rate of change in velocity:
a = Δv/t
Force can only be applied during ground contact (Newton's third law)
This is captured by Newton's second law.


But Sport is fast. Time is limited.
Let's say braking is distributed across 3 steps
Collectively they totalled 0.6s
Then in 0.6 s you produced 468 kg·m/s of braking impulse
F = m a
0.15 s
0.20 s
0.25 s
So not just a question of how much force, but how much force given time

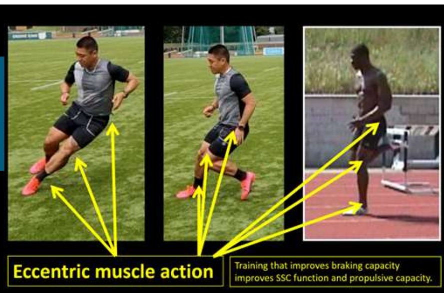

Newton's second law can be expressed to acknowledge this time constraint.
Using previous example
p = 468 kg·m/s
t = 0.6 s
Now we can calculate ave F
F = 780 N
Because acceleration is the rate of change in velocity:
$F=m \cdot \Delta v/t$
Rearranging gives:
$F \cdot t=m \cdot \Delta v$
This is the impulse-momentum relationship: $J=\Delta p$
Therefore, to change momentum, the athlete must produce an impulse.


But the goal of sport is to be faster than your opponent
Goal:
5 steps become 3
and/or
0.6 s becomes 0.5 s
Entry momentum into the turn is fixed
(mass doesn't change and you want high velocity)
∴ Braking impulse per step must increase
A
Lower braking capacity
Impulse distributed across more contacts
Net horizontal braking force
J_1 J_2 J_3 J_4 J_5
0
Time
$J_{total} = J_1 + J_2 + J_3 + J_4 + J_5 = \Delta p$
Lower impulse per contact
Greater number of braking steps
Longer braking phase
=
SAME REQUIRED TOTAL IMPULSE (SAME Δp)
B
Greater braking capacity
Impulse distributed across fewer contacts
Net horizontal braking force
J_1 J_2 J_3
0
Time
$J_{total} = J_1 + J_2 + J_3 = \Delta p$
Greater impulse per contact
Fewer braking steps
Shorter braking phase
Can you "bleed off" 468 kg·m/s faster?


Impulse can be increased in two broad ways:
1. Increase the magnitude of force.
~~2. Increase the time over which force is applied~~
468 kg·m/s ÷ 0.5 s = 936 N
Need another 156 N (936 N – 780 N)
1
F = m a
2
1
2
Force
Time
200 kg·m/s
200 kg·m/s
p = p
The goal in sport is always more force in less time.


So, we train to get (eccentrically) stronger
• 2 up 1 down
• Snap downs
• Drop catches
• Banded assistance
• Field-based decels
Sling shot!

The Deceleration Paradox



As athletes become (ecc) stronger, they can generate more braking impulse.

This translates to less steps, less time, and less distance to stop

However, stronger athletes may also become faster.

If entry velocity increases, momentum into the turn increases.

Now the problem has changed. With more momentum to bleed off, braking impulse must increase.

Which you don't have = extra step or more time

The faster you run, the slower you stop.

$F_{avg} \times t = m\Delta v \therefore \Delta v = (F_{avg} \times t)/m$

$\Delta v = (156 \times 0.5)/78 = 1 m/s$

78 kg x 7 m/s = 546 kg·m/s in 0.5 s = 1092 N

Body mass = 70 kg

- Peak approach velocity = 4 m/s ∴ peak approach momentum = 280 kg·m/s — 3 steps
- Peak approach velocity = 5 m/s ∴ peak approach momentum = 350 kg·m/s — 4 steps
- Peak approach velocity = 6 m/s ∴ peak approach momentum = 420 kg·m/s — 5 steps

