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Research article

Does "Live High-Train Low (and High)" Hypoxic Training Alter Running Mechanics In Elite Team-sport Players?

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Abstract
This study aimed to investigate if "Live High-Train Low (and High)" hypoxic training alters constant-velocity running mechanics. While residing under normobaric hypoxia (≥14 h·d^{-1}; FiO_2 14.5-14.2%) for 14 days, twenty field hockey players performed, in addition to their usual training in normoxia, six sessions (4 × 5 × 5-s maximal sprints; 25 s passive recovery; 5 min rest) under either normobaric hypoxia (FiO_2 ~14.5%, n = 9) or normoxia (FiO_2 20.9%, n = 11). Before and immediately after the intervention, their running pattern was assessed at 10 and 15 km·h^{-1} as well as during six 30-s runs at ~20 km·h^{-1} with 30-s passive recovery on an instrumented motorised treadmill. No clear changes in running kinematics and spring-mass parameters occurred globally either at 10, 15 or ~20 km·h^{-1}, with also no significant time × condition interaction for any parameters ($p > 0.14$). Independently of the condition, heart rate (all $p < 0.05$) and ratings of perceived exertion decreased post-intervention (only at 15 km·h^{-1}, $p < 0.05$). Despite indirect signs for improved psycho-physiological responses, no forthright change in stride mechanical pattern occurred after "Live High-Train Low (and High)" hypoxic training.

Key words: Altitude training, repeated-sprint training, running mechanics, constant velocity runs, team sports, psycho-physiological responses.

Introduction

Although historically used by endurance athletes, altitude training has recently gained popularity in many professional team sports (Girard et al., 2013), and this has led to interest in its underpinning haematological and ventilatory adaptations (Chapman et al., 2014). Comparatively, the neuro-mechanical aspects of altitude training have almost never been explored. In the only available study, no changes in selected gait kinematic variables occurred following four weeks of "Live High-Train Low" (LHTL), where elite endurance runners benefited from the long hypoxic exposure and from the higher intensity of training at low altitude (Stickford et al., 2017). This later result is not surprising since athletes did not train at altitude. However, the influence of altitude training on running mechanics remains unexplored.

Repeated-sprint training in a short period of time (2-5 weeks) is an efficient and practical means for inducing small-to-large concurrent improvements in various components of fitness (*i.e.*, power, speed, repeated-sprint ability and high-intensity running performance) relevant to team sports (Taylor et al., 2015). Growing evidence indicates that repeated-maximal intensity exercise in hypoxia induces larger improvement in repeated-sprint ability than in normoxia (Brocherie et al., 2017a). The rationale behind repeated-sprint training in hypoxia is to cause such perturbations to the muscle metabolic milieu and ion homeostasis as to elicit favourable muscle tissue adaptations mediated by oxygen-sensing pathway (Brocherie et al., 2017b; Faiss et al., 2013a). This innovative training method is thought to be intensity- and fibre type- dependant since the recruitment of high-threshold motor units responsible for the production of power, but with a lower O_2 extraction, is a prerequisite of its effectiveness (Faiss et al., 2013b).

Previously, we proposed to combine different altitude training methods for maximizing the benefits and reducing the main drawbacks of each one (Millet et al., 2010). In elite team-sport athletes, for instance, living high and training near sea level except for few intense workouts at altitude ("Live High-Train Low and High"; LHTLH) maximized sport-specific aerobic fitness, repeated-sprint ability and specific transcriptional muscular responses (Brocherie et al., 2015; 2017b). While repeated sprints in hypoxia and normoxia are well tolerated psychologically and physiologically (Brocherie et al., 2017c), severe hypoxia (~3600 m) is known to accentuate the inability to maintain the stride mechanical pattern (*i.e.*, incapacity to effectively apply forward-oriented ground reaction force and to maintain vertical stiffness and stride frequency) with repeated efforts (Brocherie et al., 2016), which may in turn influence the nature of training-induced adaptations in the running pattern.

Our aim was therefore to investigate if "Live High-Train Low (and High)" hypoxic training alters running mechanics at low-to-moderate (10-15 km·h^{-1}) constant-submaximal and high-intensity (~20 km·h^{-1}) intermittent velocities in elite team-sport athletes.

