One box-to-box does not fit all - insights from running energetics

M. Buchheit 1,2,3,4, C. Vassallo 5, M. Waldron 5,6,7
1 HIITScience, Revelstoke, BC, Canada
2 Institute for Health and Sport, Victoria University, Melbourne, VIC, Australia
3 Kitman Labs, Performance Research Intelligence Initiative, Dublin, Ireland
4 French National Institute of Sport (INSEP), Laboratory of Sport, Expertise and Performance (EA 7370), Paris, France
5 Applied Sports, Technology, Exercise and Medicine (A-STEM), College of Engineering, Swansea University, Swansea, UK
6 School of Health and Behavioural Sciences, University of the Sunshine Coast, Queensland, Australia
7 Welsh Institute of Performance Science, Swansea University, Swansea, UK

Headline

There is a growing interest in programming generic (i.e., no ball involved) high-speed running (HSR) drills in most team sports, especially for those played over large spaces (e.g., soccer, rugby, field hockey, Australian Rules Football). Specific HSR sessions are, today, part of most microcycles and post-match HSR top-ups for substitutes or benched players are commonly adopted (Buchheit, 2019a). Also, monitoring the distance accumulated in these speed bands (> 19.8 km/h) with GPS has become the norm for every sports scientist and conditioning coach (Laursen & Buchheit, 2019). This stems from the increasing belief that HSR should be an integral part of players' preparation for both performance and injury mitigation strategies (Buchheit, 2019a).

HSR drills can be programmed with either a metabolic conditioning purpose (high-intensity interval training, HIIT, where fixed duration (13-15 s) runs are separated with short recovery periods < 30 s) or not ("tempo runs", 10-12 s with recovery periods > 45 s). For ease of implementation, these drills are regularly performed from one box to the other on the soccer pitch (box-to-box runs, from one penalty area to the other), with all players running together.

While these two types of box-to-box drills are likely efficient to get players to accumulate a substantial amount of HSR distance (> 600-1500 m) (Buchheit, 2019a), the fact that all players run together prevents a tight individualisation of their (external) mechanical work and in turn, their internal, energetic load. The consequence of this is that some players may not benefit from the fixed HIIT box-to-box drills as a conditioning stimulus, while others may be overloaded, with large levels of metabolic perturbation and associated increased (neuromuscular) fatigue.

Aim

Using a novel over-ground energetics model, to evaluate the mechanical and energetic cost of two commonly-used HSR drills in elite team sports: box-to-box and tempo runs. To provide insights into the importance of individualisation when it comes to programming these specific training drills, we modelled the anticipated responses of four simulated players with distinct locomotor profiles.

Design

Case-study of modelling over-ground running energetics on simulated athlete profiles to determine acute session responses

Four athlete profiles were constructed: 1) Fit and Fast; 2) Fit and Slow; 3) Less Fit and Fast; 4) Less Fit and Slow (Table 1). Each athlete underwent fixed HIIT (all together, same running distance), individualised HIIT (100% velocity achieved at end of 30-15 Intermittent Fitness Test; VIFT) and tempo runs on separate occasions. Sessions were volume-matched at 18 repetitions. Raw GPS velocity data were modelled to over-ground mechanical power using an energetics model. Responses to sessions were then evaluated accordingly.

Methods

Population

The four typical player locomotor profiles (Table 1) were based on their respective maximal aerobic speed (MAS) and maximal sprinting speed (MSS). Those profiles were believed to be representative of the possible distributions in elite soccer, with examples of the corresponding positions provided for context.

Table 1. Selected Player Profiles

	Speed Profile						Energetic Profile	
	MSS (km/h)	MAS (km/h)	ASR	V_{IFT} (km/h)	CS (km/h)	*D´* (m)	CP (W)	*W´* (kJ)
Fit and Fast (Full backs)	34.0	18.5	15.5	21.0	15.5	320	515	38.0
Fit and Slow (Midfield)	29.0	18.5	10.5	20.0	16.0	220	530	28.0
Less Fit and Fast (Central defenders, Attackers)	35.0	16.0	19.0	19.5	13.2	350	440	42.0
Less Fit and Slow	30.0	16.0	14.0	18.5	13.8	300	460	32.0

Notes: MSS = maximal sprinting speed; MAS = maximal aerobic speed; ASR = anaerobic speed reserve; VIFT= velocity achieved upon termination of the 30-15 Intermittent Fitness Test; CS = critical speed; D´ = finite distance capacity above CS; CP = critical power; W´ = finite work capacity above CP.

