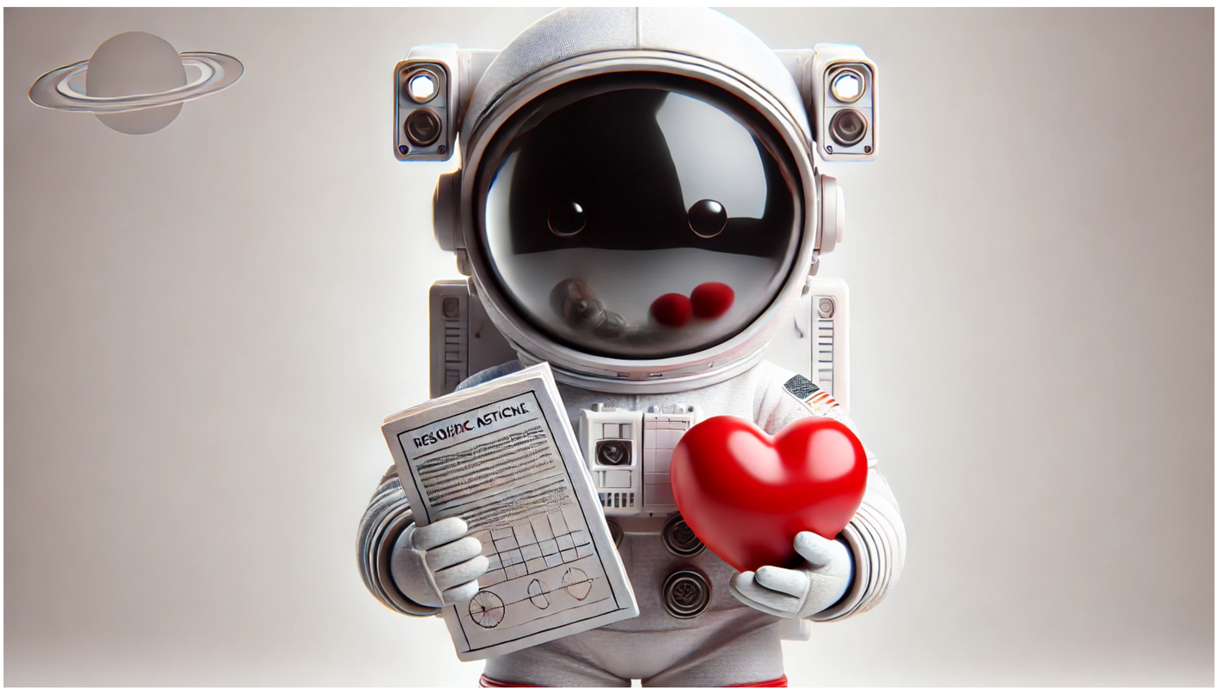
Sports Science 3.0 Series



Claude

From Rule of Thumb to Mechanistic Formula: An AI-Assisted Model for Shuttle Run Distance Correction in HIIT

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High-intensity interval training | Change of direction | Shuttle runs | Anaerobic speed reserve | 30-15 Intermittent Fitness Test | Acceleration capacity | Deceleration capacity | Individualized prescription | Running mechanics

Headline

When prescribing high-intensity intermittent training (HIIT) shuttle runs, practitioners must reduce the target distance to account for the time and energy cost of 180-degree changes of directions (COD) (Buchheit, 2008; Buchheit, 2011). For more than two decades, this adjustment has relied on empirical rules of thumb. This paper traces the evolution from the original 0.7-second time correction per COD introduced in 2000 (Buchheit, 2008; Buchheit, 2011) to the percentage-based approach formalized in 2019 (Buchheit & Laursen, 2019), identifies the limitations of both, and presents a time-based mechanistic model (t_{cod}) that replaces these fixed approaches with an individualized, speed-dependent COD time cost derived from each player's acceleration capacity (A0).

The updated prescription framework supports two equivalent pathways to target speed: vIFT from the 30-15IFT (as per the original freely available spreadsheet provided on Martin's website since 2000) and the player's anaerobic speed reserve (ASR, derived from MAS and MSS). Neither pathway is inherently superior; the choice depends on each club's testing context. The model incorporates running speed, shuttle length, and, importantly, individual acceleration and deceleration capacity into a single closed-form equation, accompanied by a freely available spreadsheet tool and a web app for squad-level prescription.

This work was developed as part of the Sport Science 3.0 series, using AI (Anthropic, Claude Opus 4) as a collaborative reasoning partner (Buchheit & Laursen, 2024).

Aim

To develop and present a time-based mechanistic model for adjusting shuttle run distance during HIIT that replaces both the empirical 0.7s per COD rule (Buchheit, 2008 & 2011) and percentage-based approach (Buchheit & Laursen, 2019) with an individualized, speed-dependent correction (t_{cod}). This correction is derived from each player's acceleration capacity (A0), with particular attention to the prescription errors that arise when test and training shuttle geometries differ. This Sport Science 3.0 project (Buchheit & Laursen, 2024) also aims to provide a framework for future empirical validation of the model's predictions.

> **Practitioner resources**
> A new Excel spreadsheet and a companion interactive web tool implementing the full model are freely available at `http://martin-buchheit.net`. Both tools support individual and squad-level prescription using either vIFT or MAS/MSS inputs, and mirror the calculations described in this paper. The web tool runs entirely in the browser with no data stored or transmitted.

Background: the original approach and its limitations

The 0.7-second correction (2000)

The concept of adjusting shuttle distance for COD cost (Figure 1) was first implemented in a freely available spreadsheet provided on Martin's website since 2000 (link here, Figure 2), and later formalized in the original 30-15 Intermittent Fitness Test (30-15IFT) publications (Buchheit, 2005 & 2008) and a practical NSCA article (Buchheit, 2011). The spreadsheet (Figure 2) has since been available via the 30-15IFT app and website (`https://30-15ift.com`) since 2018.

In that work, an empirical value of 0.7 seconds was subtracted from the 30-second running period for each change of direction. The rationale was straightforward: the effort to turn increases with running speed, and a fixed time penalty per COD captures this cost in a practically simple way. For example, at 11.5 km/h, a player would cover 96 m in a 30-second straight-line run, but the corrected shuttle distance was 91.6 m (accounting for 2 direction changes x 0.7 s each, Figure 2).

This approach had two key strengths: it was speed-sensitive (faster runners lost more absolute distance per COD, since 0.7 s at higher speed represents more meters) and it was easy to implement. However, the 0.7 s value was empirical and not individualized: it assumed all players experienced the same time cost per turn regardless of their acceleration and deceleration capacity.

The percentage-based correction (2019)

In the HIIT book (Buchheit & Laursen, 2019), this approach was refined based on physiological evidence. Comparing shuttle versus straight-line HIIT at matched distances revealed approximately 5-6% additional overall energetic cost, inferred from +3% higher heart rate, +20% higher blood lactate, and

+15-20% greater anaerobic energy contribution during shuttle runs (Buchheit et al., 2011; Buchheit & Laursen, 2019). To compensate, practitioners were advised to remove 2-3% from the target running distance per COD: 1 COD → distance -3%, 2 CODs → -5%, 3 CODs → -7% (Figure 3). While more grounded in physiology than the 0.7 s approach, this percentage method carries inherent limitations:

Speed independence. The percentage correction is applied uniformly regardless of the player's running speed. However, the physics of deceleration and reacceleration are fundamentally speed-dependent: the distance and time consumed by each turn scale with the square of the running velocity ($d_{turn} \alpha v^2$). A turn at 6.0 m/s costs substantially more distance and time than a turn at 4.5 m/s. Whether this holds in vivo across all shuttle contexts remains to be established.

No individual differentiation. The flat percentage treats all players identically. Yet a player with a maximal acceleration capacity of 7.0 m/s^2 completes the deceleration-reacceleration cycle in less time and over less distance than a player with 4.0 m/s^2, even at the same running speed. This difference is not trivial: GPS-derived maximal acceleration values in elite football range from 5 to 8 m/s^2 depending on position and playing level (Table 1).

Shuttle length insensitivity. The same percentage is applied whether the shuttle is 10 m or 40 m, despite the fact that shorter shuttles produce dramatically more turns per unit distance. As shuttle length decreases, the proportion of each interval spent accelerating and decelerating increases relative to time spent at steady-state running speed, fundamentally changing the nature of the exercise. A flat percentage correction cannot capture this.

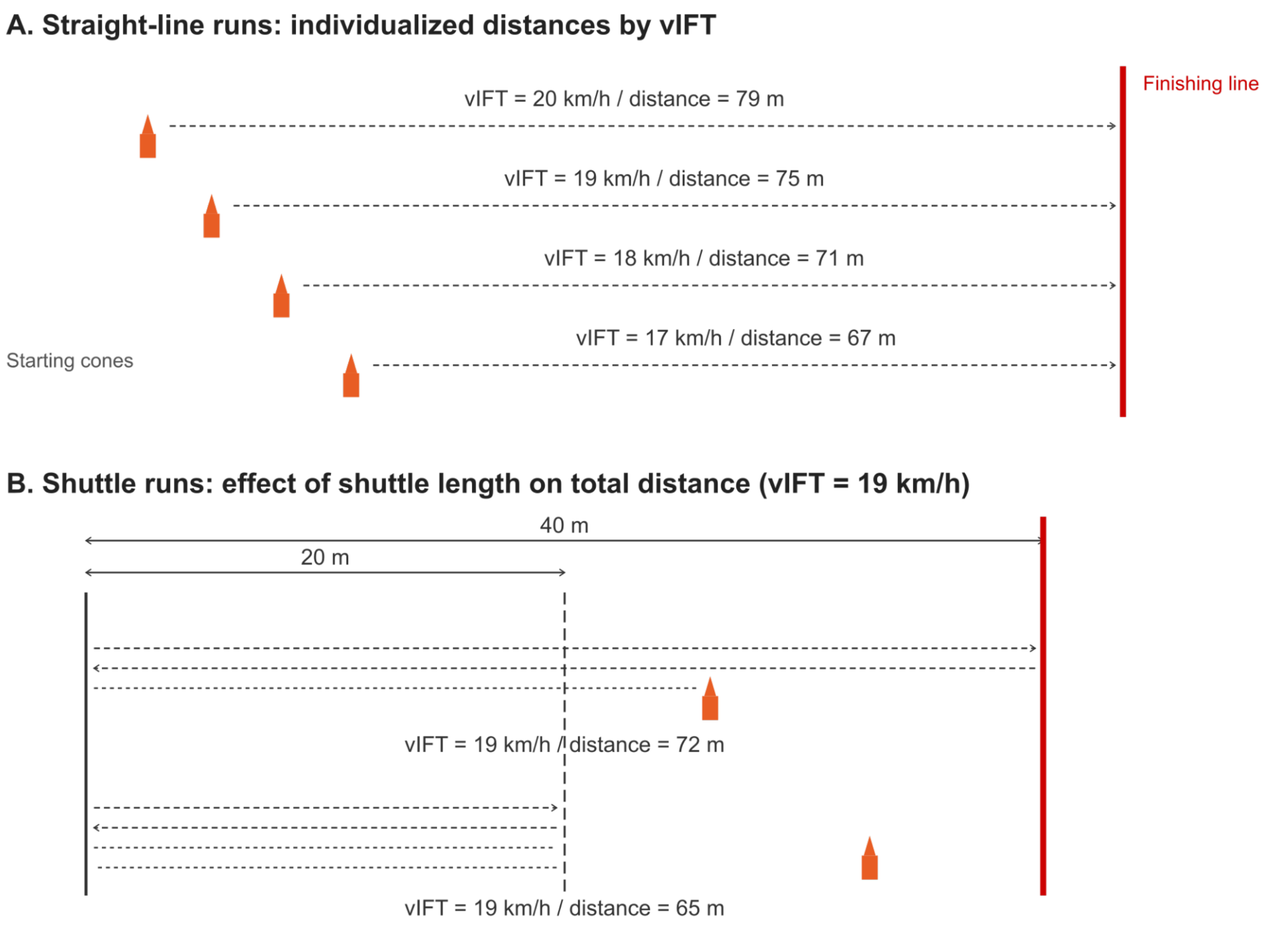

Fig. 1. Individualization and distance adjustment during high-intensity intermittent training (HIIT). (A) Straight-line runs: players with different vIFT (i.e., the speed reached at the end of the 30-15IFT) values start from staggered cones and cover individualized distances to a common finishing line. (B) Shuttle runs: for the same player (vIFT = 19 km/h), shorter shuttle lengths produce more CODs and reduce total distance covered (40 m shuttles = 72 m; 20 m shuttles = 65 m). Adapted from Buchheit 2011.