Methods

Participants

After being informed of the potential risks and benefits involved, twenty lowland elite male field-hockey players (age: 25.3 ± 4.6 years; stature: 1.78 ± 0.06 m; body mass: 75.8 ± 7.9 kg) provided their written consent to participate in this study. The experiment was approved by the

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Anti-Doping Lab Qatar institutional review board (Agreement SCH-ADL-070) and conformed to the current Declaration of Helsinki guidelines.

Experimental protocol

The experimental design as well as the main physiological and performance results has been reported previously (Brocherie et al., 2015). In addition to their usual field hockey practice, all participants undertook six repeated-sprint training sessions (at least 36 h apart) under either normobaric hypoxia (LHTLH; ~3000 m simulated altitude or FiO_2 ~14.5%, n = 9) or normoxia (LHTL; near sea level or FiO_2 20.9%, n = 11), while residing under normobaric hypoxic conditions (≥ 14 $h \cdot d^{-1}$ at 2800-3000 m simulated altitudes; FiO_2 14.5-14.2%), during a 14-d in-season training camp. Briefly, the repeated-sprint training routine included four sets of 5 × 5-s maximal sprints in alternating directions interspersed with 25 s of passive recovery and 5 min of standing rest between sets (Brocherie et al., 2015; 2017b). Training sessions were completed on an indoor synthetic grass inside a mobile inflatable simulated hypoxic equipment (Altitude Technology Solutions Pty Ltd, Brisbane, Queensland, Australia).

The main experimental session consisted of 5 min of running at 10 $km \cdot h^{-1}$, followed by 1 min each at 11, 12, 13, 14 and 15 $km \cdot h^{-1}$, then by 2-3 habituation runs of ~20 s at the target running velocity (115% of velocity associated with maximal oxygen uptake, vVO_{2max}). After 5 min of passive rest, participants undertook six, 30-s runs at 115% of each individual's vVO_{2max} (19.8 ± 0.7 and 20.0 ± 0.6 $km \cdot h^{-1}$ in LHTLH and LHTL $km.h^{-1}$, respectively), as estimated from the Yo-Yo Intermittent Recovery Level 2 field test conducted near sea level immediately before the intervention (Brocherie et al., 2015), with 30-s of passive recovery (quiet standing upright) between efforts (Girard et al., 2017). They ran on an instrumented motorised treadmill (ADAL3D-WR, Medical Development–HEF Tecmachine, France) in an indoor facility maintained at standard environmental conditions (~24ºC/45% of relative humidity). All participants had previous experience with treadmill running, as part of their regular maximal aerobic capacity assessment. Heart rate and ratings of perceived exertion were monitored exactly 10 s following each interval, respectively, via a wireless Polar monitoring system (Polar Electro Oy, Kempele, Finland) and the Borg 6-20 scale. Participants wore personal athletic training attire (T-shirt, shorts, socks, and running shoes) that was standardized throughout.

Mechanical variables

Mechanical data were continuously sampled at 1,000 Hz. After appropriate filtering (Butterworth-type 30 Hz low-pass filter), data were averaged over the support phase of each step (vertical force above 30 N). These data were completed by measurements of the main step kinematic variables: contact time (s), aerial time (s), step frequency (Hz) and step length (m). Vertical stiffness (K_{vert} in $kN \cdot m^{-1}$) was calculated as the ratio of peak vertical forces (Fz_{max} in N) to the maximal vertical downward displacement of centre of mass (Δz in m), which was determined by double integration of vertical acceleration of centre of mass over time during ground contact. Leg stiffness (K_{leg} in $kN \cdot m^{-1}$) was calculated as the ratio of Fz_{max} to the maximum leg spring compression (ΔL) ($\Delta z + L_0 - \sqrt{L_0^2 - [0.5 \times \text{running velocity} \times \text{contact time}]^2}$, in m), both occurring at mid-stance. Initial leg length (L_0, great trochanter to ground distance in a standing position) was determined from participant's stature as $L_0 = 0.53 \times$ stature. Finally, vertical mean loading rate was calculated as the mean value of the time-derivate of vertical force signal within the first 50 ms of the support phase, and expressed in body $weight \cdot s^{-1}$.