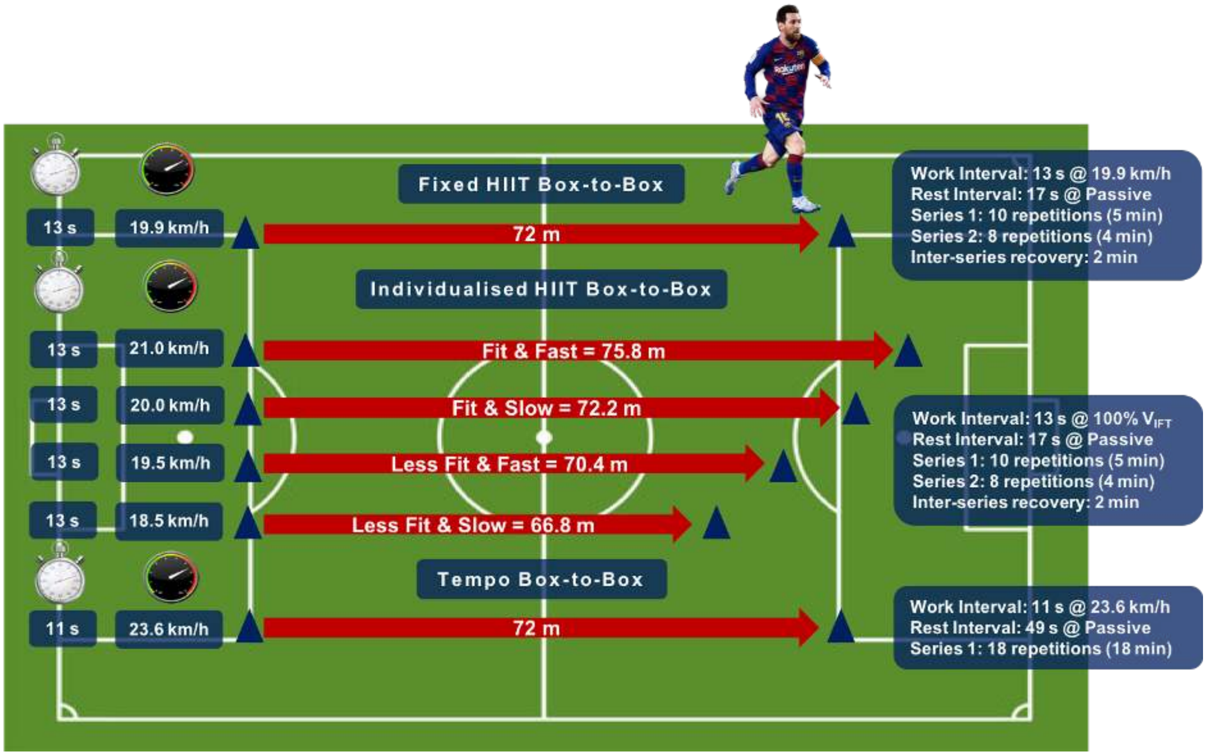

Figure 1. Detailed running prescriptions for the four-player locomotor profiles when programming fixed HIIT box-to-box runs, individualised HIIT box-to-box runs or tempo box-to-box runs.

Speed and Energetic Parameters

The players' two locomotor speeds, i.e., maximal aerobic speed (MAS) and maximal sprinting speed (MSS) permitted quantification of the anaerobic speed reserve (ASR) (Sandford et al., 2018). Their 30-15 Intermittent Fitness Test performance (VIFT) (Buchheit, 2008) was also provided. The critical speed (CS), finite distance capacity (D′, "D-prime"), critical power (CP) and finite work capacity (W′, "W-prime") completed a comprehensive speed and energetic locomotor player profile.

The CS/CP and W′/D′ are two mathematically derived parameters that integrate respiratory, metabolic and contractile physiological profiles (Poole et al., 2016), suggested to be important to the application of intermittent sport, such as football (Jones & Vanhatalo, 2017).

The CS (m/s) or CP (W) has been identified as the 'gold standard' of the maximal metabolic steady state, a critical fatigue threshold reflecting the highest work rate sustained by oxidative metabolism (Jones et al., 2019). The D′ or W′ is the finite distance (m) or work capacity (kJ) available above the CS or CP, respectively. Full depletion of W′ has been shown to be coincident with exhaustion in cycling (Skiba et al., 2012; Townsend et al., 2017) and flat over-ground intermittent running (Vassallo et al., 2020), largely attributable to the attainment of a "critical" metabolic milieu (i.e. ↑ intramuscular metabolites, ↑ blood lactate, ↑ $\dot{V}O_2$ slow component, ↓ muscle Ph, ↓ glycogen, ↓ PCr) (Chidnok et al., 2013). The W′ is thus predictive of supra-CP work capacity in the severe-intensity exercise domain, with direct application to HIIT. When mechanical power output is > CP, W′ is expended;

when power output is < CP, W′ is reconstituted, such that the balance of W′ remaining (W′BAL) may be quantified at any point in time (Skiba et al., 2012, 2015).