Spreadsheet for Intervall Training prescription based on VIFT (1.2)

30-15 Intermittent Fitness Test - Martin Buchheit - 2000

Serie #1 | 15"-15" | How to do?

%V IFT	90		Team:	Optimo FC
Running time (sec)	15		Date:	8/16/07
Shuttle length (m)	30		CD Track	n°6

Names	V IFT	Time	%	Distance Straight	Distance Shuttle	...which is on the field			
Player 1	15	15	90	56	54	1	Shuttle(s) and	24	m
Player 2	15.5	15	90	58	55	1	Shuttle(s) and	25	m
Player 3	16	15	90	60	57	1	Shuttle(s) and	27	m
Player 4	16.5	15	90	62	59	1	Shuttle(s) and	29	m
Player 5	17	15	90	64	61	1	Shuttle(s) and	31	m
Player 6	17.5	15	90	66	63	1	Shuttle(s) and	33	m
Player 7	18	15	90	68	61	2	Shuttle(s) and	1	m
Player 8	18.5	15	90	69	63	2	Shuttle(s) and	3	m
Player 9	19	15	90	71	65	2	Shuttle(s) and	5	m
Player 10	19.5	15	90	73	66	2	Shuttle(s) and	6	m
Player 11	20	15	90	75	68	2	Shuttle(s) and	8	m
Player 12	20.5	15	90	77	70	2	Shuttle(s) and	10	m
Player 13	21	15	90	79	71	2	Shuttle(s) and	11	m
Player 14	21.5	15	90	81	73	2	Shuttle(s) and	13	m
Player 15	22	15	90	83	75	2	Shuttle(s) and	15	m

Fig. 2. The original interval training prescription spreadsheet (version 1.2), freely available since 2000. The tool calculates individualized shuttle distances based on each player's vIFT, applying the 0.7-second time penalty per change of direction to adjust prescribed running distances.

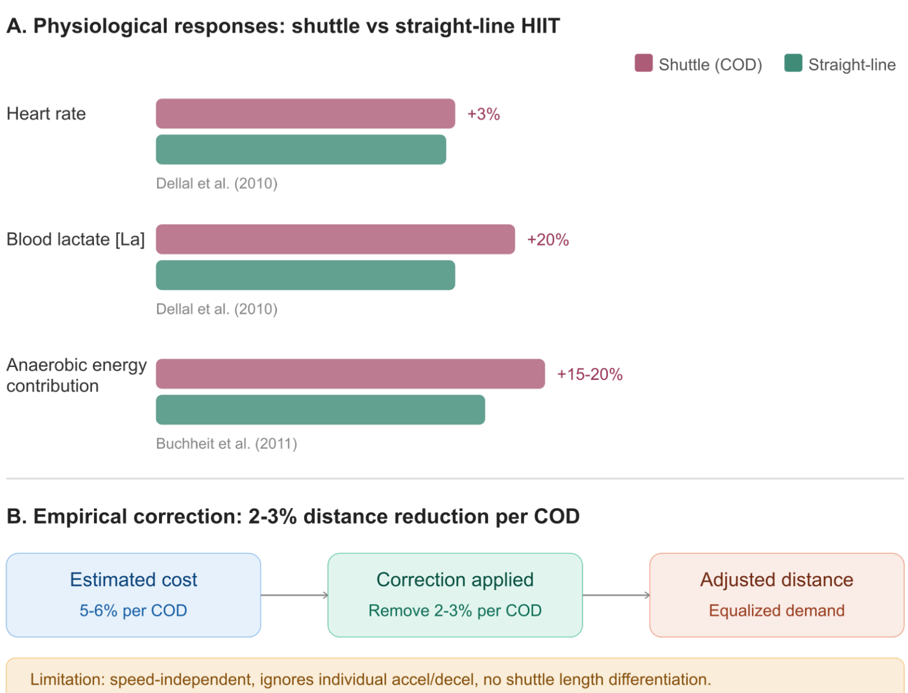

Fig. 3. Physiological basis for the empirical distance correction per change of direction (COD). (A) Physiological responses are elevated during shuttle compared to straight-line HIIT: heart rate approximately 3% higher, blood lactate approximately 20% higher (Dellal et al., 2010), and anaerobic energy contribution 15-20% greater at maximal intensity (Buchheit et al., 2011). (B) The empirical correction approach: the estimated 5-6% total additional energetic cost for a typical drill including 2 CODs translates to a 2-3% distance reduction per COD to equalize metabolic demand. This approach does not account for running speed, individual acceleration/deceleration capacity, or shuttle length (adapted from Buchheit & Laursen, 2019).

Test-training geometry mismatch

Perhaps most importantly, both the 0.7s and percentage rules are applied identically regardless of whether the training shuttle length matches the test shuttle length. The 30-15IFT uses 40m shuttles, but many HIIT sessions use 20m, 15m, or even 10m shuttles. Since the 0.7s error scales differently at different shuttle lengths, the cancellation of errors between test and training is only approximate when the two geometries differ. As shuttle length decreases, the density of turns per unit distance increases, and the underestimation of the old rule grows disproportionately. At 10m training shuttles for a player tested with the 40m-based 30-15IFT, the prescription error can exceed 15 percentage points, a magnitude that is practically meaningful for individualized internal load and overall training prescription.

Two pathways to target speed: ASR and vIFT

The model supports two equivalent pathways for computing v_{target}, each suited to different testing contexts. The first uses MAS and MSS (and their derived anaerobic speed reserve, ASR) as inputs for computing v_{target}. The second uses the vIFT reached at the end of the 30-15IFT directly as the reference speed (Buchheit, 2021). Neither pathway is inherently superior; the choice depends on which tests are available and practical within each club's context.

vIFT is a composite velocity that reflects not only aerobic capacity but also anaerobic function, inter-effort recovery ability, and in the shuttle version, COD capacity (Buchheit, 2005; Buchheit, 2008; Buchheit & Mendez-Villanueva, 2013). The major predictors of vIFT are, in order of importance, MAS and MSS (Buchheit & Mendez-Villanueva, 2013), and vIFT is consistently 20–25% higher than MAS, approximately equating to MAS + 20% of the ASR (Buchheit, 2021).

The ASR pathway is the most direct: MAS is measured independently (continuous incremental test or time trial) and MSS from GPS sprints, with no circularity involved. It also provides the richest individualization, since two players with the same vIFT but different MAS/MSS profiles will receive different v_{target} values at the same %ASR.

The vIFT pathway offers distinct practical advantages. First, testing for MSS requires maximal sprinting over a sufficient distance (typically 30–40 m) to reach top speed. While field-based outdoor sports (football, rugby) routinely assess MSS, indoor team sports such as basketball, handball, and futsal often lack the space for players to reach true maximal sprinting speed on the court. For these populations, vIFT — which can be assessed over 28 m shuttles on a basketball court (Haydar et al., 2011) — provides the only practical composite reference speed. Second, many coaches are reluctant to conduct continuous MAS tests due to perceived monotony and poor player buy-in. The 30-15IFT addresses this: it is perceived as less painful than continuous tests by 70% of players assessed, and its intermittent nature makes it specific to the training sessions it prescribes (Buchheit, 2021). Third, when vIFT is used as the reference speed for HIIT prescription, the coefficient of variation in cardiovascular responses between players drops to <3%, compared with >10% when MAS-based (only) speeds are used (Buchheit, 2008). This standardization of internal load across a squad is precisely what individualized prescription aims to achieve.

The mechanistic model

Analytical approach

The mechanistic model detailed in this study was the result of an iterative, collaborative dialogue between the first author (Martin) and Claude (Anthropic, Claude Opus 4), serving as a computational reasoning partner. This AI-driven methodology was originally conceptualized by the final author, Christof, who conducted initial explorations using ChatGPT and Gemini. Following Christof's initial findings and subsequent reflections, Martin transitioned the project to Claude to finalize the current model.

The process followed a hypothesis-driven workflow: the author defined the practical problem and physiological constraints, while the AI was used to derive a simplified kinematic description of the deceleration-reacceleration cycle from constant-acceleration assumptions and di Prampero's equivalent slope model for metabolic cost, 2) algebraically verify that within that energetic approximation the net extra energy term per turn is independent of the explicit acceleration/deceleration-rate terms, 3) identify and resolve the step-function paradox that arose from integer-based turn counting in the iterative formulation, leading to the closed-form continuous solution ($d_{adjusted} = v \times (t_{work} - n_{cod} \times t_{cod})$), and (4) build and debug the accompanying Excel spreadsheet through multiple rounds of numerical verification against manual calculations. Each intermediate result was challenged and cross-checked by the author against published data and practical experience before being accepted. The literature search for GPS-derived maximal acceleration and deceleration reference values was also conducted with AI-assisted web search, with the author verifying primary sources. This collaborative workflow — domain expert setting the direction and validating outputs, AI handling algebraic derivation, numerical computation, and systematic error-checking — exemplifies the Sport Science 3.0 approach to tool development described in this series (Buchheit & Laursen, 2024).

Importantly, the use of AI does not replace the need for formal derivation, empirical validation, or critical scrutiny of the underlying assumptions. In particular, while AI excels at maintaining internal mathematical consistency, it cannot independently challenge the empirical assumptions (A0 default value and model structure) that determine the model's real-world validity. These require field-based verification.

The physics of a single turn

In practice, instantaneous acceleration and deceleration rates vary throughout the braking and propulsive phases, following the underlying force-velocity relationship. The model simplifies this by treating a_{brake} and a_{accel} as effective average rates over each phase, an idealization that is most defensible at the submaximal speeds typical of shuttle HIIT (where the force-velocity curve is relatively flat) and for planned turns (where braking is progressive and intentional rather than reactive). Under this constant-rate approximation, the distance consumed by the deceleration-reacceleration cycle is:

$$d_{turn} = v^2 / (2 \times a_{brake}) + v^2 / (2 \times a_{accel})$$

where a_{brake} and a_{accel} are the actual deceleration and acceleration rates used during the turn. These are set to each player's maximal capacity (A0), with a default of 7.5 m/s² for both:

$$a_{brake} = A0_{brake} \text{ (default 7.5 m/s}^2\text{)}$$

$a_{accel} = A0_{accel}$ (default 7.5 m/s²)

This default is informed by the available literature on peak acceleration and deceleration across measurement approaches and sports (Table 1). Three approaches are available to practitioners for determining A0, each producing different values that reflect the measurement methodology rather than fundamentally different physical capacities.

