©Journal of Sports Science and Medicine (2021) **20**, 45-51
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2021.45

Research article

Short-Term Perceptually Regulated Interval-Walk Training in Hypoxia and Normoxia in Overweight-to-Obese Adults

Liam Hobbins [1], Steve Hunter [1], Nadia Gaoua [1] and Olivier Girard [2] ✉
[1] Sport and Exercise Science Research Centre (SESRC), London South Bank University, London, UK; [2] School of Human Sciences (Exercise and Sport Science), The University of Western Australia, Crawley, Western Australia, Australia

Abstract
We compared the effects of short-term, perceptually regulated training using interval-walking in hypoxia *vs.* normoxia on health outcomes in overweight-to-obese individuals. Sixteen adults (body mass index = 33 ± 3 kg·m^{-2}) completed eight interval-walk training sessions (15 × 2 min walking at a rating of perceived exertion of 14 on the 6-20 Borg scale; rest = 2 min) either in hypoxia (FiO_2 = 13.0%) or normoxia during two weeks. Treadmill velocity did not differ between conditions or over time ($p > 0.05$). Heart rate was higher in hypoxia (+10 ± 3%; $p = 0.04$) during the first session and this was consistent within condition across the training sessions ($p > 0.05$). Similarly, arterial oxygen saturation was lower in hypoxia than normoxia (83 ± 1% *vs.* 96 ± 1%, $p < 0.05$), and did not vary over time ($p > 0.05$). After training, perceived mood state (+11.8 ± 2.7%, $p = 0.06$) and exercise self-efficacy (+10.6 ± 4.1%, $p = 0.03$) improved in both groups. Body mass (~~(~~p = 0.55), systolic and diastolic blood pressure ($p = 0.19$ and 0.07, respectively) and distance covered during a 6-min walk test ($p = 0.11$) did not change from pre- to post-tests. Short term (2-week) perceptually regulated interval-walk training sessions with or without hypoxia had no effect on exercise-related sensations, health markers and functional performance. This mode and duration of hypoxic conditioning does not appear to modify the measured cardiometabolic risk factors or improve exercise tolerance in overweight-to-obese individuals.

Key words: Obesity, hypoxic conditioning, perceptually regulated exercise, cardio-metabolic health, interval training.

Introduction

Recently there has been an increased interest in the use of hypoxic conditioning (HC) as a strategy for promoting indicators of health and weight loss in individuals with obesity (Hobbins et al. 2017; Ramos-Campo et al. 2019). In comparison to normoxic constant-load exercise training programmes (e.g., 60-90 min walking/running, cycling or cross-training at 60-75% maximal oxygen uptake [$\dot{V}O_{2max}$] or heart rate [HR_{max}]), HC with an FiO_2 in the range 13–16.5% for 4-8 weeks has been shown to elicit greater reductions in body mass and fat mass (Netzer et al. 2008; Wiesner et al. 2009), along with improvements in blood glucose concentrations (Haufe et al. 2008; De Groote et al. 2018), blood pressure (Kong et al. 2014) and exercise capacity (Chacaroun et al. 2020). Comparatively, perceptual responses and exercise-related sensations associated with this type of training have so far been overlooked.

Weight loss within the early phase of an exercise training intervention (within 2–4 weeks) is a prominent predictor of exercise adherence (Burgess et al. 2017). HC studies involving individuals with obesity have typically implemented a training duration of 4-8 weeks (Hobbins et al. 2017; Ramos-Campo et al. 2019). However, Morishima et al. (2015) noted improvements in $\dot{V}O_{2max}$ and mean blood pressure in adults with obesity following completion of twelve hypoxic (FiO_2 = 15.0%) 60-min cycling sessions at 65% of relative $\dot{V}O_{2max}$ over 2 weeks. Further, these adaptations were similar to those observed following the same number of sessions spread over 4 weeks in normoxia. Therefore, achieving similar (or better) positive health and functional fitness outcomes in a shorter time frame (with the same exercise load) may improve confidence and likelihood of adherence to regular exercise in obese populations.

Perceptually regulated exercise intensity is defined as maintaining a target intensity, through the use of, for example, rating of perceived exertion (RPE) to self-adjust the absolute intensity (i.e., velocity or power output) (Tucker, 2009). Previously, it has been suggested that this mode of exercise may be considered more enjoyable than absolute fixed-intensity exercise (Hobbins et al. 2017; Ramos-Campo et al. 2019). HC studies have typically implemented continuous, fixed-intensity exercise (60-75% $\dot{V}O_{2max}$), which may prove detrimental in terms of exercise adherence and other indicators of exercise satisfaction and pleasure (Burgess et al. 2017).