Box-to-box running drills examined (Figure 1)

● Fixed HIIT box-to-box (runs in 13 s, interspersed with 17 s of recovery)
○ Distance = 72 metres
● Individualised HIIT box-to-box @ 100% VIFT (runs in 13 s, interspersed with 17 s of recovery)
○ Fit and Fast = 75.8 metres
○ Fit and Slow = 72.2 metres
○ Less Fit and Fast = 70.4 metres
○ Less Fit and Slow = 66.8 metres
● Tempo box-to-box runs (runs in 11 s, interspersed with 49 s of recovery)
○ Distance = 72 metres

Volume of work

● Fixed and individualised HIIT box-to-box runs:
○ Series 1 = 10 repetitions
○ Between-series recovery = 2 min
○ Series 2 = 8 repetitions
● Tempo box-to-box runs:
○ 18 repetitions in one series

Modelling GPS derived velocity to over-ground mechanical power

Raw velocity data were exported and sampled in Microsoft Excel. From this, estimations of work done were performed using an energetics model previously applied to team sports (Gray et al., 2018, 2020). By drawing upon principles of the work-energy theorem, this model assumes the runner as a multi-segment system of stature and mass, whereby metabolic energy demand is determined by the summation of total mechanical work, partitioned into external work and internal work. External work is further calculated into horizontal (negative and positive) and vertical (negative and positive) planes, reflecting the degree to which the centre of mass (COM) is accelerated/decelerated and raised/lowered, respectively (Cavagna et al., 1964). The final component of external work consists of overcoming air resistance (di Prampero, 1986). Internal work reflects work done to swing the limbs with each step (Minetti, 1998). In the absence of uneven terrain, varying loads or changes in wind direction and speed, limb mechanics are tightly coupled with forward velocity in running (Gray et al., 2018; 2020). Thus, with knowledge of forward running velocity, total mechanical work was summed to ascertain total energy expenditure (J), from which over-ground mechanical power (W) was derived by dividing total mechanical work from GPS device sampling duration.

Results

The three mechanical and energetic simulations for the four-player locomotor profiles are shown in Figure 2 (fixed HIIT box-to-box runs), 3 (individualised HIIT box-to-box runs), and 4 (tempo box-to-box runs).

External load responses

All three box-to-box running drills allowed players to cover between 1200-1300 m of total distance and 500-800 m in the HSR (> 19.8 km/h) zones.