Category 1: Acceleration-Speed (A-S) profile in-situ. This method, introduced by Morin et al. (2021), extrapolates the theoretical maximal acceleration (A0) from a linear regression of acceleration versus speed data collected passively via GPS during training or matches. Typical values for elite football players range from 6.0 to 8.5 m/s² depending on the training context, position, and period of the season (Morin et al., 2021; Lopez-Sagarra et al., 2022; Alonso-Callejo et al., 2022; Clavel et al., 2023). This approach requires specific GPS data processing (e.g., GPEXE native support or custom scripts) and produces a theoretical maximum, not an observed peak value.

Category 2: Dedicated sprint testing. Sprint force-velocity (F-V) profiling using timing gates, radar, or motorized resistance devices (e.g., 1080 Sprint) provides F0 relative to body mass (F0/BM), which is conceptually equivalent to A0. Published values range from 6.1 to 8.7 m/s² for acceleration and up to 8.7 m/s² for deceleration (Jimenez-Reyes et al., 2018; Buchheit & Eriksrud, 2024). This approach requires dedicated testing time but provides the most reliable individual values. Importantly, the measurement window (e.g., 0.5 s for the 1080 Sprint) influences the absolute values reported: shorter windows capture higher instantaneous peaks.

Category 3: Raw GPS session peaks. This is what most practitioners have access to: the highest instantaneous acceleration or deceleration recorded by the GPS system during training or matches. These values are substantially lower than those from Categories 1 and 2, typically ranging from 3.5 to 6.4 m/s² (Akenhead et al., 2013; Oliva-Lozano et al., 2020; Buchheit, Lazar et al., 2024). The difference is driven by GPS filtering algorithms, measurement windows (typically 0.8s for Catapult vs 0.5s for STATSports), and the sub-maximal nature of most training and match actions. Critically, the same deceleration action measured with a 0.5s window (STATSports, during a 15-0-5 test) yields -6.8 m/s² while a 0.8s window (Catapult, during match play) gives only -3.5 m/s² (Buchheit, Lazar et al., 2024), highlighting that differences between systems reflect measurement methodology as much as player capacity.

Across other team sports, the literature predominantly reports threshold-based frequency counts (events exceeding 2.5 or 3.5 m/s²) rather than absolute peak values (Harper et al., 2019; Yamamoto et al., 2020; Garcia et al., 2021), making direct comparison to A0 difficult. Nevertheless, the finding that high-intensity decelerations consistently outnumber accelerations across virtually all field sports (Harper et al., 2019) is relevant to the model, as it suggests that deceleration capacity may be the more constraining parameter in shuttle HIIT prescription.

The default of 7.5 m/s-squared represents a player's theoretical maximal capacity (A0) during planned, anticipated turns. The biomechanical rationale is as follows: during shuttle HIIT, target speeds typically fall in the 18-22 km/h range, which represents the high end of high-speed running but remains well below maximal sprinting speed for most players. At these submaximal speeds, the force-velocity relationship leaves substantial force reserve available, meaning the player CAN apply near-maximal braking and propulsive forces if the action is anticipated. Because planned shuttle turns are exactly that (the player knows precisely when and where to stop), the effective braking rate during the turn is expected to approach A0 rather than the lower values observed during reactive or unplanned actions at higher speeds. At v = 5.41 m/s (95% of vIFT 20.5 km/h) with A0 = 7.5 m/s-squared, the model produces t_{cod} = 0.72s, nearly matching the original 0.7s calibration. This convergence provides indirect support for the default: the value of A0 that best reproduces 20 years of validated practice is 7.5 m/s-squared, consistent with the theoretical maximal capacity of a typical elite footballer applying full braking effort at submaximal running speeds. The model makes this relationship explicit while adding speed-dependency (t_{cod} increases at higher speeds) and individualization (players with lower A0 get larger corrections).

The spreadsheet includes a utilization ratio parameter that scales A0 downward to reflect the effective acceleration/deceleration rate during sub-maximal shuttle turns. The appropriate setting depends on the source of A0: practitioners using A-S profile A0 or sprint F-V F0/BM (Category 1 or 2, typically 6-8 m/s²) should set the utilization ratio to 60-80%, reflecting the sub-maximal, fatigued nature of shuttle HIIT turns compared to maximal sprint testing. At 70% utilization with A0 = 7.5 m/s², the effective rate becomes 5.25 m/s², consistent with field observations. Practitioners using raw GPS peak values (Category 3, typically 3.5-6 m/s²) should enter these directly as A0 with the utilization ratio at 100%, as the GPS filtering and sub-maximal context are already embedded in the measured value. Both pathways converge on an effective acceleration/deceleration rate of approximately 4-5 m/s² during shuttle HIIT, which aligns with field-testing observations and produces prescriptions consistent with the original empirically calibrated 0.7s correction.

Note that A0 does not need to be adjusted for shuttle length. The v_{target} is set by the prescription (%ASR or %vIFT), not by the shuttle length, so t_{cod} is the same whether the shuttle is 8m or 40m. What changes with shorter shuttles is only the number of CODs: more turns per interval means a larger total correction. The model's validity limitation at short shuttles arises when d_{turn} approaches or exceeds shuttle length, meaning the player cannot reach v_{target} within a single shuttle segment. When this occurs, the spreadsheet flags it as a warning and the practitioner should either increase the shuttle length or reduce the target speed. In practice, with A0 = 7.5 m/s² at typical HIIT speeds (95% of vIFT 22.5 km/h), d_{turn} = 4.8m, so shuttles of 10m or longer remain well within the valid range (see more detail in the 'Model behaviour at short shuttle lengths' section).

Sensitivity analysis reveals that A0 is the key individualizing parameter. The difference between A0 = 7.5 (good) and A0 = 5.0 (low) shifts the distance reduction by approximately 7 percentage points at 20m shuttles.

The corresponding time for the turn is:

$$t_{turn} = v / a_{brake} + v / a_{accel}$$

Under the constant-acceleration assumption, the distance "lost" per turn relative to steady-state running equals exactly d_{turn}. The proof is direct:

Distance the player would have covered at steady state during the turn:

$$d_{steady} = v \times t_{turn}$$

$$d_{steady} = v \times (v / a_{brake} + v / a_{accel})$$

$d_{steady} = v^2 / a_{brake} + v^2 / a_{accel}$

$d_{steady} = 2 \times d_{turn}$

Actual distance covered during the deceleration-reacceleration cycle:

$d_{actual} = v^2 / (2 \times a_{brake}) + v^2 / (2 \times a_{accel})$

$d_{actual} = d_{turn}$

Distance lost per turn:

$d_{lost} = d_{steady} - d_{actual}$

$d_{lost} = 2 \times d_{turn} - d_{turn}$

$d_{lost} = d_{turn}$

The factor of 2 arises because distance at constant speed scales as v^2 / a, while distance under constant acceleration (or deceleration) scales as $v^2 / (2a)$. This kinematic identity, while exact within the model, should not be read as a claim that real-world shuttle turns produce exactly this displacement. This deceleration-reacceleration sequence and its key variables are illustrated in Figure 4.

Table 1. Peak acceleration and deceleration values across measurement approaches and sports (Values represent theoretical maximal (A0, F0/BM), peak instantaneous (GPS/device), or threshold-based demands. All values in m/s²)

Reference	Sport / Population	Device	Context	Peak Accel (m/s²)	Peak Decel (m/s²)	Key finding
Category 1: Acceleration-Speed profile in-situ (A0) – theoretical max from GPS linear regression						
Morin et al. 2021	Pro football (n=28)	GPS (GPEXE)	Training, 2-wk blocks	7.20 ± 0.40 (range 6.55–8.43)	—	Proof of concept for in-situ profiling
Lopez-Sagarra et al. 2022	Elite football (n=14)	GPS (WIMU 18Hz)	Match, full season	6.20 ± 0.51	—	Season average; lower than training values
Alonso-Callejo et al. 2022	Elite football, La Liga 2	GPS	Match + training	5.73 (FB, MD-2) to 8.68 (CD, MD)	—	A0 varies by position and microcycle day
Clavel, Buchheit et al. 2023	Elite U19 football (n=18)	GPS	Training, weekly	~6.5–8.0	—	Reliability depends on data spread
Category 2: Dedicated sprint testing (F-V profile, 1080 Sprint, radar)						
Jimenez-Reyes et al. 2018	Pro football	Timing gates	Sprint test	7.14 ± 0.58	—	Sprint F-V profile (F0/BM)
Buchheit et al. 2014	Youth football (n=86)	Radar	40m sprint test	~6.5–8.5 (age-dependent)	—	Mechanical determinants of acceleration
Buchheit & Eriksrud 2024	Elite football (n=21)	1080 Sprint	40m sprint	6.08 ± 1.15	8.66 ± 0.91	0.5s window
Slovak FA (in Buchheit & Eriksrud 2024)	U19 football (n=228)	1080 Sprint	15-0-5 COD test	—	8.30 ± 0.82 (full backs)	Position-dependent deceleration
Category 3: Raw GPS peak values from training and match play – Football						
Buchheit, Lazar et al. 2024	Elite football	STATSports / Catapult	15-0-5 test / Match	—	-6.8 ± 0.5 (0.5s) / -3.5 ± 1.0 (0.8s)	Same action: different device/window = different values
Pimenta et a. 2025	U19/U23 football (n=40)	GPS	Sprint drills	5.62–7.09 (drill-dependent)	—	Chasing sprints elicit highest values
Pimenta et al> 2026	U23 Portuguese football (n=19)	GPS (Catapult S7)	Season peak (avg top 3)	5.36 ± 0.54	-6.35 ± 0.61	Best published GPS peak values (0.8s window)
Oliva-Lozano et al. 2020	Pro football, La Liga	GPS (WIMU)	Match play	~3.5–4.5 (by position)	~3.5–4.5 (by position)	WMF highest ACCMAX and DECMAX

Category 3 continued: Other team sports (GPS match demands)					
Harper et al. 2019 (meta-analysis)	7 sports: football, rugby (league, union, sevens), Australian football, hockey, American football (n=469)	GPS (various)	Match play	Thresholds: high >2.5, very high >3.5 m/s^2. Decels > accels in all sports except American football.	Soccer: greatest asymmetry. Soccer SMD=-3.19 for very high decel vs accel
Yamamoto et al. 2020	Elite Japanese rugby union (45 matches)	GPS (GPSports)	Match play	Accel >2.5: Fwd 19.2/match, Backs 37.2/match. Accel >1.5: Fwd 76/match, Backs 101/match. No peak values reported.	Backs perform more high-intensity accels
Garcia et al. 2021	Basketball, 5 age groups (n=64)	LPS (UWB)	Match play	U18 peak accels up to 3.6 m/s^2. Threshold of 2 m/s^2 may be insufficient. Peak demands much higher than averages.	60-s rolling avg needed to capture true demands
Ferraz et al. 2024	Elite rink hockey	GPS	Training vs match	Training underestimates match accel/decel demands.	Gap between training and competition demands
Cotteret et al. 2025 (review)	Football (narrative review)	Various GPS	Match + training	Common thresholds: 2.78, 3.0, 3.5 m/s^2. 85% of accels occur below 19.8 km/h. Accel capacity decreases with initial speed.	Highlights need for speed-dependent thresholds

Key observations for A0 selection in the COD shuttle model:

1. A-S profile A0 (Category 1) and sprint F-V F0/BM (Category 2) represent theoretical maximal capacity, typically 6–8.5 m/s^2 in elite football. These should be used with a utilization ratio of 60–80% to reflect sub-maximal HIIT conditions.
2. Raw GPS peak values (Category 3) are substantially lower (3.5–6.4 m/s^2), reflecting GPS filtering, measurement window effects, and the sub-maximal nature of match/training contexts. These can be used with 100% utilization.
3. The measurement window has a large effect: the same deceleration action measured with a 0.5s window (STATSports) gives -6.8 m/s^2 while a 0.8s window (Catapult) in matches gives -3.5 m/s^2 (Buchheit, Lazar et al. 2024).
4. Most GPS-based research reports threshold-based counts (events >2.5 or >3.5 m/s^2) rather than absolute peak values, making direct comparison to A0 difficult.
5. For practical HIIT shuttle prescription, the effective A0 during sub-maximal 180-degree turns is likely 4–5 m/s^2, regardless of which measurement approach is used.