Data analysis and statistics

Mechanical data for all steps collected over a 20-s sampling period (from the 38th to 58th second of the 10 and 15 $km.h^{-1}$ runs and from the 8th to 28th second of each 30-s runs that were finally averaged for the six high-intensity intermittent bouts) were considered for subsequent analysis. Two-way ANOVA with repeated measures (Time [Before and After] × Condition [LHTLH and LHTL]), followed by Bonferroni post hoc comparisons, were performed at each speed. Partial eta-squared (η^2) was calculated as measures of effect size. The significance level was set at $P < 0.05$.

Results

No significant changes in running kinematics and spring-mass parameters - be it at 10 $km \cdot h^{-1}$ (Table 1), 15 $km \cdot h^{-1}$ (Table 2) or during the high-intensity (~20 $km.h^{-1}$) intermittent (Table 3) runs - occurred globally (i.e., in both groups) after compared to before the intervention. Furthermore, no time × condition interaction was found for any mechanical parameter (lowest p value of 0.14, 0.22 and 0.22 for 10 $km \cdot h^{-1}$, 15 $km \cdot h^{-1}$ and intermittent runs, respectively). Independently of the condition, heart rate (all $p < 0.05$) and ratings of perceived exertion (only at 15 $km \cdot h^{-1}$, $p < 0.05$) decreased post-intervention.

Discussion

The main finding of this study was a lack of significant change in running mechanics after either a 14-d LHTL or LHTLH period, whether at constant low-to-moderate velocities (10-15 $km \cdot h^{-1}$) or during high-intensity (~20 $km \cdot h^{-1}$) intermittent runs. This occurred despite physiological (heart rate) and to a lesser extent perceptual (RPE) responses being improved.

Although higher K_{vert} (10 $km \cdot h^{-1}$) and lower vertical oscillation (10 and 15 $km.h^{-1}$) values might reflect a more economical running style after the 14-d camp, the magnitude of these changes was quite small (<5%) and its potential relationship with changes in running economy is beyond the scope of the present study. To date, it is unknown if the improved economy seen in some studies (though not all) post-altitude training is partly caused by mechanical factors (Chapman et al., 2014). Of interest is that no change was observed at supra-maximal running velocities. This relative stability of the running pattern has previously been reported in response to various acute (*i.e.*, footwear, fatiguing exercise) or chronic (*i.e.*, verbal and visual feedback, gait re-training) interventions (*i.e.*, as reviewed by Moore, 2016). For example, both low (10 km·h^{-1}) and high (20 km·h^{-1}) constant-velocity running patterns were found unchanged from before to ~3 min after a repeated-sprint exercise, despite marked exercise-induced reductions in propulsive power (~20%) and knee extensor maximal strength (~30%) (Morin et al., 2012). Our results, together with those of Stickford et al., (2017), therefore suggest a robustness of sea-level running mechanical pattern in response to altitude training during constant-velocity exercises at low-to-moderate sub-maximal and supra-maximal intensities. However, whether the same also holds true during successive "all out" efforts is unknown. Despite performance decrements and neuro-mechanical adjustments were larger with increasing hypoxia severity during an initial set of repeated treadmill sprints, acute hypoxia had no residual effect during a subsequent set performed in normoxia after 6 min of rest near sea level (Girard et al., 2015). Altogether, the neuro-mechanical alterations after RSH were recovered shortly after resting in normoxia. Consequently, screening the running pattern of team-sport athletes during an actual repeated-sprints exercise under both normoxic and hypoxic conditions should form the basis of future studies.

Table 1. Constant low (10 km.h^{-1}) velocity running kinematics, spring-mass variables and psycho-physiological responses before and after the intervention in LHTL and LHTLH groups. Data are means (±SD).