Assuming the goal is to stop ASAP

Peak approach velocity = 5 m/s

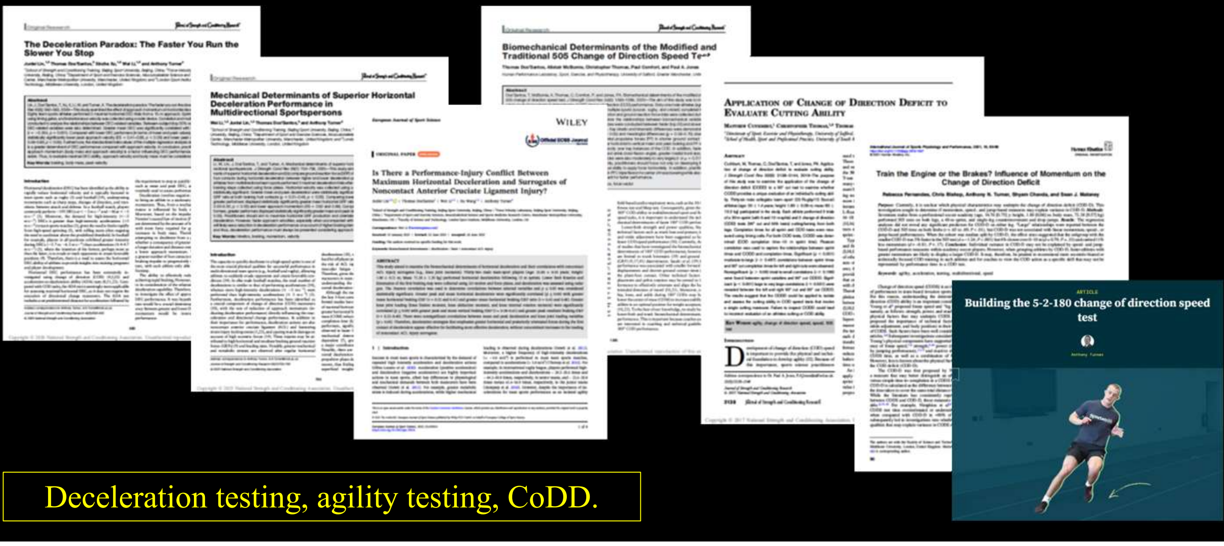
- Body mass = 60 kg ∴ peak approach momentum = 300 kg·m/s — 3 steps
- Body mass = 80 kg ∴ peak approach momentum = 400 kg·m/s — 4 steps
- Body mass = 100 kg ∴ peak approach momentum = 500 kg·m/s — 5 steps

Peak approach momentum = 350 kg·m/s

- Peak approach velocity = 4 m/s ∴ body mass = 100 kg — 3 steps
- Peak approach velocity = 4.5 m/s ∴ body mass = 77.8 kg — 3 steps
- Peak approach velocity = 5.5 m/s ∴ body mass = 63.64 kg — 3 steps

An inescapable paradox!

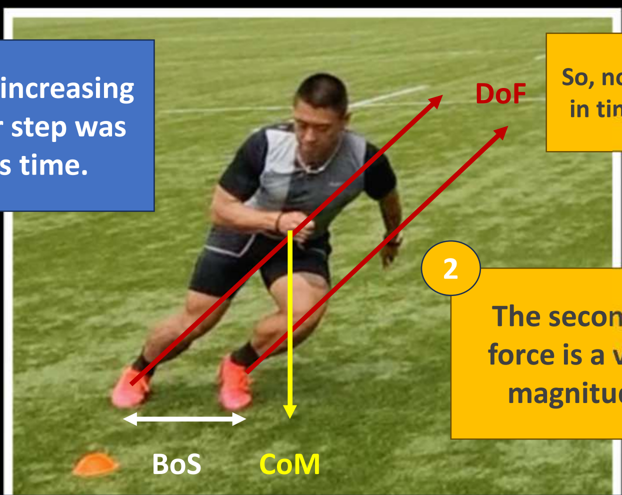
The fastest into the turn are the slowest out.



Deceleration testing, agility testing, CoDD.

DoF = *f*(CoM relative to BoS)

1 The first solution to increasing braking impulse per step was more force in less time.



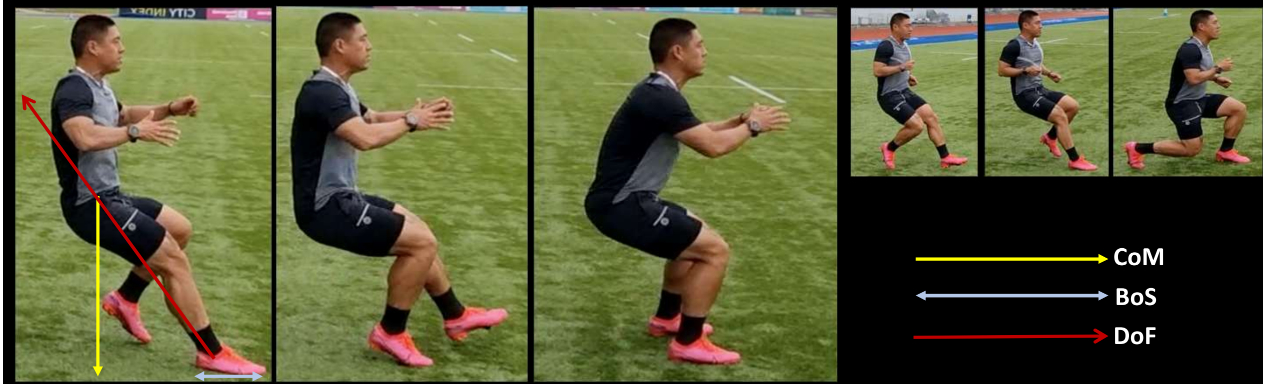
So, now not just how much force in time, but where it is directed