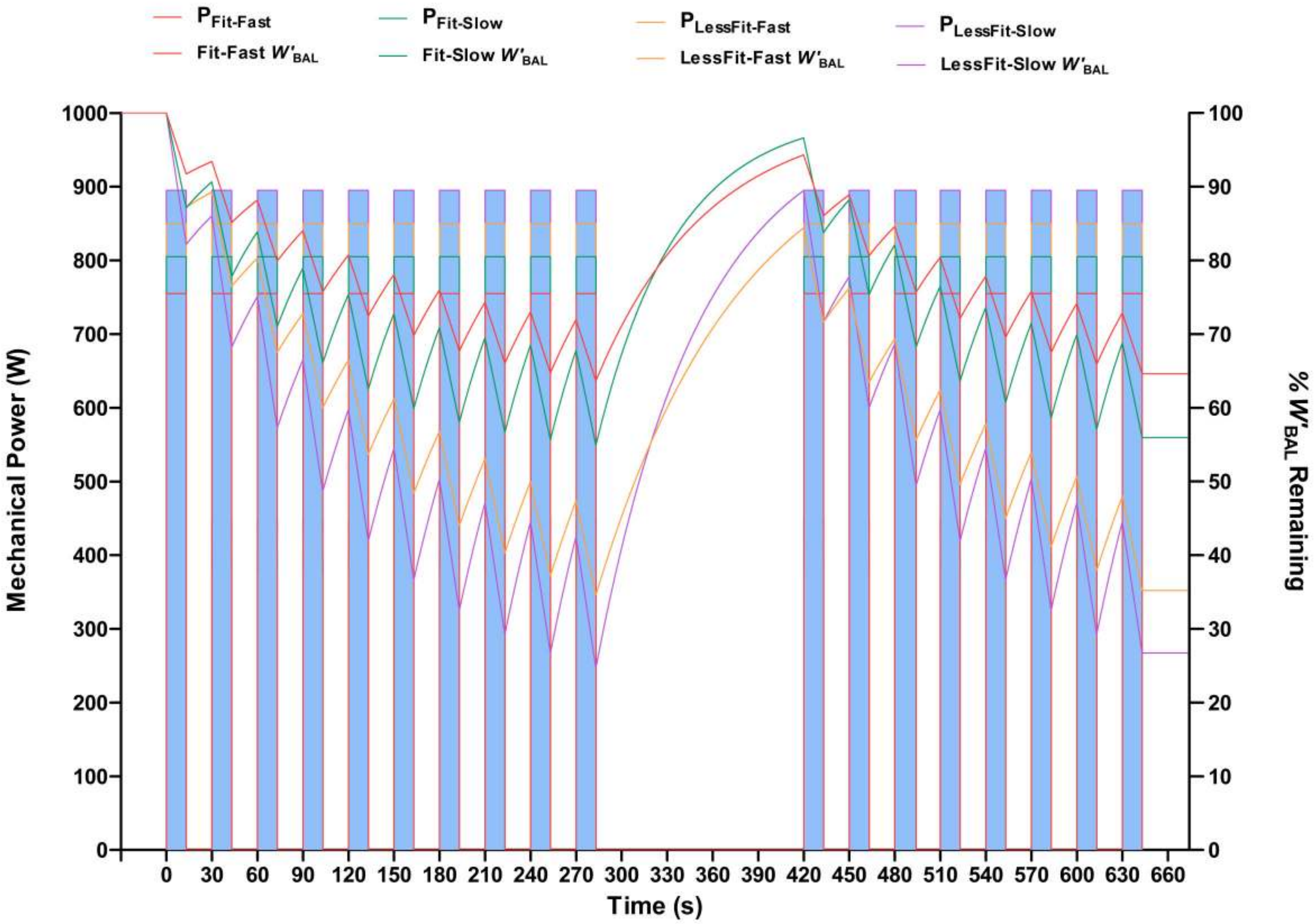

Figure 2. Fixed HIIT box-to-box consisting of 72 m runs in 13 s, interspersed by 17 s for series 1 (10 repetitions) and series 2 (8 repetitions), with 2 min recovery between series. External mechanical power output (P) and balance of remaining W′ (W′BAL), expressed in relative %, is displayed for all four athlete profiles. Note how despite the fixed running speed (19.9 km/h), there exist differences in over-ground mechanical power output accounting for the influence of body mass and stature (i.e. varied player profile) on work done during each work interval. When P is > CP, W′ is expended; when P is < CP, W′ is reconstituted, such that the balance of W′ remaining (W′BAL) was quantified across the HIIT session. Note also the influence of higher critical power (i.e. aerobic 'fitness') on the between-series recovery kinetics of W′. Fixed HIIT produced large disparity in inter-individual responses.

Internal load responses

There were very large between-player profile differences in W′ depletion with the fixed HIIT box-to-box runs (Figure 2 and Table 2), i.e., with Fit & Fast and Less Fit & Slow players finishing with 65% and 27% of their W′BAL, respectively. In contrast, with the individualised HIIT prescription, all player profiles finished within the same level of W′ depletion (approx 40% for all, Figure 3 and Table 2).