An important finding: the energy cost per turn within the simplified model is speed-dependent only

When applying di Prampero's equivalent slope model for the metabolic cost of accelerated running, an interesting result emerges. Within this simplified energetic framework, the net extra energy cost per turn beyond steady-state running simplifies to:

$$dE = Cr \times v^2 \times (1 + ecc) / (2g)$$

where Cr is the steady-state running cost (~3.6 J/kg/m), ecc is the eccentric cost factor (~0.5), and g is gravitational acceleration. The acceleration and deceleration terms cancel algebraically: whether the player brakes over 3 m or 10 m, they dissipate the same kinetic energy ($\frac{1}{2}mv^2$). Accordingly, within this energetic approximation, the extra term depends on running speed but not explicitly on the acceleration-rate parameters.

The cancellation follows from the fact that the total kinetic energy dissipated and regenerated per turn (0.5 × v^2 per kg) is independent of the rate at which the work is performed.

Individual differentiation in the present model therefore arises primarily from time/displacement effects: a player with lower A0 spends more time in each turn, leaving less time at v_{target}, and covers less total distance.

The closed-form solution

In a shuttle drill of length L, each shuttle segment requires the player to cover L meters of path plus d_{turn} meters of deceleration-reacceleration overhead. The effective shuttle length is therefore ($L + d_{turn}$). The total distance the player can cover in the work interval is:

$$d_{adjusted} = v \times (t_{work} - n_{cod} \times t_{cod})$$

where $t_{cod} = v/(2 \times A0_{brake}) + v/(2 \times A0_{accel})$ is the time lost per COD, and n_{cod} is the number of CODs determined iteratively from the adjusted distance. This formula preserves the time-subtraction structure of the original 0.7s rule but replaces the fixed 0.7s with an individualized, speed-dependent value. At A0 = 7.5 m/s^2, t_{cod} = 0.72s at v = 5.41 m/s, matching the original calibration to within 0.02s.

The iteration converges in 2–3 passes: estimate n_{cod} from the straight-line distance, compute $d_{adjusted}$, refine n_{cod} from

$d_{adjusted}$, and repeat. The spreadsheet implements this iterative approach.

For practical setup, the number of legs equals CODs + 1 (each COD adds a shuttle segment), and the last leg distance is the remaining distance from the final turn point. Figure 5 compares the distance reductions predicted by the new model across shuttle lengths and accel/decel profiles with the old 2.5% per COD rule of thumb. These outputs should be interpreted as model-based estimates, not yet as validated prescriptions.

An important validity constraint: when d_{turn} exceeds the shuttle length, the player physically cannot reach v_{target} within a single shuttle, and the constant-speed assumption underlying the formula breaks down. In this regime, the model overestimates the time cost per turn (because the player is moving slower than v_{target} at the onset of braking), leading to an overly conservative prescription. The iterative COD counting also becomes unreliable in this range, as the adjusted distance can fall below the shuttle length, producing inconsistent results. For a player with A0 = 7.5 m/s^2 running at 5.9 m/s, d_{turn} = 4.6 m, so shuttles of any practical length remain valid. For players with low A0 (e.g., 5.0 m/s^2), d_{turn} = 7.0 m, meaning shuttle lengths should be at least 8 m; for very low A0 (4.0 m/s^2), d_{turn} = 8.7 m, requiring shuttles of at least 9-10 m. In practice, this constraint is rarely limiting since shuttle HIIT typically uses distances of 10 m or greater, but the spreadsheet flags cases where d_{turn} approaches or exceeds the shuttle length as a warning.

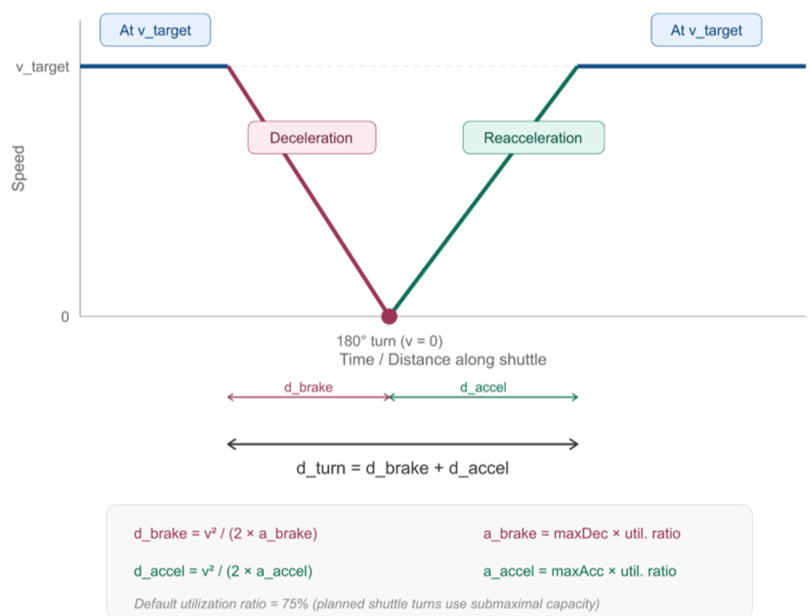

Fig. 4. Anatomy of a single 180° change of direction during a shuttle run. The velocity profile shows the four phases of a shuttle segment: steady-state running at v_{target} (blue), deceleration to zero at the turn point (pink), reacceleration back to v_{target} (green), and resumption of steady-state running (blue). The total distance consumed by the deceleration-reacceleration cycle (d_{turn}) is the sum of the braking distance ($d_{brake} = v^2 / (2 \times a_{brake})$) and the reacceleration distance ($d_{accel} = v^2 / (2 \times a_{accel})$), where a_{brake} and a_{accel} are the player's A0 values (default 7.5 m/s^2) representing full braking capacity during planned, anticipated shuttle turns. Since d_{turn} scales with the square of running speed and inversely with the player's accel/decel capacity, faster players and those with lower mechanical capacity lose proportionally more distance per turn. This distance displacement — not the metabolic energy cost, which is independent of accel/decel capacity — is what drives the individualized prescription.

Resolving the step-function paradox

An important consideration is the step-function paradox inherent to any integer-based COD counting. At certain boundary conditions, a player with worse A0 can receive fewer CODs than a player with better A0, because the larger t_{cod} reduces the adjusted distance enough to cross an integer shuttle boundary. This is mitigated by the iterative convergence in the spreadsheet but can still occur at specific edge cases.

For visualization (Figure 5), the continuous formula $d_{adjusted} = d_{straight} / (1 + d_{turn}/L)$ is used, which is guaranteed monotonic. In practice, the iterative t_{cod} approach in the spreadsheet produces correct results at the specific shuttle length selected by the practitioner.

Individualization

The model requires three categories of input: a speed profile, accel/decel capacity, and drill parameters. All three effects operate simultaneously and continuously for every player.

1. Speed Profile

For the speed profile, the new tool supports two pathways to accommodate different testing practices across clubs:

MAS + MSS (and ASR) Pathway. When both locomotor anchors are available, v_{target} is computed from MAS and a chosen proportion of the ASR. This pathway is free of the circularity that affects vIFT-based prescription (see Reconciling section below), and the mechanistic COD correction can be applied directly without any conversion factor. For this reason, Pathway A should be the default when reliable MAS and MSS values exist.

vIFT-based Pathway. When the 30-15IFT is the primary or sole test, v_{target} is set directly as a percentage of vIFT (e.g., 90% or 95% vIFT). This avoids back-calculating MAS from vIFT, an estimation that depends on the ASR itself and therefore introduces circularity (Buchheit, 2021; Sandford et al., 2021). Since vIFT already integrates aerobic capacity, anaerobic function, and inter-effort recovery into a single prescription-ready speed, using it directly is both simpler and more honest about what the test actually measures. This pathway is particularly suited to indoor team sports where MSS cannot be reliably assessed, but it is equally valid for any setting where the 30-15IFT is the primary fitness reference. With A0 = 7.5 m/s², the old %vIFT values remain essentially unchanged. The model's distinctive value for the vIFT Pathway lies in individualizing for players with different A0 and correcting the test-training shuttle length mismatch.

Note: when comparing prescriptions across pathways, practitioners should be mindful that the percentage scales are not equivalent. Because vIFT approximates MAS + 20-25% of the ASR (Buchheit, 2021), 100% vIFT corresponds approximately to 20% ASR, not 100% ASR. As a practical guide: 100% vIFT ≈ 20% ASR, 95% vIFT ≈ 15% ASR, and 90% vIFT ≈ 10% ASR. These equivalences are approximate and depend on each player's speed reserve profile (MSS/MAS ratio), but they ensure that both pathways land on comparable target speeds for the same player.

Regardless of pathway, the accel/decel capacity inputs and the COD correction formula operate identically.

2. Accel/decel capacity

Maximal acceleration and deceleration values (default A0 = 7.5 m/s² for both). These defaults are informed by in-situ acceleration-speed profiles in elite football, where match-derived A0 values typically range from approximately 5.5 to 7.0 m/s² (Morin et al., 2021; Clavel et al., 2023; Jimenez-Reyes et al., 2022), with higher values (up to 8-9 m/s²) observed during dedicated sprint testing using motorized resistance devices (Buchheit & Eriksrud, 2024). Players with A0 below 7.5 m/s² receive larger t_{cod} values and more correction. Deceleration capacity during planned COD actions has been shown to vary substantially between players and to depend on approach speed (Norman et al., 2025; Buchheit, Lazar et al., 2024), supporting the need for individual profiling rather than fixed default values. These values should be updated from each player's GPS-derived maxima whenever available, ideally using rolling averages rather than single-session peaks given the measurement variability inherent in GPS-derived acceleration data (Buchheit et al., 2014; Clavel et al., 2023).

For direct assessment of maximal acceleration and deceleration capacity, a standardized sprint protocol using a motorized resistance device (e.g., 1080 Sprint) offers the most controlled approach. The 15-0-5 protocol, which combines a 15m maximal acceleration phase with a maximal deceleration phase from various approach speeds, yields individualized A0 values for both acceleration and deceleration that can be entered directly into the model (Buchheit & Eriksrud, 2024). For clubs without access to such devices, GPS-derived in-situ acceleration-speed profiles remain a valid alternative, keeping in mind that match-derived values typically underestimate true maximal capacity since players rarely produce maximal efforts during competitive play.

3. Drill parameters

Work interval duration (e.g., 15 s), target intensity (%ASR or %vIFT), and shuttle length (constrained by available space).