2 The second recognises that force is a vector; it has both magnitude and direction

Greater the separation, more acute the ∠, the greater the horizontally directed *F*.

Deceleration

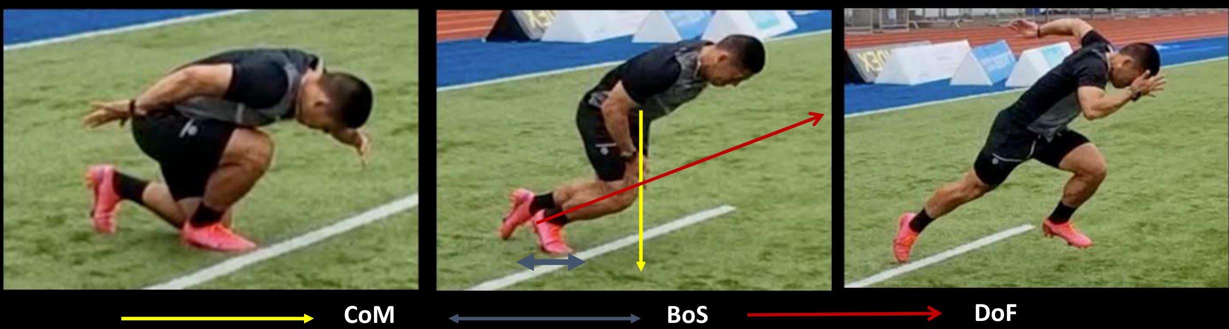
Relationship between BoS, CoM and DoF



Separation between CoM and BoS determines DoF and thus net horizontal braking force

Acceleration

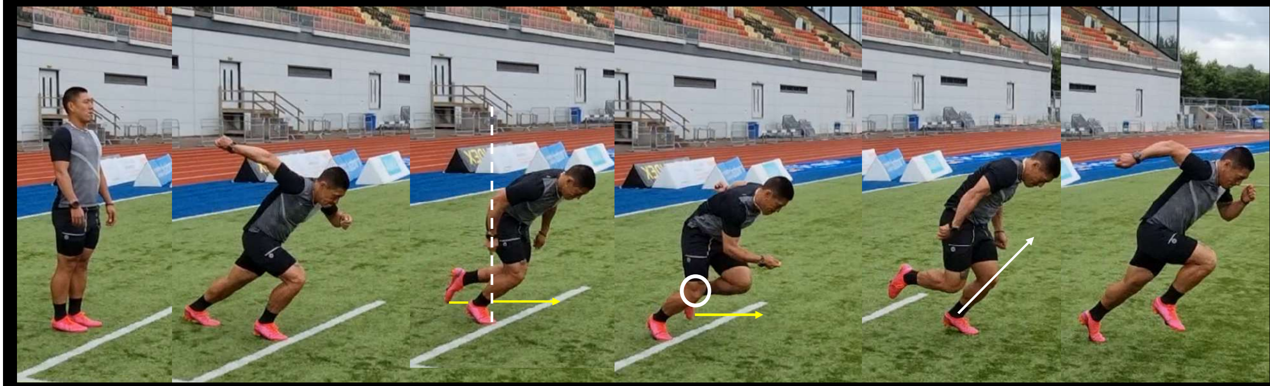
Relationship between BoS, CoM and DoF



Separation between the CoM and BoS determines DoF angle and thus net horizontal propulsive force