	LHTL		LHTLH		ANOVA *P* value (η^2)		
	Before	After	Before	After	Group	Time	Interaction
Running kinematics							
Contact time (s)	.266 (.023)	.268 (.021)	.257 (.013)	.255 (.012)	.197 (*.09*)	.937 (*.00*)	.300 (*.06*)
Aerial time (s)	.106 (.030)	.100 (.027)	.104 (.013)	.100 (.012)	.909 (*.01*)	.078 (*.16*)	.744 (*.06*)
Step frequency (Hz)	2.70 (.16)	2.73 (.16)	2.78 (.14)	2.82 (.15)	.188 (*.09*)	**.046** (*.20*)	.665 (*.02*)
Step length (m)	1.03 (.06)	1.02 (.06)	1.00 (.05)	.99 (.05)	.192 (*.09*)	.078 (*.16*)	.917 (*.01*)
Dynamics and spring-mass characteristics							
Mean loading rate (BW·s^{-1})	43.2 (7.5)	41.8 (7.1)	44.4 (12.5)	43.0 (10.1)	.772 (*.01*)	.197 (*.09*)	.966 (*.00*)
Peak vertical forces (BW)	2.43 (.24)	2.39 (.22)	2.50 (.14)	2.44 (.12)	.513 (*.02*)	.061 (*.18*)	.575 (*.02*)
CoM vertical displacement (m)	.063 (.008)	.061 (.009)	.060 (.008)	.055 (.007)	.263 (*.07*)	**.012** (*.30*)	.208 (*.09*)
Leg compression (m)	.115 (.012)	.113 (.013)	.107 (.009)	.101 (.009)	.046 (*.20*)	**.033** (*.23*)	.140 (*.12*)
Vertical stiffness (kN·m^{-1})	30.3 (2.8)	31.1 (4.2)	32.2 (4.7)	34.4 (4.4)	.150 (*.11*)	**.021** (*.26*)	.273 (*.07*)
Leg stiffness (kN·m^{-1})	16.6 (2.2)	16.6 (2.3)	18.0 (2.9)	18.5 (2.6)	.151 (*.11*)	.345 (*.05*)	.199 (*.09*)
Psycho-physiological responses							
Heart rate (beats·m^{-1})	131 (11)	123 (8)	125 (14)	121 (11)	.431 (*.04*)	**.003** (*.41*)	.153 (*.11*)
RPE (points)	6.8 (1.0)	7.7 (2.0)	7.2 (.8)	7.4 (1.4)	.905 (*.00*)	.125 (*.13*)	.341 (*.05*)

BW: Body weight, CoM: Center of mass vertical displacement, RPE: Ratings of perceived exertion

Table 2. Constant moderate (15 km.h^{-1}) velocity running kinematics, spring-mass variables and psychophysiological responses before and after the intervention in LHTL and LHTLH groups. Data are means (±SD).

	LHTL		LHTLH		ANOVA *P* value (η^2)		
	Before	After	Before	After	Group	Time	Interaction
Running kinematics							
Contact time (s)	.218 (.016)	.215 (.015)	.204 (.013)	.203 (.012)	.056 (*.19*)	.110 (*.14*)	.346 (*.05*)
Aerial time (s)	.137 (.017)	.134 (.017)	.141 (.015)	.140 (.014)	.461 (*.03*)	.400 (*.04*)	.666 (*.01*)
Step frequency (Hz)	2.82 (.17)	2.87 (.16)	2.91 (.19)	2.92 (.18)	.384 (*.04*)	.124 (*.12*)	.442 (*.03*)
Step length (m)	1.48 (.09)	1.45 (.08)	1.44 (.10)	1.43 (.09)	.444 (*.03*)	.074 (*.17*)	.287 (*.06*)
Dynamics and spring-mass characteristics							
Mean loading rate (BW·s^{-1})	65.3 (13.9)	65.0 (15.6)	66.8 (15.8)	63.6 (12.4)	.994 (*.00*)	.419 (*.04*)	.497(*.03*)
Peak vertical forces (BW)	2.79 (.18)	2.72 (.17)	2.90 (.19)	2.88 (.14)	.080 (*.16*)	.140 (*.18*)	.364 (*.05*)
CoM vertical displacement (m)	.058 (.008)	.054 (.007)	.054 (.008)	.052 (.006)	.328 (*.05*)	**.047** (*.20*)	.429 (*.04*)
Leg compression (m)	.145 (.018)	.150 (.023)	.129 (.011)	.127 (.009)	.367 (*.05*)	.773 (*.05*)	.367 (*.05*)
Vertical stiffness (kN·m^{-1})	38.2 (4.8)	39.3 (4.3)	41.8 (5.6)	42.7 (5.1)	.110 (*.14*)	.223 (*.08*)	.849 (*.01*)
Leg stiffness (kN·m^{-1})	15.1 (1.7)	14.2 (1.5)	17.2 (2.1)	17.3 (2.0)	**.002** (*.41*)	.402 (*.04*)	.219 (*.08*)
Psycho-physiological responses							
Heart rate (beats·m^{-1})	171 (10)	165 (8)	167 (11)	165 (13)	.630(*.01*)	**.034** (*.23*)	.196 (*.09*)
RPE (points)	13.4 (1.6)	12.3 (1.1)	13.4 (1.2)	12.8 (2.6)	.667 (*.01*)	**.035** (*.22*)	.589 (*.02*)