The output for each player includes: adjusted shuttle distance, number of legs (CODs + 1), total CODs, last leg distance, and distance reduction percentage. These can be printed and used directly for pitch setup.

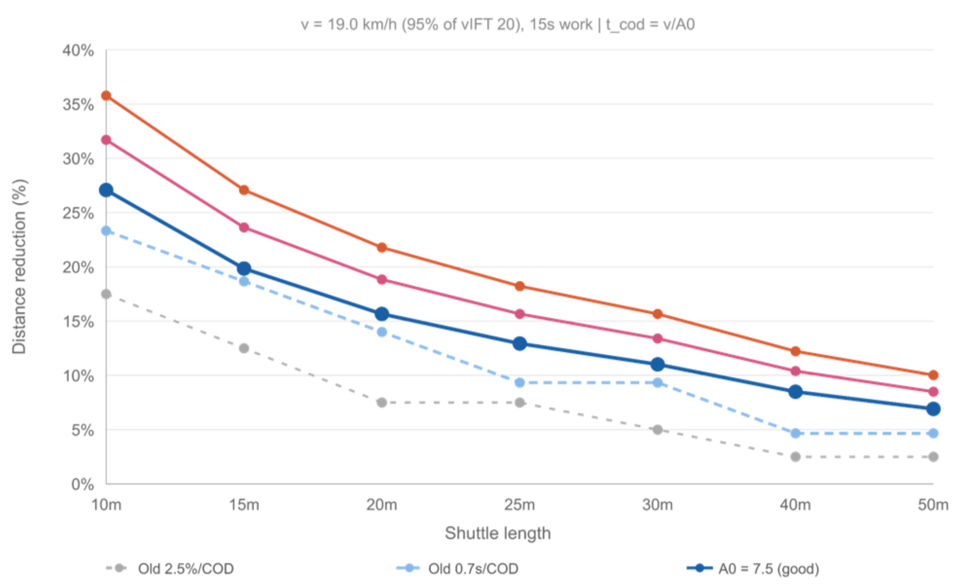

Fig. 5. Distance reduction (% of straight-line distance) as a function of shuttle length (10-50 m) for three A0 profiles: good (A0 = 7.5 m/s²), average (A0 = 6.0 m/s²), and low (A0 = 5.0 m/s²), compared with the two old empirical rules: the 0.7s per COD time correction (dashed blue) and the 2.5% per COD percentage rule (dotted grey). All calculations use v_{target} = 5.3 m/s (95% of vIFT 20.0 km/h), t_{work} = 15 s, and 100% utilization of A0. The good A0 profile (7.5 m/s²) closely tracks the old 0.7s rule, confirming that the model reproduces 20 years of time-based practice for standard players. The 2.5% per COD rule consistently underestimates the correction, particularly at short shuttle lengths. The separation between the three A0 profiles demonstrates the individualization: at 20m shuttles, the reduction ranges from ∼16% (good A0) to ∼22% (low A0). The model differentiates players at all shuttle lengths, with larger individualization effects at shorter shuttles where more CODs occur.

Practical example

MAS + MSS Pathway prescription

The model's clearest practical value emerges with this pathway, where no legacy COD calibration issues arise. Table 2 compares two players with different speed profiles: Player 1 (MAS = 16.0, MSS = 32.0 km/h, expected vIFT ≈ 19, v_{target} = 20.0 km/h, t_{cod} = 0.74s) and Player 2 (MAS = 18.0, MSS = 36.0 km/h, expected vIFT ≈ 21.5, v_{target} = 22.5 km/h, t_{cod} = 0.83s), both training at 25% ASR with A0 = 7.5 m/s² and 15 s work intervals. At 20.0 km/h, the new model closely matches the 0.7s rule, confirming its original calibration. At 22.5 km/h, the speed-dependent t_{cod} diverges from the fixed 0.7s, producing 1.7-2.5m shorter distances, particularly at short shuttles. The 2.5% per COD rule underestimates the correction at both speeds:

Table 2. Prescribed shuttle distances for two players (A0 = 7.5 m/s², 25% ASR, 15 s work) across three methods.

Player	Shuttle	Old 2.5%/COD	Old 0.7s/COD	New model	New vs 2.5%	New vs 0.7s
1	Straight line	83.3 m	83.3 m	83.3 m	0 m	0 m
	40 m	79.2 m	79.4 m	79.2 m	∼0 m	∼0 m
	30 m	79.2 m	75.6 m	75.1 m	4.1 m	-0.5 m
	20 m	75.0 m	71.7 m	71.0 m	4.0 m	-0.7 m
2	Straight line	93.8 m	93.8 m	93.8 m	0 m	0 m
	40 m	89.1 m	85.0 m	83.3 m	5.7 m	-1.7 m
	30 m	86.7 m	85.0 m	83.3 m	3.4 m	-1.7 m
	20 m	84.4 m	80.6 m	78.1 m	6.2 m	-2.5 m

Three methods: old percentage rule (2.5% per COD), old time rule (0.7s per COD), and the new mechanistic model. Straight-line distances (no COD) are included as reference. All new-model values use 100% utilization.

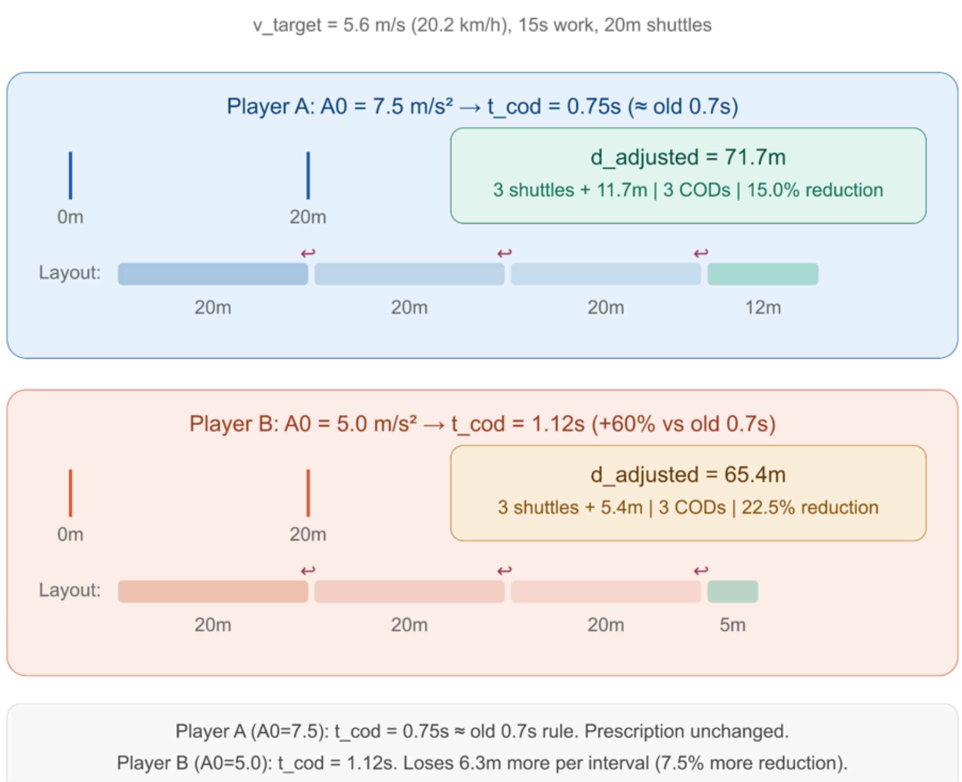

Fig. 6. Individualized pitch setup for two players with identical speed profiles (MAS = 16.2, MSS = 32.4 km/h, expected vIFT ≈ 20.2, v_{target} = 5.6 m/s) but contrasting acceleration and deceleration capacities, performing 15 s work intervals with 20 m shuttles. Player A (A0 = 7.5 m/s²) receives t_{cod} = 0.75s (matching the old 0.7s rule), producing an adjusted distance of 71.7 m (15.0% reduction). Player B (A0 = 5.0 m/s²) receives t_{cod} = 1.12s, producing an adjusted distance of 65.4 m (22.5% reduction). The bottom panel summarizes the cone layout for each player. Despite running at the same target speed, Player B covers 6.3 m less per interval, reflecting the greater proportion of the work interval spent in the deceleration-reacceleration phases. This example illustrates why a flat percentage correction per COD cannot capture the true individual cost of direction changes.