Acceleration

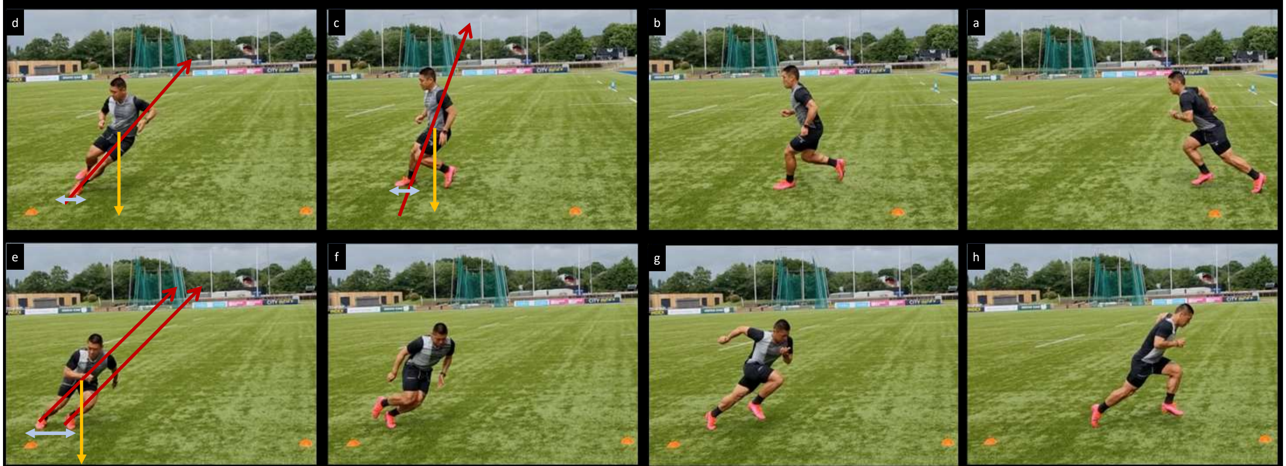
The split step is pre-programmed.



We do it to create favourable angles to produce horizontal force production

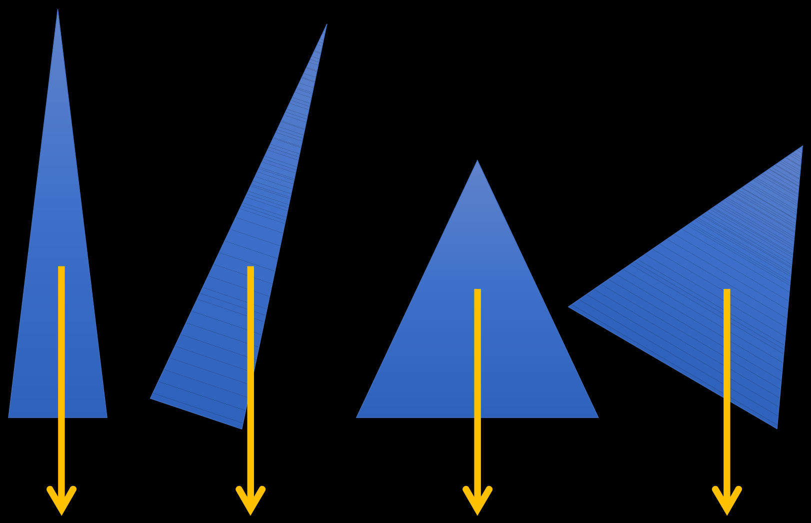
180° CoD

In a 180, we must finish braking in a position primed to Reaccelerate.



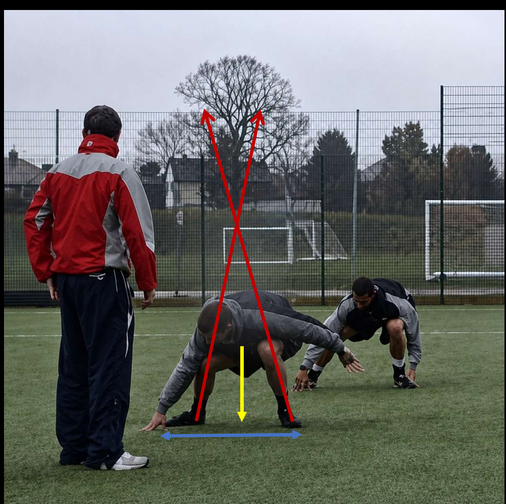
My favourite coaching cue: "head never goes between toes"

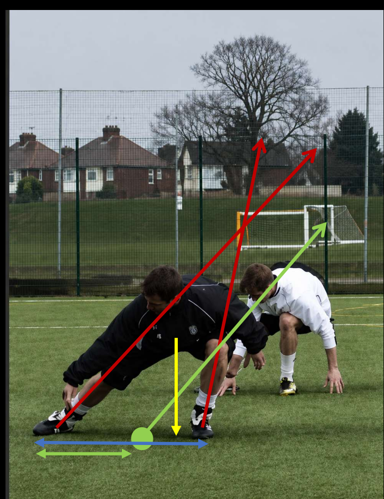
Resisting or Encouraging a CoD? You need to “fall”!