BW: Body weight, CoM: Center of mass vertical displacement, RPE: Ratings of perceived exertion

Given the co-variance of changes in running velocity and stride kinematics / spring-mass parameters, as evidenced here from substantial differences in mechanical values across the three tested velocities, implementing constant-submaximal runs was an appropriate methodological approach for the ease of pre-post intervention comparisons. This approach may, however, be challenged by the fact that, as previously reported in Brocherie et al., (2015), distance covered during the Yo-Yo intermittent recovery test, level 2 improved substantially (~20%) post-intervention.

In addition to well-developed physical fitness, the ability to withstand high levels of effort, pain and fatigue (*i.e.*, minimizing perceived fatigue) is paramount in order to reach the highest level of competitive proficiency in team sports (Enoka and Duchateau, 2016). Important findings of our study were also the pre-post training camp reduction in heart rate values and lower ratings of perceived exertion readings (albeit only significant at 15 km·h^{-1}) during constant-velocity runs, meaning that submaximal exercise tolerance was ameliorated. However, improvement in psycho-physiological responses was similar between conditions, which may relate to an effective hypoxic "acclimation" (Brocherie et al., 2017c).

Table 3. Average values during high-intensity intermittent treadmill runs velocity of running kinematics, spring-mass variables and psychophysiological responses before and after the intervention in LHTL and LHTLH groups. Data are means (±SD).

	LHTL		LHTLH		ANOVA *P* value (η^2)		
	Before	After	Before	After	Group	Time	Interaction
Running kinematics							
Contact time (s)	.179 (.010)	.179 (.010)	.172 (.011)	.170 (.012)	.127 *(.12)*	.262 *(.07)*	.225 *(.08)*
Aerial time (s)	.145 (.013)	.145 (.013)	.148 (.017)	.150 (.015)	.499 *(.03)*	.225 *(.08)*	.387 *(.04)*
Step frequency (Hz)	3.10 (.14)	3.10 (.14)	3.13 (.22)	3.13 (.21)	.667 *(.01)*	.836 *(.01)*	.912 *(.01)*
Step length (m)	1.79 (.10)	1.79 (.10)	1.76 (.10)	1.76 (.09)	.508 *(.03)*	.901 *(.00)*	.769 *(.00)*
Dynamics and spring-mass characteristics							
Mean loading rate (BW·s^{-1})	90.7 (17.2)	91.5 (16.1)	89.3 (17.7)	89.1 (13.8)	.800 *(.01)*	.865 *(.00)*	.775 *(.01)*
Peak vertical forces (BW)	2.93 (.18)	2.90 (.16)	3.05 (.18)	3.04 (.21)	.107 *(.14)*	.479 *(.03)*	.717 *(.01)*
CoM vertical displacement (m)	.045 (.005)	.045 (.005)	.044 (.007)	.043 (.006)	.724 *(.01)*	.292 *(.06)*	.724 *(.01)*
Leg compression (m)	.154 (.017)	.154 (.019)	.142 (.013)	.138 (.013)	**.048** *(.20)*	.358 *(.05)*	.422 *(.04)*
Vertical stiffness (kN·m^{-1})	50.8 (5.8)	50.7 (4.1)	53.2 (5.6)	54.1 (5.7)	.190 *(.09)*	.737 *(.01)*	.694 *(.01)*
Leg stiffness (kN·m^{-1})	15.0 (1.7)	14.7 (1.6)	16.6 (3.1)	17.0 (3.2)	.084 (.16)	.903 *(.00)*	.251 *(.07)*
Psycho-physiological responses							
Heart rate (beats·m^{-1})	179 (9)	174 (8)	174 (10)	173 (11)	.515 *(.02)*	**.044** *(.21)*	.162 *(.11)*
RPE (points)	14.9 (1.6)	14.3 (1.0)	14.7 (1.2)	14.3 (1.6)	.840 *(.00)*	.151 *(.11)*	.918 *(.00)*

BW: Body weight, CoM: Center of mass vertical displacement, RPE: Ratings of perceived exertion. Interval-training treadmill runs consisted of six 30-s runs at 115% of each individuals' velocity associated with maximal oxygen uptake (20.0 ± 0.6 and 19.8 ± 0.7 km·h^{-1} in LHTL and LHTLH groups with 30-s passive recovery on an instrumented treadmill.