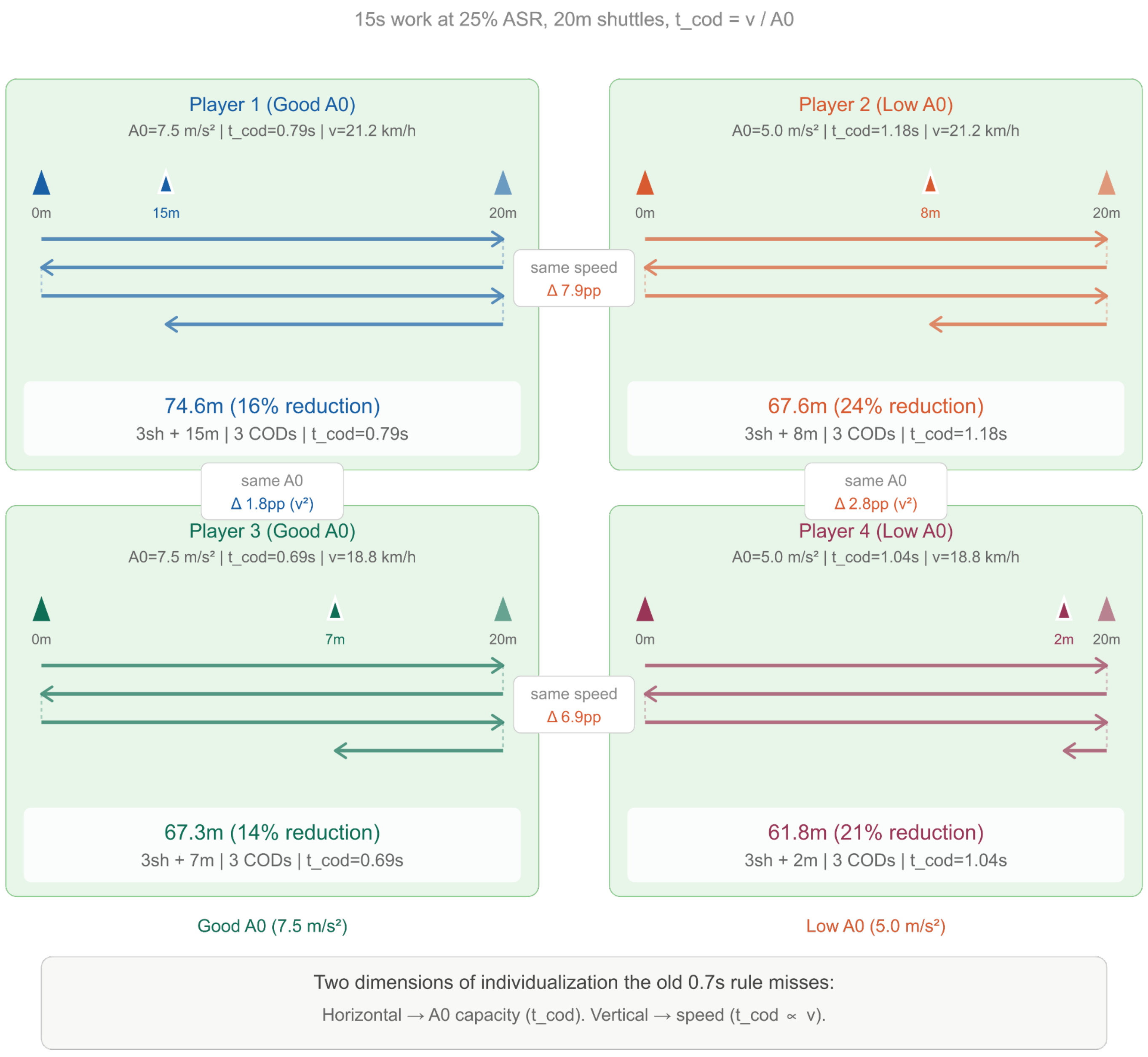

Fig. 7. **Individualized pitch setup for four players organized in two paired comparisons. Within each pair, players share identical speed profiles (MAS and MSS) but differ in acceleration and deceleration capacity. Pair 1 (MAS = 17, MSS = 34 km/h, expected vIFT ≈ 20.5): Player 1 (A0 = 7.5 m/s², t_{cod} = 0.79s) covers 74.6 m with 3 CODs, while Player 2 (A0 = 5.0 m/s², t_{cod} = 1.18s) covers 67.6 m with 3 CODs - a 7.9 percentage-point difference. Pair 2 (MAS = 15, MSS = 30 km/h, expected vIFT ≈ 18): Player 3 (A0 = 7.5, t_{cod} = 0.69s) covers 67.3 m vs Player 4 (A0 = 5.0, t_{cod} = 1.04s) at 61.8 m. Arrows represent individual shuttle legs stacked vertically (top = first leg). Triangle markers indicate cone positions: start cone, 20 m turn cone, and individualized 3rd cones for partial shuttle distances. This layout can be printed directly from the spreadsheet's Squad Prescription sheet for pitch-side use.**

Table 3. Running distance correction in three players with identical speed profiles but different A0 values.

Player	MaxAcc	MaxDec	t_{cod}	SL dist	COD dist	Reduc.
A	7.5	7.5	0.79s	88.5 m	74.6 m	15.7%
B	6.0	6.5	0.95s	88.5 m	71.8 m	18.9%
C	5.0	5.0	1.18s	88.5 m	67.6 m	23.6%

Player A (A0=7.5) receives t_{cod} = 0.79s, closely matching the old 0.7s rule. Player B (A0=6.0/6.5) receives t_{cod} = 0.95s. Player C (A0=5.0) receives t_{cod} = 1.18s, representing a 7.9 percentage-point additional reduction vs Player A. The individualization is continuous across all three players, with no threshold effect.

Mechanical capacity individualization

Consider three players performing a 15 s-15 s HIIT session at 25% of their anaerobic speed reserve, with 20 m shuttles. All three players share MAS = 17.0 and MSS = 34.0 km/h (expected vIFT ≈ 20.5) (Table 3).

All three players have the same v_{target} (5.9 m/s) and the same straight-line distance (88.5 m). The old rule of thumb would prescribe identical corrections for all three. The new model differentiates them continuously based on A0 (Figure 6).

Importantly, the model also captures the speed-dependent cost of COD that the old percentage rule ignores. Figure 7 illustrates both dimensions of individualization: horizontally, players with the same speed but different A0 receive different prescriptions (Δ 6.9–7.9 percentage points); vertically, players with the same A0 but different speeds also receive different prescriptions (Δ 1.8–2.8 percentage points), reflecting the v^2 relationship between running speed and turn cost. The faster the player, the greater the proportion of the work interval consumed by each turn — a non-linear effect that a flat percentage correction cannot capture!

Model behaviour at short shuttle lengths

At short shuttle lengths, the proportion of each work interval consumed by CODs increases substantially. For example, at 16m shuttles with 10s work at 95% vIFT, a player with vIFT = 20 km/h performs 2 CODs costing 1.4s (14% of the interval), while at 40m shuttles the same player performs 1 COD costing 0.7s (7% of the interval). The model captures this effect: shorter shuttles produce more CODs and therefore larger total corrections.

With A0 = 7.5 m/s^2, d_{turn} remains well below the shuttle length for all practical scenarios: at 95% of vIFT 22.5 km/h (equivalent to 25% ASR with MAS = 18.0 km/h, MSS = 36.0 km/h), d_{turn} = 4.7m, comfortably within even a 10m shuttle. The model therefore differentiates between players across all practical shuttle lengths: at 16m shuttles with 10s work, adjusted distances range from 41.5m (vIFT 18 km/h, ∼MAS 15.0, MSS 30.0 km/h) to 49.1m (vIFT 22 km/h, ∼MAS 18.3, MSS 36.7 km/h), an 8m spread driven by the speed-dependent t_{cod}. Whether the model's distance predictions fully hold at very short shuttle lengths where deceleration-reacceleration cycles dominate the interval remains to be validated empirically, and practitioners should interpret short-shuttle prescriptions with appropriate caution.

Practical considerations for pitch setup

Terminal shuttle rule. At certain speed and shuttle length combinations, the adjusted distance falls just beyond a multiple of the shuttle length, producing a very short final partial run after the last COD. For instance, at 16m shuttles with vIFT = 22 km/h (equivalent to ∼25% ASR with ∼MAS 18.3, MSS 36.7 km/h), the model prescribes 49.1m with 3 CODs, but the last partial shuttle is only 1.1m, while the reacceleration distance ($d_{accel} = v^2/(2 \times A0_{accel})$) is 2.3m. After decelerating to zero at the last cone, the player would need 2.3m just to begin meaningfully reaccelerating, but has only 1.1m of runway before the interval ends. In contrast, a slightly slower player (vIFT = 21 km/h) covers 47.2m with only 2 CODs and a comfortable final straight of 15.2m.

To address this, when the remaining distance after the last COD falls below the reacceleration distance (d_{accel}), the final turn is removed and the player extends the previous straight-line run instead. The vIFT 22 km/h player would run 16m + 16m + 17.1m = 49.1m with 2 CODs instead of 16m + 16m + 16m + 1.1m = 49.1m with 3 CODs. The total prescribed distance stays the same, but the layout avoids a turn that serves no practical purpose. This rule also prevents a counter-intuitive outcome where a faster player performs an extra COD compared to a slightly slower one, despite covering similar total distance. The threshold is individualized (d_{accel} varies with running speed and A0) rather than a fixed cutoff, consistent with the model's overall philosophy of player-specific prescription.

Layout options. Once the adjusted distance and number of CODs are determined for each player, practitioners face a second practical question: how to physically set up cones on the pitch (Figures 8 and 9). Two layout options are available. In Option A (fixed shuttle + last leg, Figure 8), a base shuttle length is set for all players (e.g., 16m or 40m), and only the final leg distance varies per individual. All players share the same turn cones, which simplifies pitch setup considerably. In Option B (equal legs, Figure 9), the total adjusted distance is divided equally across all legs, so every leg is the same length for a given player. This produces cleaner geometry but requires fully individualized cone placement. Both options yield the same total distance, the same number of CODs, and therefore the same metabolic load.

The distinction between options is minor at long shuttles (e.g., 40m), where there are few CODs and last legs remain close to the shuttle length. At shorter shuttles (e.g., 16m), the layout choice becomes more consequential: last legs can range from well below to above the shuttle length, and the terminal rule may extend the final leg past the shuttle line (Figure 8). Option A is generally recommended for squad settings because it allows grouping players into distance-based buckets (e.g., 5m ranges) where everyone within a group runs the same shuttle corridor, with only the last cone varying. Option B (Figure 9) suits individual or small-group prescription where cone flexibility is not a constraint.

Locomotor profiling. The ratio MSS/MAS provides additional context for each player's speed-endurance profile: below 1.7 (endurance profile), between 1.7 and 1.9 (hybrid), or above 1.9 (speed profile) (Sandford et al., 2021). A speed-profile player has a larger anaerobic speed reserve and therefore a higher v_{target} at the same %ASR, meaning more COD cost per interval. When only vIFT and MSS are available, the profile can be estimated using MAS = vIFT/1.25 (Buchheit, 2011).

This is the only context in which estimating MAS from vIFT is appropriate: as a proxy for locomotor profiling within this spreadsheet. It should not be used as a programming objective (e.g., setting MAS-based training zones or continuous running prescriptions from this estimated value), as this would introduce substantial errors. The strength of vIFT lies precisely in the fact that it captures more than aerobic capacity alone: it integrates anaerobic function, inter-effort recovery, and neuromuscular qualities into a single composite speed (Buchheit, 2008; Buchheit & Mendez-Villanueva, 2013; Sandford et al., 2021). Reverse-engineering a single component (MAS) from this composite inevitably discards the very information that makes vIFT a superior prescription anchor in the first place. For a detailed discussion of this distinction and its implications for metabolic conditioning programming, see Buchheit (2025). Profile cannot be determined from vIFT alone.