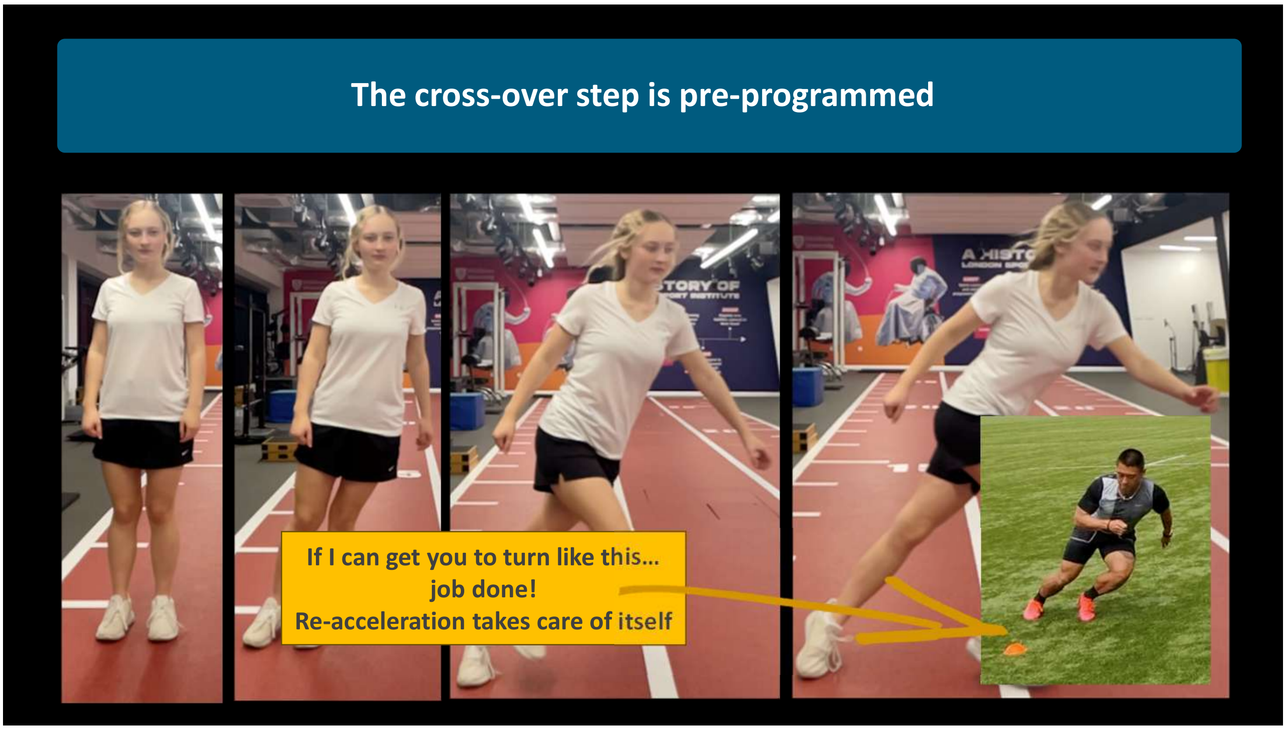


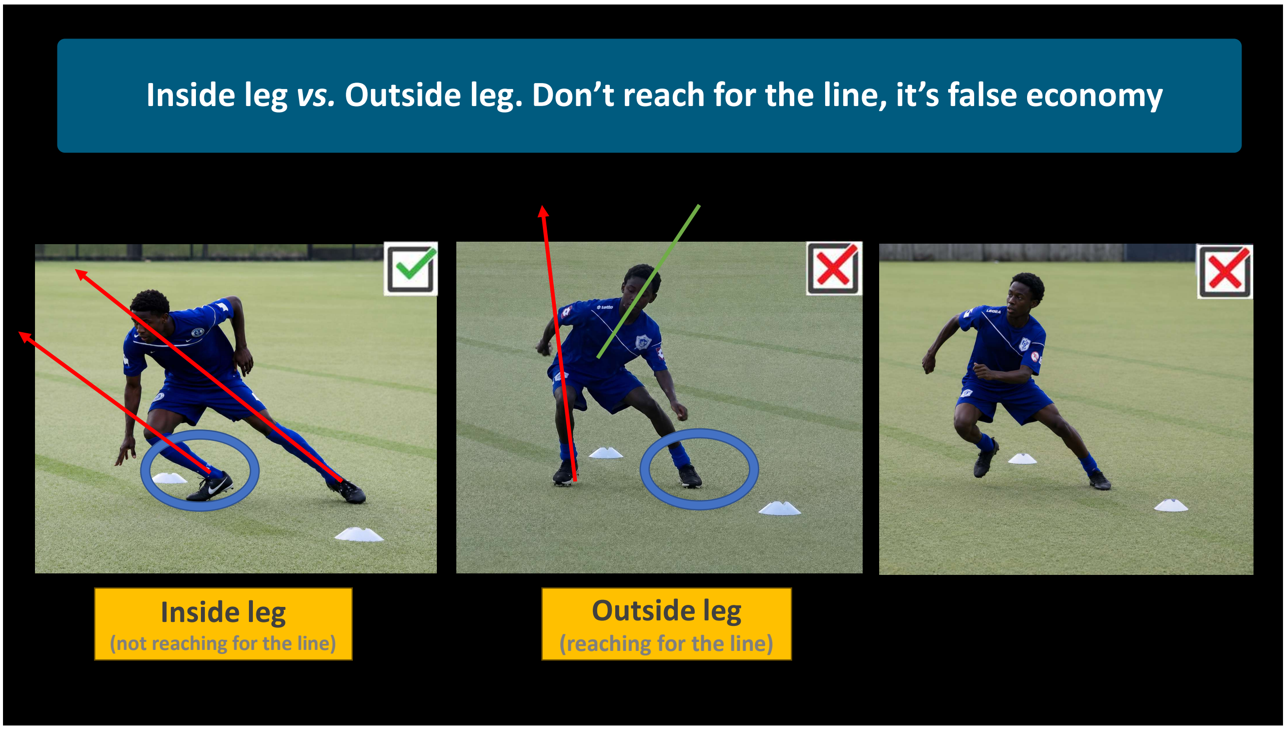
180° CoD

Turning is less intuitive. Especially as we instinctively reach for the line






The cross-over step is pre-programmed
If I can get you to turn like this…
job done!
Re-acceleration takes care of itself