Therefore, our intention was to compare the effects of a short-term (eight, 60-min sessions over two weeks) perceptually regulated (RPE = 14) interval training intervention in both hypoxic and normoxic conditions. The training intervention involved 15 × 2 min walking blocks interspersed with 2 min of rest and measurement of exercise-related sensations, cardio-metabolic markers, and functional performance in overweight-to-obese individuals were made. It was hypothesised that health outcomes would be improved more after training in hypoxia compared to normoxia, despite the perceptually regulated selection of a lower training workload (i.e., slower treadmill walking velocity).

Methods

Male and female adults were recruited to participate in this study from a University staff population of approximately 1700 individuals. Inclusion criteria required that participants were sedentary (<1 h of moderate-intensity exercise/week), did not smoke, had no current or recent (within 3 months) musculoskeletal injury or recent URT infection. Recruited participants were also classified in the BMI

Received: 09 October 2020 / Accepted: 23 November 2020 / Published (online): 01 March 2021

range of 27-35 kg.m^{-2} (overweight: 25-29.9; obesity: 30+) and had not been exposed to hypoxic conditions within the previous 6 months prior to the start of the study (see Table 1 for anthropometric data of the sample). Written informed consent was obtained from all participants. This study was carried out in accordance with the *Declaration of Helsinki*. Ethical approval was received from the School of Applied Sciences Ethics Committee (SAS1822).

This study compared two separate groups of adults who were classified as overweight or obese, whereby, half of the participants completed their sessions in hypoxic conditions (FiO_2 = 13.0%, equivalent to ~3500 m elevation above sea level, HYP; n = 8), and the other half completed their sessions in normoxic conditions (sea level, NOR; n = 8). Participants were randomly allocated to training conditions through simple randomization. Participants completed eleven separate visits across three consecutive weeks and were instructed to maintain their normal daily habits in terms of activity, diet, social interactions and sleep patterns. The first session (visit 1) consisted of eligibility determination, familiarisation with the measures and treadmill walking (Pulsar, h/p/cosmos, Germany), and identification of the walking velocity associated with a RPE of 14, as described previously (Hobbins et al. 2019). Within 72 h, participants returned to the lab for pre-testing (visit 2), which consisted of assessment of anthropometrics (body mass and stature), physiological responses (blood pressure), exercise-related sensations (perceived mood change and exercise self-efficacy) and functional fitness (6-min walk test). After 24-72 h, participants undertook the first of eight supervised 60-min self-paced interval-walking training interventions. Visits 4–10 involved the remainder of the 8 training sessions, which were completed within a 2-week period. Within 72 h of the final perceptually regulated interval walking session, participants returned to the lab (visit 11) for post-intervention testing. Testing and training environments were maintained at 23°C and 45% relative humidity.

The eight supervised 60-min perceptually regulated interval-walk sessions were completed across two consecutive weeks in a commercial gym (Academy of Sport, London South Bank University). Each session began with a 5-min warm up at 3.0 km·h^{-1} on the treadmill (Fusion Run Series3, Pulse Fitness, UK). A facemask connected to a portable hypoxic generator (*see below*) was then attached and remained in place for the entire session. During all sessions, the first 30 s of each 2-min interval began at the participants' perceptually regulated walking velocity (RPE = 14) identified at visit 1. Following this, participants were able, every 30 s, to decide if and how treadmill velocity needed to be altered (i.e., increased or decreased by 0.5, 1.0 or 1.5 km·h^{-1}, or maintained) to ensure maintenance of an RPE of 14 whilst walking.

The facemask (Altitude Training Mask, Hypoxico Altitude Training Systems, USA) was connected *via* corrugated plastic tubing to a hypoxic generator (Everest Training Summit II, Hypoxico Altitude Training Systems, USA) to create hypoxic conditions. The hypoxic level provided in this study was an FiO_2 13.0% (simulated altitude of ~3500 m), while the total hypoxic exposure corresponded to exactly 480 min for those in the HYP group. Participants in the normoxic group were blinded to the condition by being connect to the same hypoxicator system set at sea level equivalent FiO_2 (21%).

Treadmill velocity, HR (M400, Polar, Finland) and arterial oxygen saturation (SpO_2) (iHealth Air, iHealth-Labs, USA) were recorded every 30 s during interval walking. Before each session, perceived recovery was assessed in response to a numeric scale, ranging from 0 being '*very poorly recovered*' to 10 being '*very well recovered*' (Laurent et al. 2011). Perceived motivation was assessed *via* a 20 cm visual analog scale, with 0 being '*not very motivated*' (white colored) and 20 being '*very motivated*' (black colored) (Crewther et al. 2016). Immediately after each training session, perceived breathlessness and limb comfort were determined in response to a numeric scale ranging from 0 being '*nothing at all*' to 10 being '*very, very severe*' (Ward and Whipp, 1989), whilst perceived pleasure was assessed *via* a 20-cm visual analog scale ranging from 0 being '*not very pleasant*' (white colored) and 20 being '*very pleasant*' (black colored).