Positive haematological (*i.e.*, increase in haemoglobin mass; Brocherie et al., 2015) and molecular (*i.e.*, HIF-1α and related transcriptional genes; Brocherie et al., 2017b) adaptations as a result of LHTL or LHTLH can make players more responsive to training when they return to sea level. If residence in normobaric hypoxia superimposed with repeated maximal-intensity hypoxic or normoxic exercise responses do not negatively affect constant-velocity running pattern (*i.e.*, neuro-mechanical factors) of tested players, our findings further point to a minimized perceived fatigue. Anecdotally, many distance runners report that they feel like they have lost turnover (*i.e.*, the sensation of feeling coordinated at fast running speeds) (Chapman et al., 2014), yet without providing any convincing reasons. Nevertheless, in our study, this "feel easier" perception post-altitude training intervention might result in a willingness to train harder when returning to sea level.

This study is not without limitations. First, we did not assess whether mechanical properties were actually altered during sprints completed during each of the six exercise training sessions. Second, the present study is limited by a lack of mechanical measurements performed several weeks after the end of the altitude camp. Gains in repeated-sprint ability are maintained 3-wk post LHTLH but not LHTL (Brocherie et al., 2015); however, the biomechanical mechanism(s) for this difference still needs to be determined. When determining the proper timing of return to sea level, it could be informative to investigate the time needed to help re-establish the neuromuscular sensation of having coordinated running mechanics at fast speeds (*i.e.*, sprinting) similar to competition (Chapman et al., 2014). Importantly, measurements of leg and vertical stiffness as well as related kinematic parameters during submaximal treadmill were found highly reliable across days (Pappas et al., 2014). In the present study, LHTLH and LHTL groups included 9 and 11 participants, respectively. Here, we acknowledge that sample size in the present larger study (Brocherie et al., 2015) was calculated on the basis of physiological parameters (*i.e.*, haemoglobin mass) and that there is a high variability in some other biomechanical parameters.

Conclusion

In summary, combination of hypoxic residence with repeated-sprints exercise in normobaric hypoxia or normoxia has no (or minimal) influence on constant-velocity running mechanics, while physiological (heart rate) and to a lesser extent perceptual (RPE) responses were improved.

Acknowledgements

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References

Brocherie, F., Girard, O., Faiss, R. and Millet, G.P. (2017a) Effects of repeated-sprint training in hypoxia on sea-level performance: a meta-analysis. *Sports Medicine* [Epub ahead of print]

Brocherie, F., Millet, G.P., D'Hulst, G., Van Thienen, R., Deldicque, L. and Girard, O. (2017b) Repeated maximal-intensity hypoxic exercise superimposed to hypoxic residence boosts skeletal muscle transcriptional responses in elite team-sport athletes. *Acta Physiologica (Oxford)* [Epub ahead of print]

Brocherie, F., Millet, G.P. and Girard, O. (2017c) Psycho-physiological responses to repeated-sprint training in normobaric hypoxia and normoxia. *International Journal of Sports Physiology and Performance* **12**, 115-123.

Brocherie, F., Millet, G. ., Hauser, A., Steiner, T., Rysman, J., Wehrlin, J.P. and Girard, O. (2015) "Live High-Train Low and High" hypoxic training improves team-sport performance. *Medicine and Science in Sports and Exercise* **47**, 2140-2149.

Brocherie, F., Millet, G. P., Morin, J-B. and Girard, O. (2016) Mechanical alterations to repeated treadmill sprints in normobaric hypoxia. *Medicine and Science in Sports and Exercise* **48**, 1570-1579.