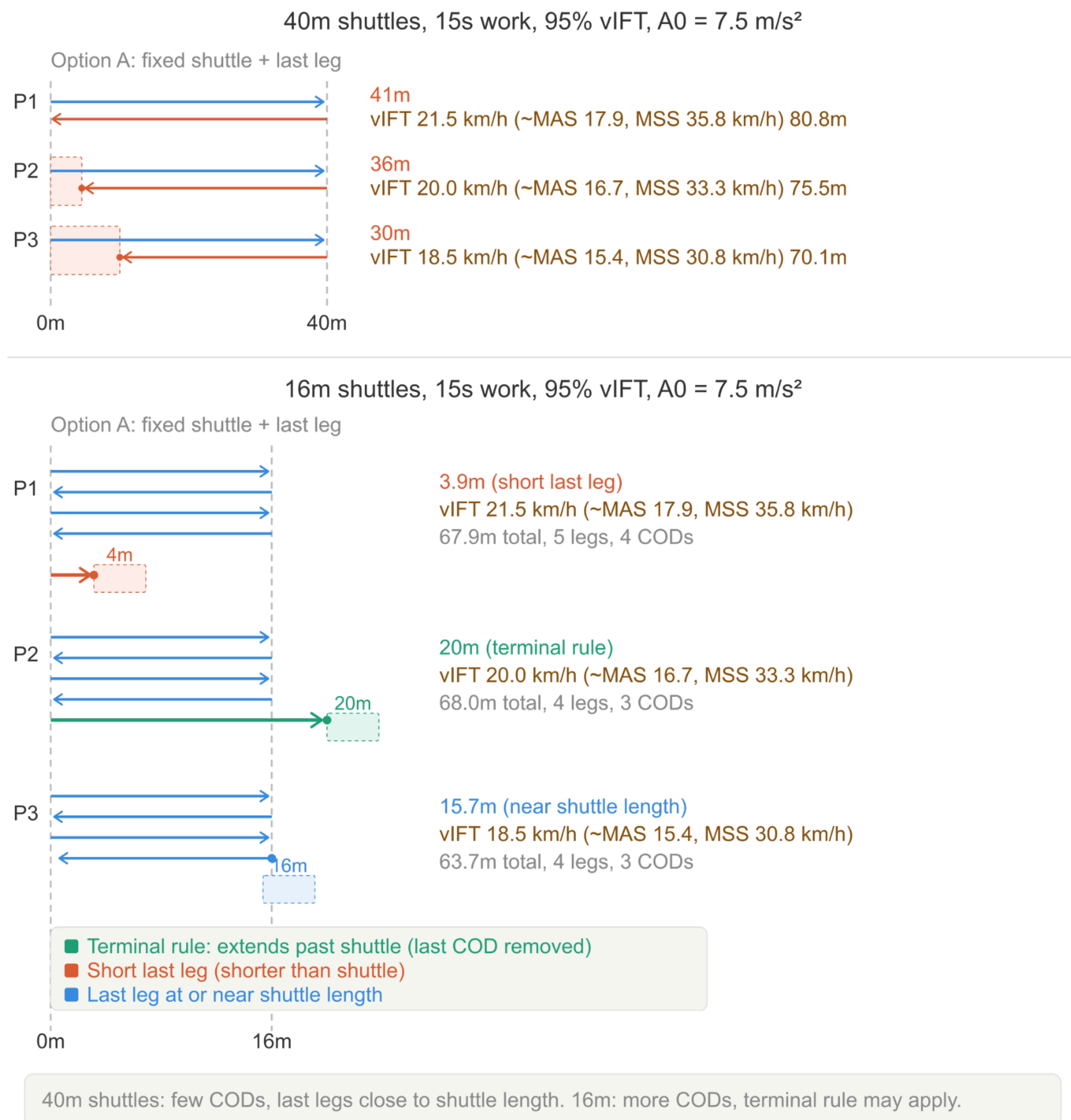

Fig. 8. Pitch layout for individualized shuttle HIIT prescription using Option A (fixed shuttle length with variable last leg), comparing 40 m (top) and 16 m (bottom) shuttles. Three players with different vIFT values (P1: 21.5 km/h, P2: 20.0 km/h, P3: 18.5 km/h) are prescribed at 95% vIFT with A0 = 7.5 m/s² and 15 s work intervals. At 40 m shuttles (top), all three players perform 1 COD with last legs ranging from 30 to 41 m. At 16 m shuttles (bottom), three distinct last-leg scenarios emerge: P1 receives a short last leg (3.9 m, shorter than the shuttle), P2 triggers the terminal rule (last COD removed, final leg extended to 20 m past the shuttle line), and P3 lands near the shuttle length (15.7 m). All players share the same turn cones; only the last cone varies per individual. Arrows represent individual shuttle legs; colored markers indicate the last-leg endpoint for each player.

The spreadsheet tool

A new Excel spreadsheet and a companion web tool implementing the full model are freely available at `http://martin-buchheit.net`.

It includes a printable roster for up to 25 players. For each player, outputs include adjusted distance, number of legs (= CODs + 1), total CODs, last leg distance (colour-coded orange when shorter than the shuttle length and green when equal or longer), equal leg distance (total distance divided equally across all legs), locomotor profile, distance reduction percentage, and auto-assigned group (based on a settable distance bucket, default 5m). The terminal shuttle rule is applied automatically. Both layout options (fixed shuttle + last leg and equal legs) are presented side by side so practitioners can choose the setup that best fits their pitch constraints. Designed for direct pitch-side use, though the spreadsheet should currently be considered a decision-support prototype pending empirical validation.

The squad sheet supports two prescription pathways: MAS + MSS pathway, using a target %ASR, and vIFT pathway, using a target %vIFT. When vIFT is entered for a player, this pathway takes priority automatically. Both pathways feed into the same COD correction formula.

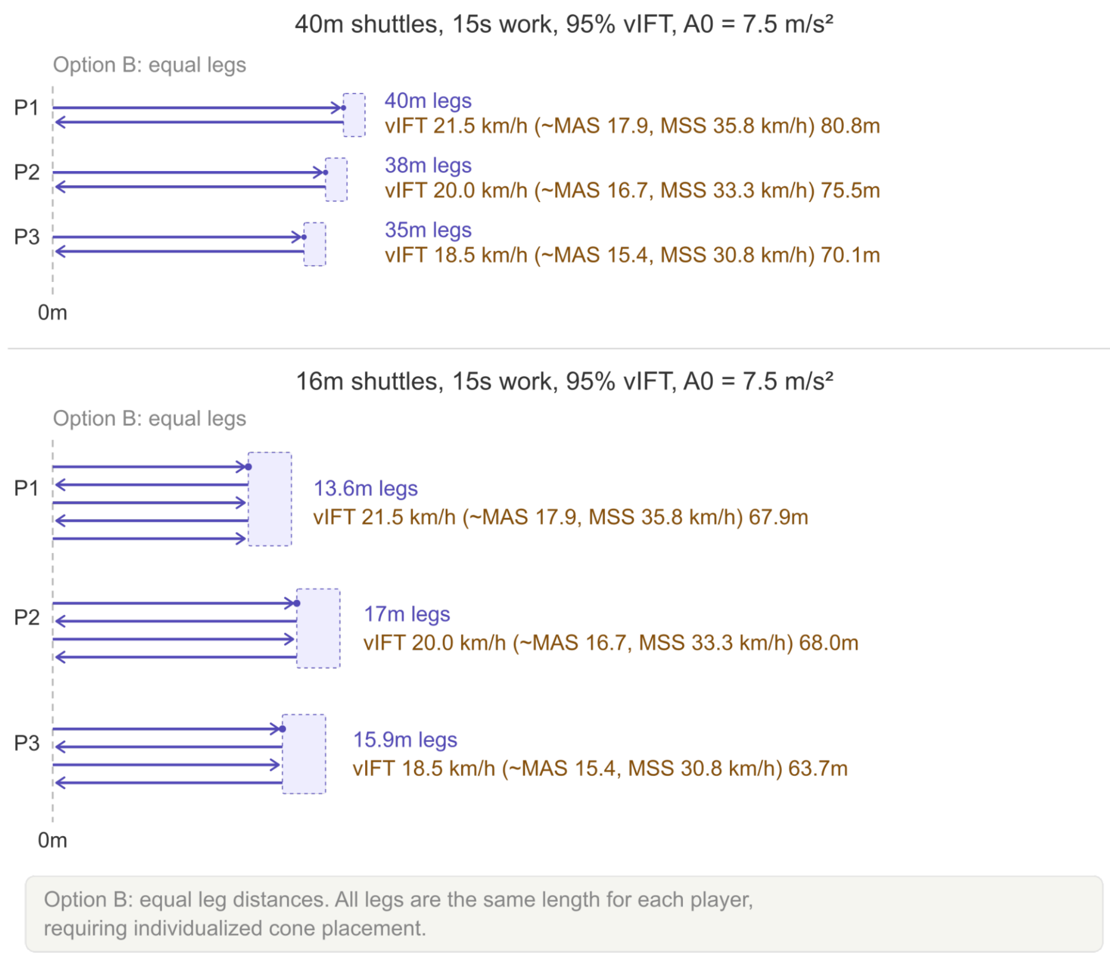

Fig. 9. Pitch layout for individualized shuttle HIIT prescription using Option B (equal leg distances), comparing 40 m (top) and 16 m (bottom) shuttles. Same three players and prescription parameters as Figure 8. In this layout, the total adjusted distance is divided equally across all legs, producing individualized cone placement for each player. At 40 m shuttles, equal legs range from 35 to 40 m. At 16 m shuttles, equal legs range from 13.6 m (P1, 5 legs) to 17.0 m (P2, 4 legs). Option B produces cleaner geometry but requires fully individualized cone placement, making it best suited for individual or small-group prescription settings.

The test-training shuttle length mismatch

With A0 = 7.5 m/s², the new model closely matches the 0.7 s rule, and the 30-15IFT-training mismatch is negligible for standard players. However, for players whose A0 differs from 7.5, the mismatch re-emerges because the fixed 0.7 s cannot adapt to individual braking capacity. The model corrects this by applying the player-specific t_{cod} at whatever shuttle length is used for training. The self-consistency of the old system holds well for standard players (A0 near 7.5), but breaks down for players with substantially different A0 values (Table 1).

The mechanism is straightforward: the 0.7s rule underestimates the true COD cost at speeds above ∼19 km/h, and this underestimation accumulates with each additional COD. At 40 m training shuttles, a typical 15s interval contains only 1-2 CODs, so the error remains small. At 20 m shuttles, the same interval contains 3 CODs, and at 10m shuttles, 6 or more. Each additional COD adds to the overprescription, which is why the mismatch grows disproportionately as shuttle length decreases.

This finding provides the strongest practical argument for the mechanistic model when used with vIFT-based prescription: it produces correct prescriptions regardless of shuttle length, whereas the old system is accurate only when test and training geometries match. For practitioners who routinely train with 20 m or shorter shuttles after testing with the 30-15IFT, the old system has been systematically over-prescribing distance, potentially inflating the true training intensity beyond the intended level.

Reconciling the new model with established vIFT-based prescription

An important consideration arises when applying the mechanistic model to vIFT-based prescription. The 30-15IFT itself uses the 0.7s per COD rule to compute the shuttle distances at each stage (the original spreadsheet for stage distance calculation is available at `http://martin-buchheit.net`). With $A0 = 7.5$ m/s^2, the model predicts t_{cod} values of 0.63s at 17 km/h, 0.72s at 19.5 km/h, and 0.83s at 22.5 km/h, closely tracking the original 0.7s rule across the typical speed range of the 30-15IFT. This near-equivalence explains why the old self-consistent system worked so well in practice.

For 20 years, practitioners have prescribed shuttle HIIT as a percentage of this vIFT (typically 90-100%) and applied the same 0.7s rule to compute training distances (Buchheit 2008, 2011). This created a self-consistent system: the 0.7s assumption at the test level and at the prescription level (especially using 40m shuttles) produced matching results. The resulting training distances produced the expected physiological responses, and the approach has been validated extensively in practice (Buchheit 2008, 2011).

With $A0 = 7.5$ m/s^2, the new model preserves this self-consistency. Adjustments are 0-3 percentage points for standard formats, meaning the old %vIFT values practitioners have been using remain essentially correct. The model's value for this pathway is therefore not in changing the percentages but in two other contributions: (a) individualizing for players whose A0 differs from 7.5 m/s^2 (Table 1, who receive a different t_{cod} and correspondingly different distances), and (b) making the underlying physics explicit so that practitioners can understand why the 0.7s worked and when it might not.

It is worth noting that a conceptually cleaner alternative exists. Recalculating the 30-15IFT stage distances using the mechanistic model would produce revised (higher) vIFT values for the same player. However, with $A0 = 7.5$, the recalculated values would be nearly identical to the current ones, precisely because t_{cod} closely matches 0.7s. This confirms that the test does not need to change. The old stage-distance spreadsheet served its purpose within the test, and continues to do so. What changes is only how we understand and extend the prescription, particularly for players whose A0 falls below the 7.5 m/s^2 default.

For the MAS + MSS pathway, this circularity does not arise. MAS is measured independently (continuous incremental test, time trial) with no COD involvement, and MSS from maximal sprints. The %ASR values used for prescription (typically 20-30%) can be applied directly with the new model without any conversion.