Participants arrived at the lab following an 8-h fasting period (water exempt). Stature and body mass, and subsequently BMI, were assessed using an electric stadiometer (220, Seca GmbH, USA). After 10 min of rest, participants were asked '*how are you feeling right now?*' and instructed to verbally specify a number on an 11-point scale anchored '*very bad*' (-5) up to '*very good*' (+5) for perceived mood state (Hardy and Rejeski, 1989). Exercise self-efficacy was determined by participants completing a six item, 11-point Likert scales (Smith et al. 2012). Blood pressure (systolic and diastolic) was assessed *via* an automated pressure cuff (Omron M4, Omron, Japan) attached, secured and inflated around the upper arm, level with the heart.

Participants completed a standardised warm up (5 min at 3 km·h^{-1}) before a functional fitness test involving 6 min of perceptually regulated continuous walking in normoxic conditions. The treadmill velocity was set at 50%

Table 1. Effect of a 2-week exercise training program in hypoxia or normoxia on anthropometrics, blood pressure and functional fitness. Data presented as mean ± SD.

	Hypoxia		Normoxia		ANOVA *p* value (effect size)		
Parameters	**Pre-tests**	**Post-tests**	**Pre-tests**	**Post-tests**	**Condition**	**Time**	**Interaction**
Gender	4 Males, 4 Females		5 Males, 3 Females				
Age (years)	32.1 ± 10.2		41.1 ± 13.0		-	-	-
Stature (m)	1.70 ± 0.09		1.70 ± 0.01				
Body mass (kg)	92.2 ± 12.0	91.7 ± 11.9	95.5 ± 9.5	95.5 ± 10.0	0.55 (0.05)	0.45 (0.08)	0.56 (0.05)
Body mass index (kg/m^{-2})	31.9 ± 3.6	32.6 ± 3.6	33.0 ± 1.4	32.0 ± 2.0	0.75 (0.02)	0.21 (0.21)	0.72 (0.02)
Systolic blood pressure (mmHg)	119 ± 8	117 ± 14	132 ± 14	125 ± 17	0.19 (0.23)	0.22 (0.20)	0.40 (0.10)
Diastolic blood pressure (mmHg)	77 ± 9	74 ± 6	84 ± 8	81 ± 7	0.07 (0.39)	0.10 (0.34)	0.88 (0.01)
Functional fitness (m)	670 ± 43	680 ± 72	613 ± 88	618 ± 102	0.11 (0.31)	0.58 (0.05)	0.74 (0.02)

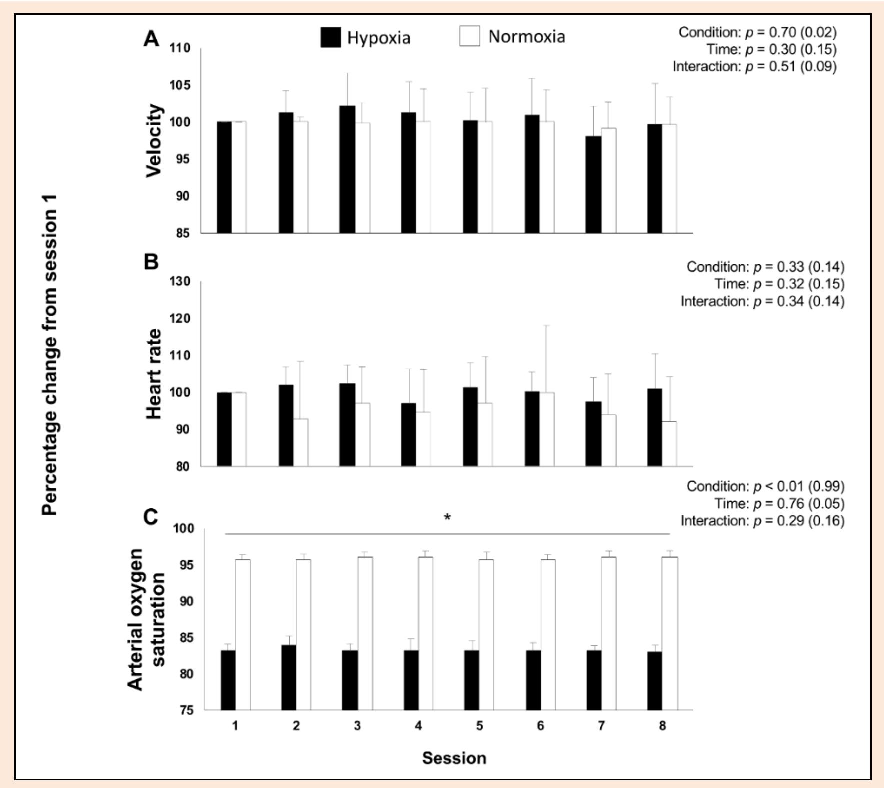

Figure 1. Changes in velocity (A), heart rate (B) and arterial oxygen saturation (C) during the interval walking workouts. Velocity and heart rate from sessions 2–8 are calculated as change from session 1. All data are presented as mean ± SD. ANOVA main effects of time, condition and interaction are stated along with partial-eta squared into brackets. * denotes a statistically significant difference (p < 0.05) between hypoxia and normoxia.