Inside leg vs. Outside leg. Don't reach for the line, it's false economy
Inside leg
(not reaching for the line)
Outside leg
(reaching for the line)

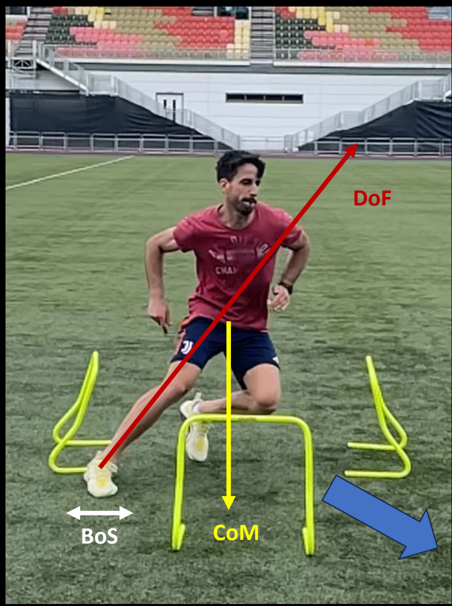
60 – 90 ˚ turns

Outside leg turn

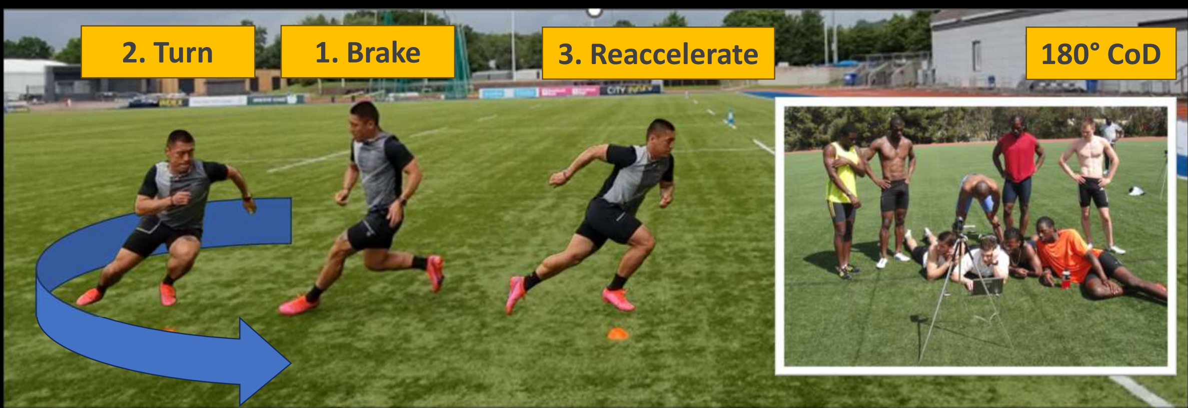
Feint in one direction to "dummy" the opponent and load the outside leg