Chapman, R.F., Laymon Stickford, A.S., Lundby, C. and Levine, B. (2014) Timing of return from altitude training for optimal sea level performance. *Journal of Applied Physiology* **116**, 837-843.

Enoka, R. and Duchateau, J. (2016) Translating fatigue to human performance. *Medicine and Science in Sports and Exercise* **48**, 2228-2238.

Faiss, R., Léger, B., Vesin, J.M., Fournier, P.E., Eggel, Y., Dériaz, O. and Millet, G.P. (2013a) Significant molecular and systemic adaptations after repeated sprint training in hypoxia. *PLoS One* **8**: e56522.

Faiss, R., Girard, O. and Millet, G.P. (2013b) Advancing hypoxic training in team sports: from intermittent hypoxic training to repeated sprint training in hypoxia. *British Journal of Sports Medicine* **47**, i45-50.

Girard, O., Amann, M., Aughey, R.J, Billaut, F., Bishop, D.J., Bourdon, P., Buchheit, M., Chapman, R., D'Hooghe, M., Garvican-Lewis, L.A., Gore, C.J., Millet, G.P., Roach, G.D., Sargent, C., Saunders, P.U., Schmidt, W. and Schumacher, Y.O. (2013) Position statement – altitude training for improving team-sport players' performance: current knowledge and unresolved issues. *British Journal of Sports Medicine* **47**, i8-i16.

Girard, O., Brocherie, F., Morin, J-B. and Millet, G.P. (2015) Neuro-mechanical determinants of repeated treadmill sprints - Usefulness of an "hypoxic to normoxic recovery" approach. *Frontiers in Physiology* **6,** 260.

Girard, O., Brocherie, F., Morin, J.B., and Millet, G.P. (2017) Mechanical alterations during interval-training treadmill runs in high-level male team-sport players. *Journal of Science and Medicine in Sport* **20**, 87-91.

Millet, G.P., Roels, B., Schmitt, L., Woorons, X. and Richalet, J.P. (2010) Combining hypoxic methods for peak performance. *Sports Medicine* **40**, 1-25.

Moore, I.S. (2016) Is there an economical running technique? A review of modifiable biomechanical factors affecting running economy. *Sports Medicine* **46**, 793-807.

Morin, J-B., Tomazin, K., Samozino, P., Edouard, P. and Millet, G.Y. (2012). High-intensity sprint fatigue does not alter constant-submaximal velocity running mechanics and spring-mass behavior. *European Journal of Applied Physiology* **112**, 1419-1428.

Pappas, P., Paradisis, G., Tsolakis, C., Smirniotou, A. and Morin, J. B. (2014) Reliabilities of leg and vertical stiffness during treadmill running. *Sports Biomechanics*, **13**, 391-399.

Stickford, A.S., Wilhite, D.P. and Chapman, R.F. (2017) Live high – train low altitude training does not alter running mechanics in elite distance runners. *International Journal of Sports Physiology and Performance* **12**, 133-136.

Taylor, J., Macpherson, T., Spears, I. and Weston, M. (2015) The effects of repeated-sprint training on field-based fitness measures: a meta-analysis of controlled and non-controlled trials. *Sports Medicine* **45**, 881-891.

Key points

- There are indirect signs for improved psycho-physiological responses in responses to "Live High-Train Low (and High)" hypoxic training.
- This hypoxic training regimen, however, does not modify the running mechanics of elite team-sport players at low and high velocities.
- Coaches can be confident that this intervention, known for inducing significant metabolic benefits, is appropriate for athletes since their running kinetics and kinematics are not negatively affected by chronic hypoxic exposure.

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Innovative training methods in hypoxia for intermittent sports, optimization of interval-training, prevention of injuries, biomechanical-physiological coupling in various sport locomotion.
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Jean-Benoit MORIN
Employment
Professor in locomotion biomechanics and sports performance (Université Côte d'Azur, France)
Degree
PhD
Research interest
New concepts and new methods to investigate human locomotion (sprint running) and performance biomechanics
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Employment
Researcher / Exercise physiologist at French Institute of Sport (Paris, France)
Degree
PhD
Research interest
Neurophysiological and biomechanical determinants and mechanisms of fatigue resistance during exercise. Innovative (environmental) training methods to enhance high-intensity intermittent sports performance.
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