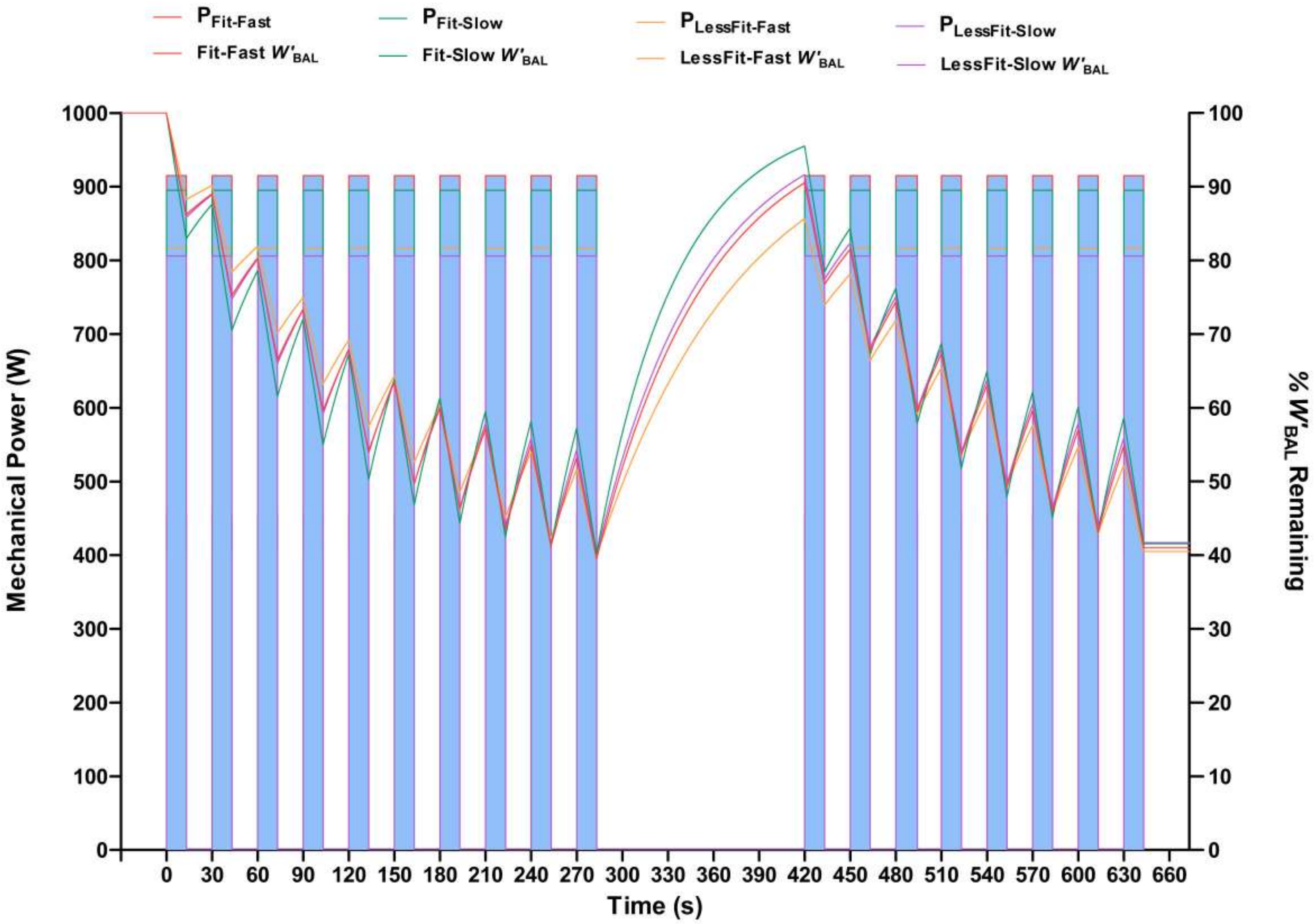

Figure 3. Individualised HIIT box-to-box at 100% VIFT. Runs in 13 s, interspersed by 17 s for series 1 (10 repetitions) and series 2 (8 repetitions), with 2 min recovery between series. For each athlete profile, speed (100% VIFT) was modelled into external mechanical power output (P) using the over-ground running energetics model. Balance of remaining W′ (W′BAL), expressed in relative %, is displayed for all four athlete profiles. When P is > CP, W′ is expended; when P is < CP, W′ is reconstituted, such that the balance of W′ remaining (W′BAL) was quantified across the HIIT session. Individualised HIIT achieved a homogeneous internal response for all four athlete profiles.