Dummy-jab step

Jab implies you hit the ground hard, but fast



What does this mean for testing?



Don't just focus on the outcome (time), focus on the how it was achieved (mechanics)

Other CoDS test? Including the CoDD?

6 REPS

Asymmetry?

Variability often greater than the imbalance

But even if it wasn't, because the output variable is time, the cause of a side-to-side imbalance is unknown:

Is it a: (1) weaker limb, (2) suboptimal motor pattern, (3) or some combination of those?

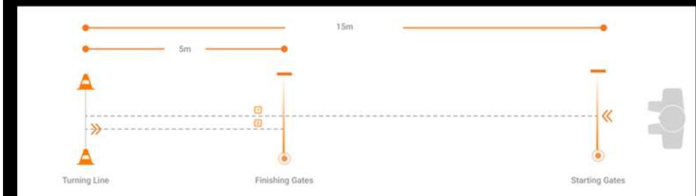
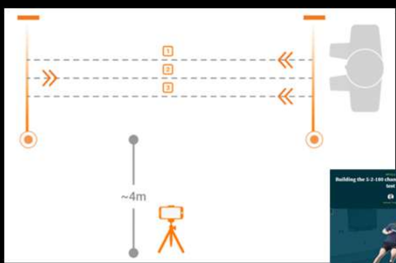
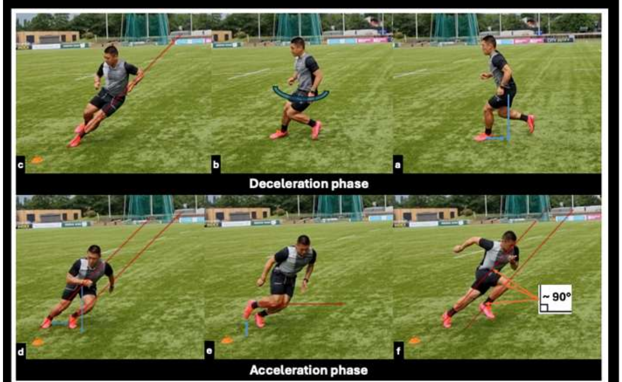