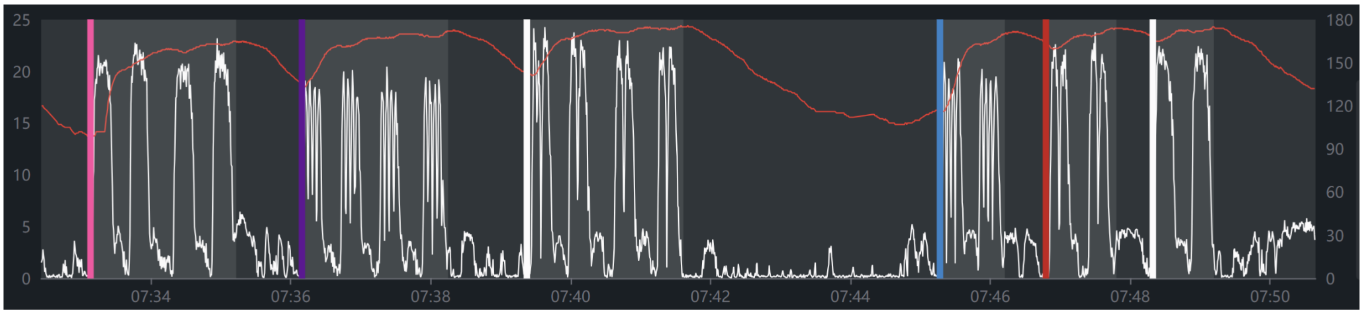

Fig. 10. Time course of running speed (white, left y-axis, km·h^{-1}) and heart rate (red, right y-axis, bpm) during the pilot session for one representative participant. Block 1: Linear run, 16 m shuttle, 40 m shuttle; passive rest (∼07:42-07:45); block 2: 16 m shuttle, 40 m shuttle, Linear run. The HR trace demonstrates the kinetic lag at session onset, justifying the use of the second Linear bout for HR extraction while the 16 m and 40 m shuttles were extracted from the first bout where HR had stabilized.

Pilot field-test data supporting the prescription approach

To provide initial empirical support for the proposed prescription framework, seven recreational team sport players (age: 36 ± 6 y) each completed three drill formats prescribed at 95% of individual vIFT using $A0 = 5$ m·s^{-2} at 100% utilization: a linear run (4 × 72-86 m), a 40 m shuttle (68-82 m), and a 16 m (63-68 m) shuttle. Heart rate was recorded throughout (WIMU PRO, RealTrack Systems, Spain), and individual HRmax was estimated as 220 minus age (Fox et al., 1971). Global RPE and neuromuscular RPE (RPE-NM, perceived "heaviness" in the lower limbs; McLaren et al., 2015; Buchheit & Laursen, 2026) were collected via self-report on the Borg CR-10 scale following the session.

The session was structured in two blocks: block 1 (Linear run, 16 m shuttle, 40 m shuttle) and block 2 (16 m shuttle, 40 m shuttle, Linear run), separated by passive rest (Figure 10). Because the first Linear run occurred at session onset before HR had reached steady state, the HR response for the Linear format was extracted from the second bout (end-of-session, HR fully primed). For the 16 m and 40 m shuttles, the longer first bout (∼125-135 s) was retained.

The cardiovascular response was remarkably similar across formats: group mean HR sat within 3 bpm (158-161 bpm, 86-87% HRmax) and peak HR converged at 91-93% HRmax (Table 4). However, the perceptual responses revealed a clear gradient. Global RPE increased from the Linear run (4.8 ± 1.3) to the shuttles (16 m: 6.0 ± 1.9; 40 m: 6.2 ± 1.5), and RPE-NM followed a more pronounced pattern: Linear 3.5 ± 0.5, 40 m 5.2 ± 1.2, 16 m 5.8 ± 1.8. On the Linear run, RPE-NM sat 1.3 points below global RPE, indicating a primarily cardiovascular effort. On the 16 m shuttle, RPE-NM nearly matched global RPE (difference: -0.2), suggesting the neuromuscular cost was the dominant perceptual feature. This is consistent with the strong correlation (r = -0.89) between RPE-NM and objective contractile cost reported in Buchheit and Laursen (2026).

This dissociation between HR and RPE responses confirms that the prescription model successfully equated cardiovascular demand while the neuromuscular cost remained drill-geometry dependent. From a practical standpoint, the three formats can be used interchangeably to deliver a target cardiovascular dose, with shuttle length serving as a lever to modulate the neuromuscular stimulus independently (Buchheit & Laursen 2019). These findings should be interpreted as pilot-level evidence given the small sample, the absence of lactate or VO2 measurements, the reliance on age-predicted HRmax, and the use of a single session.

Table 4. Running distance correction in three players with identical speed profiles but different A0 values.

	Linear run (4 × 80 m)	16 m shuttle	40 m shuttle
HR mean (bpm)	161 ± 11	158 ± 16	160 ± 12
HR peak (bpm)	168 ± 11	171 ± 14	170 ± 10
%HRmax from mean (%)	87 ± 5	86 ± 8	87 ± 6
%HRmax from peak (%)	91 ± 5	93 ± 7	92 ± 5
Global RPE (0-10)	4.8 ± 1.3	6.0 ± 1.9	6.2 ± 1.5
RPE-NM (0-10)	3.5 ± 0.5	5.8 ± 1.8	5.2 ± 1.2

HR = heart rate; HRmax = 220 minus age (Fox et al., 1971); this estimate carries ~±10 bpm error and %HRmax values should be interpreted accordingly. vIFT = peak velocity at the end of the 30-15 Intermittent Fitness Test. RPE-NM = differential RPE focused on the neuromuscular system (McLaren et al., 2015; Buchheit & Laursen, 2026). HR for the Linear run was extracted from the second bout (HR at steady state); HR for the 16 m and 40 m shuttles from the first bout (longer duration, stable plateau). Values are mean ± SD.

Conclusion and practical applications

The mechanistic model presented here should be viewed as a simplified, explicit alternative to the empirical "0.7 s per COD" (Buchheit 2008, 2011) or "2-3% per COD" rules (Laursen & Buchheit 2019). Its main strengths are that it is transparent, closed-form, and able to incorporate speed, shuttle length, individual mechanical parameters, and a utilization ratio to account for different A0 measurement sources in a single expression.

The model's practical contributions can be summarized in three tiers. First, it reveals that the original 0.7s rule was not completely arbitrary but corresponds to the physics of a COD at ~19 km/h with A0 ~7.5 m/s², validating 20 years of practice while making the underlying assumptions explicit. Second, for vIFT-based prescription, the model corrects the previously unrecognized prescription error when training shuttle lengths differ from the 40m 30-15IFT geometry. Third, the model individualizes continuously based on each player's A0 and utilization ratio, with the largest impact when the effective A0 falls below 5-6.0 m/s², whether from genuinely lower capacity (youth, rehabilitation, indoor sport populations) or from applying a reduced utilization ratio to sub-maximal contexts.

Pilot field-test data from seven recreational team sport players performing linear, 40 m, and 16 m shuttle drills prescribed at 95% vIFT with A0 = 5 $m \cdot s^{-2}$ provide initial support: HR mean and peak were equivalent across the three formats (within 3 bpm), while RPE-NM tracked the acceleration-deceleration profile of each drill, with the 16 m shuttle rated highest (5.8 ± 1.8) and the Linear run lowest (3.5 ± 0.5). This confirms that the model equated cardiovascular demand while the neuromuscular cost remained drill-geometry dependent, consistent with the model's intended function. Further validation including lactate, VO2, and GPS-derived external load metrics in elite athletes is warranted to strengthen these preliminary observations.

An important limitation of the current model is that it addresses only 180° shuttle turns. In practice, many HIIT drills involve changes of direction at other angles (90°, 120°, 135°), which produce different deceleration demands, i.e., the player does not need to brake to a complete stop and the biomechanics of the reacceleration phase differ substantially (Hader et al. 2014, 2015). Extending the model to incorporate angle-dependent d_{turn} values, potentially using empirical scaling factors derived from GPS and advanced analysis (i.e., ADI; Buchheit, 2026) at various COD angles, represents a logical and practically important next step. Until such data are available, the 180° model should be considered a simplified upper-bound approximation, with smaller angles likely requiring proportionally less adjustment.

A related consideration is the initial acceleration from rest at the start of each work interval, which is not included in the model because it cancels between shuttle and straight-line running. This simplification may become less accurate for very short shuttles and work intervals, where non-steady phases dominate a larger portion of the bout.

Additionally, the model assumes constant acceleration and deceleration rates (A0), whereas in reality, acceleration follows a force-velocity relationship and decreases as the player approaches higher speeds. However, A0 is used here as an effective average, consistent with how GPS systems report maximal acceleration capacity (a single value per player). Incorporating a full force-velocity profile would require multiple parameters per player and a numerical solver, making the model less practical for field use without a meaningful gain in prescription accuracy given the other sources of uncertainty already present (GPS measurement noise, day-to-day variation, utilization ratio). For a comprehensive overview of available A0 values across measurement approaches, sports, and devices, see Table 1.

Overall, the present paper should be considered a conceptual and practical modelling proposal rather than a definitive prescription framework. Its value lies in making the assumptions explicit, offering a transparent alternative to rules of thumb, and generating testable predictions for future validation work.

Key points

- The time lost per COD is $t_{cod} = v/(2 \text{ x } A0_{brake}) + v/(2 \text{ x } A0_{accel})$, where A0 defaults to 7.5 m/s² (planned turns at full braking capacity, 100% utilization). At v = 5.41 m/s with A0 = 7.5, t_{cod} = 0.72s, matching the original 0.7s calibration.

- The prescription formula $d_{adjusted}$ = v x (t_{work} - n_{cod} x t_{cod}) preserves the time-subtraction structure of the original 0.7s rule while making the correction individualized and speed-dependent.
- MAS + MSS prescription pathway: At A0 = 7.5 m/s² with 100% utilization, the model matches the old 0.7s rule; at lower A0 or reduced utilization, corrections are larger and individualized.
- vIFT prescription patway: At A0 = 7.5 m/s² with 100% utilization, the old %vIFT values remain essentially unchanged (0-3pp adjustment). The model's value for this pathway lies in individualizing for players with different A0 and correcting the test-training shuttle length mismatch.
- When switching between pathways, 100% vIFT corresponds approximately to 20% ASR, not 100% ASR. Practitioners should use this approximate equivalence to ensure comparable target speeds across prescription methods.
- The old self-consistent system (0.7s rule in both test and training) breaks down when training shuttle length differs from the 40m test geometry of the 30-15IFT, producing systematic overprescription of up to 15 percentage points at short shuttle lengths. The mechanistic model corrects this mismatch.
- Individualization based on A0 is continuous: all players receive individualized t_{cod} values, with the largest corrections for players whose A0 falls in the 4.0-5.5 m/s² range, common in youth, rehabilitation, and indoor sport populations.
- A0 can be sourced from in-situ acceleration-speed profiling (typically 6-8 m/s²), dedicated sprint testing (6-9 m/s²), or raw GPS session peaks (3.5-6 m/s²). These values differ due to measurement methodology, not player capacity (Table 1). The utilization ratio parameter in the spreadsheet bridges the gap: use 60-80% with profiling/testing values, or 100% with raw GPS peaks. Both converge on an effective rate of ∼4-5 m/s² during shuttle HIIT.
- A new spreadsheet and companion web tool are freely available at `http://martin-buchheit.net`. They implement the full model with a printable squad prescription sheet for pitch-side use, but should currently be considered a hypothesis-guided tool pending empirical validation.
- As a Sport Science 3.0 project, empirical validation against physiological responses during shuttle HIIT is the next priority. Pilot data from three drill formats (linear, 40 m, 16 m shuttles) prescribed at 95% vIFT with A0 = 5 m·s^{-2} (100% utilization) showed equivalent HR responses across formats (158-161 bpm mean, 86-87% HRmax), supporting the model's ability to equate cardiovascular demand across different shuttle geometries.
- Despite equivalent HR, RPE-NM differentiated the three formats (Linear 3.5, 40 m 5.2, 16 m 5.8), confirming that shuttle length modulates the neuromuscular stimulus independently of the cardiovascular dose. This positions drill geometry as a practical lever for controlling the mechanical signature of a session while maintaining a target internal load.

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