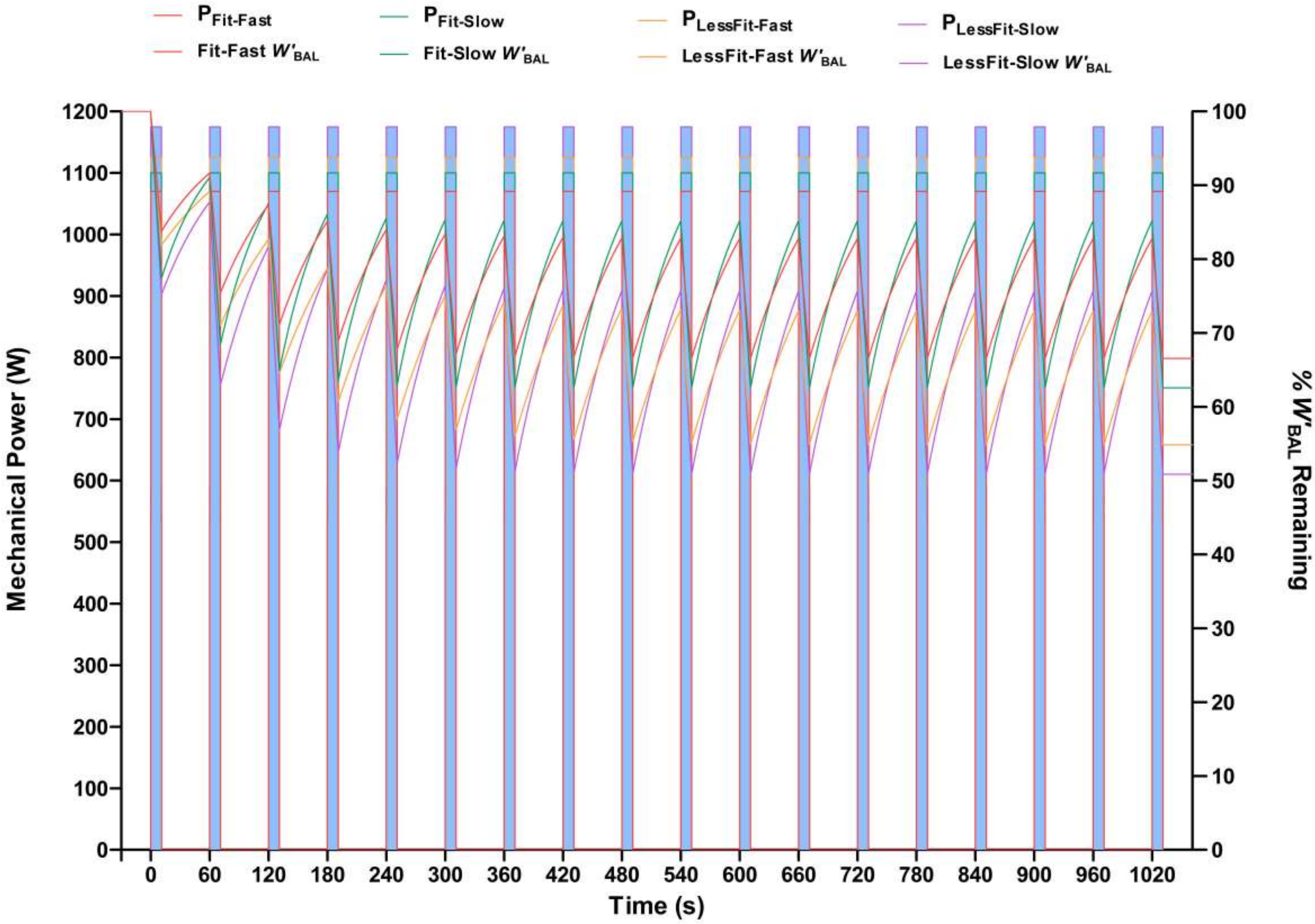

Figure 4. Tempo box-to-box runs consisting of 72 m runs in 11 s, interspersed by 49 s for a total volume of 18 repetitions. External mechanical power output (P) and balance of remaining W´ (W´BAL), expressed in relative %, is displayed for all four athlete profiles. Note how despite the fixed running speed (23.6 km/h), there exist differences in over-ground mechanical power output accounting for the influence of body mass and stature (i.e. varied player profile) on work done during each work interval. Note also the preservation of W´BAL (> 50%) and reduction of metabolic stress induced across all four profiles, with the accompanying larger mechanical power outputs likely eliciting greater neuromuscular load.

Discussion

The first observation from the present study was that when players with different locomotor profiles performed similar, fixed HIIT box-to-box runs, they presented with very large differences in internal energetic responses. While some of them finished their series with their W´ almost unaffected, for others, it approached near-severe depletion (Figure 2 and Table 2).

Table 2. Balance of remaining W´ (W´BAL) expressed in relative % for all four player profiles at the end of each series for each box-to-box drill.

	Fixed HIIT		Individualised HIIT		Tempo Runs
	Series 1 (% W'_{BAL})	Series 2 (% W'_{BAL})	Series 1 (% W'_{BAL})	Series 2 (% W'_{BAL})	Series 1 (% W'_{BAL})
Fit and Fast	63.7	64.7	39.6	41.1	66.7
Fit and Slow	55.0	56.1	40.3	41.7	62.8
Less Fit and Fast	34.7	35.3	40.0	40.5	55.0
Less Fit and Slow	24.8	26.9	40.2	41.8	51.1

When individualising the distance of the runs based on players' individual locomotor profiles (Figure 3 and Table 2); however, the magnitude of W´ depletion and the likely associated metabolic demands and neuromuscular fatigue were very similar. This lends support to the principle of exercise intensity individualisation to induce homogeneous physiological responses and, in turn, more precise and efficient training stimulus (Buchheit, 2008; Laursen & Buchheit, 2019).