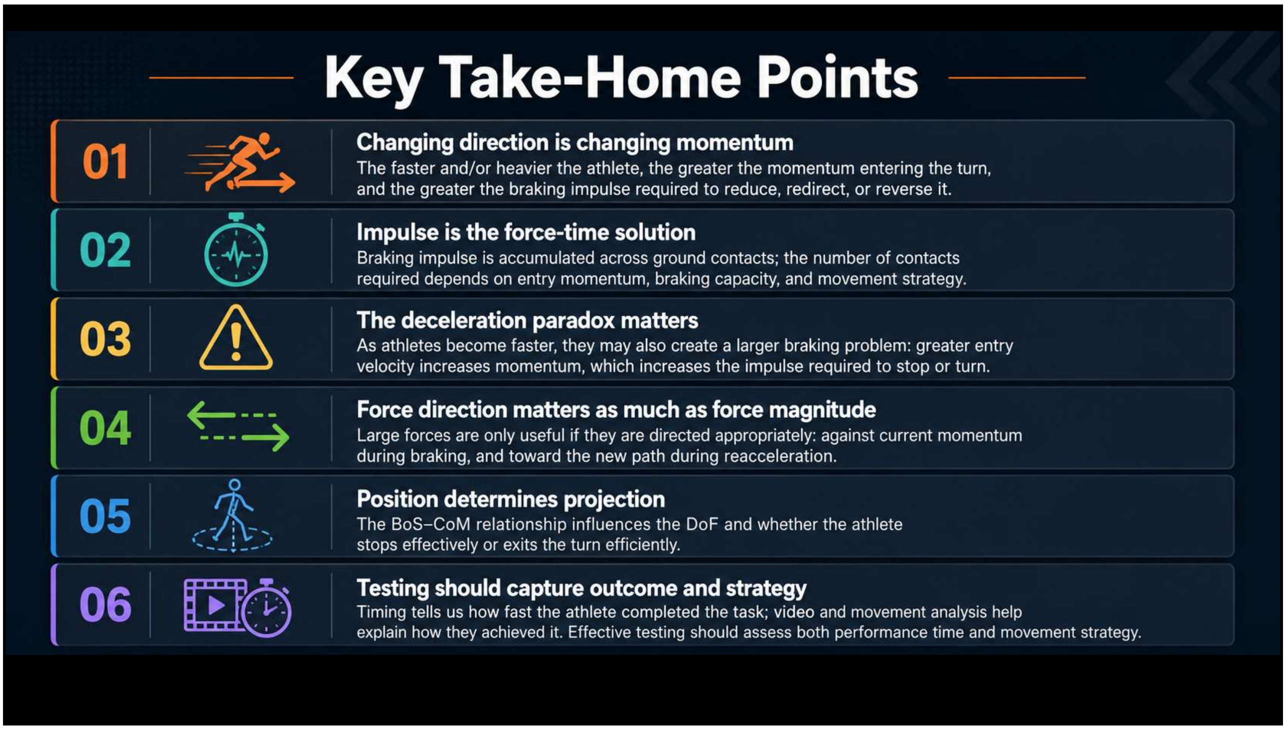
Figure 1: Traditional 5-0-5. To ensure the athlete reaches ≥ 95% of their max 10 meter speed, place timing gates at the start line.





5-2-180 check sheet

Phase		Movement sequence	Left Turn	Score	Right Turn	Score
Deceleration	a	Distance between CoM (hips) and CoP (foot) increases as athlete "sits"	Yes ☐ No ☐		Yes ☐ No ☐	
	b	Athlete re-orients themselves into a side-on position	Yes ☐ No ☐		Yes ☐ No ☐	
	c	Penultimate foot contact: inside leg performs a shallow squat with DoF orientated toward intended direction of travel	Yes ☐ No ☐		Yes ☐ No ☐	
Acceleration	d	At final foot contact:				
		- upper body and shins are aligned to direction of travel (~ 45°)	Yes ☐ No ☐		Yes ☐ No ☐	
		- CoM (belly button) falls outside narrow BoS (feet); At turn, "head never goes between toes"	Yes ☐ No ☐		Yes ☐ No ☐	
		- Outside leg "bounces" off ground	Yes ☐ No ☐		Yes ☐ No ☐	
	e	Outside leg:				
		- knee drives ~ horizontally forward	Yes ☐ No ☐		Yes ☐ No ☐	
		- foot stays close to ground, and will pass ~ below opposite knee	Yes ☐ No ☐		Yes ☐ No ☐	
	f	Athlete achieves acceleration posture:				
		- ~ 90° at ankle (dorsiflexion)	Yes ☐ No ☐		Yes ☐ No ☐	
		- ~ 90° at knee	Yes ☐ No ☐		Yes ☐ No ☐	
		- ~ 90° at hips	Yes ☐ No ☐		Yes ☐ No ☐	
		- Shins run ~ parallel	Yes ☐ No ☐		Yes ☐ No ☐	
Total score (out of 24, 12 points per side)			Left Total		Right Total	


Key Take-Home Points
01
Changing direction is changing momentum
The faster and/or heavier the athlete, the greater the momentum entering the turn, and the greater the braking impulse required to reduce, redirect, or reverse it.
02
Impulse is the force-time solution
Braking impulse is accumulated across ground contacts; the number of contacts required depends on entry momentum, braking capacity, and movement strategy.
03
The deceleration paradox matters
As athletes become faster, they may also create a larger braking problem: greater entry velocity increases momentum, which increases the impulse required to stop or turn.
04
Force direction matters as much as force magnitude
Large forces are only useful if they are directed appropriately: against current momentum during braking, and toward the new path during reacceleration.
05
Position determines projection
The BoS–CoM relationship influences the DoF and whether the athlete stops effectively or exits the turn efficiently.
06
Testing should capture outcome and strategy
Timing tells us how fast the athlete completed the task; video and movement analysis help explain how they achieved it. Effective testing should assess both performance time and movement strategy.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Thank you for Listening :-)
Any Questions?
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