While this is regularly seen in today's football (mainly after matches as part of the substitutes compensation workout), the present results question this current fixed practice that consists of having all players run together during box-to-box drills. The direct consequences of not individualising running drills are various, with some players receiving insufficient metabolic load, and others completing the drills in an advanced state of both metabolic stress and neuromuscular fatigue. In short, while the individualised approach allows practitioners to target specific biological systems, i.e., both the aerobic and anaerobic metabolic systems, and neuromuscular system consecutive to the 500-800 m of HSR (considered as Type 4 HIIT format following the HIIT science classification) (Laursen & Buchheit, 2019), it remains unclear what the contribution of these biologic systems is when using the fixed box-to-box approach (and which HIIT Type they fit in). This complicates, rather than helping to solve the training plan, since the aim is generally to manage the individual within the team, avoid excessive differences in load (e.g., starters vs. substitutes) and compensate their load accordingly at the individual level.

The modelling of responses to the Tempo box-to-box runs (Figure 4) showed that this method allows preservation of the W´ for all locomotor profiles (i.e., >50% for all, Table 2), and suggests that these types of drills lack sufficient metabolic stress to be classified as HIIT. In fact, HIIT is generally defined as exercise eliciting at least 90% of maximal oxygen uptake (Midgley & Mc Naughton, 2006), which often occurs during intermittent exercise with substantial concomitant W´ depletion (Chidnok et al., 2012; Skiba et al., 2012). Therefore, Tempo runs should be used to accumulate HSR, but not necessarily as a metabolic conditioning tool. Following the HIIT science classification, they are likely Type 6 (high neuromuscular load, but moderate aerobic and anaerobic responses). Of interest, since both the HIIT and Tempo run drills included 18 repetitions, the total distance ran at high speed (above 19.8 km/h) was similar (500-

800m); in reality however the peak speeds reached were likely higher for the Tempo (24-26 km/h) compared with the HIIT (20-24 km/h) runs. Overall, this suggests that Tempo runs could be used as an alternative to the other box-to-box drills when accumulation of HSR is required, but without a metabolic conditioning objective (rehab players, congested fixtures, etc.).
Finally, it is worth commenting on the timing of implementation of these box-to-box running drills (e.g. pre-, intra- or post-session) (Buchheit, 2019b). The internal energetic responses (Table 2) were modelled with all four profiles starting at 100% W´BAL, which is consistent with a scenario where drills are prescribed either at the beginning of the session or as a post-match HSR top-up for benched players (i.e. high degree of 'freshness'). The actual degree of metabolic perturbation reported (% W´BAL depletion) may therefore be greater for HIIT drills programmed later in the session, having undergone prior W´ depletion.

Practical applications

● Practitioners choosing to have all players run together during fixed box-to-box runs, irrespective of their metabolic profile, expose them to varying metabolic responses and neuromuscular loads. This is likely to be problematic at many levels, since it does not guarantee optimal player development, adding unnecessary fatigue to some (only) players.

● Prescribing individualised HIIT using players' locomotor profile and/or the VIFT allows a tight individualisation of exercise intensity, and in turn, provides a homogeneous and optimal metabolic and neuromuscular load to all players.

● Tempo runs should be used as a useful tool to accumulate HSR - this makes them a good alternative to HIIT in specific situations when metabolic conditioning is not the objective.

Limitations

The present results are limited to modelled data; whether real players with similar locomotor profiles as those examined here would display the exact same responses remains to be determined.

References

1. Buchheit, M. (2008). The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. Journal of Strength and Conditioning Research, 22(2), 365–374. https://doi.org/10.1519/jsc.0b013e3181635b2e

2. Buchheit, M. (2019a). Managing high-speed running load in professional soccer players: The benefit of high-intensity interval training supplementation. Sport Performance & Science Reports, March 53 (V1), 1-5.

3. Buchheit, M. (2019b). Programming high-speed running and mechanical work in relation to technical contents and match schedule in professional soccer. Sport Performance & Science Reports, July 69 (V1), 1-3.

4. Cavagna, G. A., Saibene, F. P., & Margaria, R. (1964). Mechanical work in running. Journal of Applied Physiology, 19, 249–256. https://doi.org/10.1152/jappl.1964.19.2.249

5. Chidnok, W., Dimenna, F. J., Bailey, S. J., Vanhatalo, A., Morton, R. H., Wilkerson, D. P., & Jones, A. M. (2012). Exercise tolerance in intermittent cycling: application of the critical power concept. Medicine and Science in Sports and Exercise, 44(5), 966–976. https://doi.org/10.1249/MSS.0b013e31823ea28a

6. Chidnok, W., Fulford, J., Bailey, S. J., Dimenna, F. J., Skiba, P. F., Vanhatalo, A., & Jones, A. M. (2013). Muscle metabolic determinants of exercise tolerance following exhaustion: relationship to the "critical power". Journal of Applied Physiology (1985), 115(2), 243–250. https://doi.org/10.1152/japplphysiol.00334.2013

7. Di Prampero, P. E. (1986). The energy cost of human locomotion on land and in water. International Journal of Sports Medicine, 7(2), 55–72. https://doi.org/10.1055/s-2008-1025736

8. Gray, A. J., Shorter, K., Cummins, C., Murphy, A., & Waldron, M. (2018). Modelling Movement Energetics Using Global Positioning System Devices in Contact Team Sports: Limitations and Solutions. Sports Medicine, 48(6), 1357–1368. https://doi.org/10.1007/s40279-018-0899-z

9. Gray, A., Andrews, M., Waldron, M., & Jenkins, D. (2020). A model for calculating the mechanical demands of overground running. Sports Biomechanics, 1–22. https://doi.org/10.1080/14763141.2020.1795238

10. Jones, A. M., & Vanhatalo, A. (2017). The 'critical power' concept: Applications to sports performance with a focus on intermittent high-intensity exercise. Sports Medicine, 47(1), 65–78. https://doi.org/10.1007/s40279-017-0688-0

11. Jones, A. M., Burnley M., Black, M. I., Poole, D. C., & Vanhatalo, A. (2019) The maximal metabolic steady state: redefining the 'gold standard'. Physiological Reports, 7(10), 1-16. https://doi.org/10.14814/phy2.14098

12. Laursen, P. B., & Buchheit, M. (Eds.). (2019). Science and Application of High-Intensity Interval Training. Human Kinetics.

13. Midgley, A. W., & Mc Naughton, L. R. (2006). Time at or near VO2max during continuous and intermittent running. A review with special reference to considerations for the optimisation of training protocols to elicit the longest time at or near VO2max. The Journal of Sports Medicine and Physical Fitness, 46(1), 1–14.

14. Minetti, A. E. (1998). A model equation for the prediction of mechanical internal work of terrestrial locomotion. Journal of Biomechanics, 31(5), 463–468. https://doi.org/10.1016/s0021-9290(98)00038-4

15. Poole, D. C., Burnley, M., Vanhatalo, A., Rossiter, H. B., & Jones, A. M. (2016) Critical power: An important fatigue threshold in exercise physiology. Medicine and Science in Sports and Exercise, 48(11), 2320–2334. https://doi.org/10.1249/mss.0000000000000939

16. Sandford, G. N., Kilding, A. E., Ross, A., & Laursen, P. B. (2019). Maximal Sprint Speed and the Anaerobic Speed Reserve Domain: The Untapped Tools that Differentiate the World's Best Male 800 m Runners. Sports Medicine, 49(6), 843–852. https://doi.org/10.1007/s40279-018-1010-517.

17. Skiba, P. F., Chidnok, W., Vanhatalo, A., & Jones, A. M. (2012). Modeling the expenditure and reconstitution of work capacity above critical power. Medicine and Science in Sports and Exercise, 44(8), 1526–1532. https://doi.org/10.1249/MSS.0b013e3182517a80

18. Skiba, P. F., Fulford, J., Clarke, D. C., Vanhatalo, A., & Jones, A. M. (2015). Intramuscular determinants of the ability to recover work capacity above critical power. European Journal of Applied Physiology, 115(4), 703–713. https://doi.org/10.1007/s00421-014-3050-3

19. Townsend, N. E., Nichols, D. S., Skiba, P. F., Racinais, S., & Périard, J. D. (2017). Prediction of critical power and W' in hypoxia: Application to work-balance modelling. Frontiers in Physiology, 8(180), 1-9. https://doi.org/10.3389/fphys.2017.00180

20. Vassallo, C., Gray, A., Cummins, C., Murphy, A., & Waldron, M. (2020). Exercise tolerance during flat over-ground intermittent running: Modelling the expenditure and reconstitution kinetics of work done above critical power. European Journal of Applied Physiology, 120(1), 219–230. https://doi.org/10.1007/s00421-019-04266-8

Acknowledgements

The first author would like to express thanks towards Rainer Schrey, proponent of fixed box-to-box runs; without him this project would not have been instigated.

Twitter Handle

@mart1buch
@cvassallocv
@MarkWaldron13

Copyright: The articles published on Science Performance and Science Reports are distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.