of their self-selected walking velocity, and participants stepped on whilst the velocity was increased to their velocity associated with an RPE of 14 within 10 s. Participants were instructed to '*walk as far as possible in six minutes without running or jogging*'. They were able to maintain the velocity or increase/decrease it by 0.5, 1.0 or 1.5 $km{\cdot}h^{-1}$ every 30 s. Following completion of the 6-min period the total distance covered was recorded (Gibson et al. 2015).

Preliminary analysis (paired-sample, equal variance *t*-test) was carried out to determine whether pre-tests measurements were statistically significantly different between HYP and NOR. If statistical differences were found, data collected during and post-training were normalized to the pre-training measurement. Velocity, HR and SpO_2 were averaged across each 60-min session. Velocity, HR and exercise-related sensations recorded during sessions 2-8 were calculated as a percentage change from session 1 (100%) due to differences in the initial velocity deemed equal to RPE 14 between HYP and NOR.

Data are presented as mean ± standard deviation. A *t*-test was used to determine any statistically significant differences in the absolute velocity, HR, SpO_2, perceived recovery, motivation, breathlessness, limb discomfort and pleasure values (averaged across the session) during session 1. A two-way repeated-measures ANOVA was used to investigate the main effect of condition (hypoxia *vs.* normoxia), time (pre-training *vs.* post-training or session 1 *vs.* 2, 3, 4, 5, 6, 7 and 8) and the condition × time interaction. A *Bonferroni* post hoc multiple comparison was performed if a significant main effect was observed. Effect sizes were described in terms of partial eta-squared (η_p^2, with $\eta_p^2 \geq 0.06$ representing a moderate effect and $\eta_p^2 \geq 0.14$ a large effect). All statistical calculations were performed using SPSS statistical software (IBM Corp., Armonk, NY, USA). The significance level was set at $p < 0.05$.

Table 2. Velocity, HR, SpO_2 and perceived recovery, motivation, breathlessness, limb discomfort and pleasure during session 1 (averaged across the session). Data presented as mean ± SD.

	Condition		
Parameter	**HYP**	**NOR**	***p* value**
Velocity ($km{\cdot}h^{-1}$)	6.5 ± 0.3	6.3 ± 0.6	0.23
HR (bpm)	144 ± 16	129 ± 20	0.04
SpO_2 (%)	83.2 ± 0.9$^{\#\#}$	95.7 ± 0.7	0.01
Perceived recovery (au)	8.4 ± 1.6	8.1 ± 1.9	0.38
Perceived motivation (au)	13.8 ± 1.8$^{\#\#}$	16.4 ± 2.3	0.01
Perceived breathlessness (au)	2.5 ± 1.3	2.3 ± 1.4	0.28
Perceived limb discomfort (au)	3.3 ± 2.1	2.4 ± 1.7	0.15
Perceived pleasure (au)	12.4 ± 1.5$^{\#}$	14.3 ± 3.5	0.07

HR = heart rate, HYP = hypoxic condition, NOR = normoxic condition, SpO_2 = arterial oxygen saturation. $^{\#\#}$ denotes a statistically significant difference ($p \leq 0.05$) versus NOR, $^{\#}$ denotes a statistically significant trend ($p \leq 0.07$) versus NOR.

Results

Treadmill velocity did not differ between conditions or over time (i.e., session 1: 6.5 ± 0.3 *vs.* 6.3 ± 0.6 $km.h^{-1}$; p > 0.05, Figure 1A; Table 2). During the first session, HR was higher in HYP *vs.* NOR (144 ± 16 *vs.* 129 ± 20 bpm; +10 ± 3%; p = 0.04; Table 2). While this difference persisted between conditions there were no changes within condition across the training sessions (p > 0.05, Figure 1B). Similarly, SpO_2 was lower during HYP *vs.* NOR (83 ± 1% *vs.* 96 ± 1%, p < 0.05), but did not vary over time (p > 0.05, Figure 1C; Table 2).

Perceived recovery was lower prior to session 4 (76 ± 16%, p < 0.01) and 7 (75 ± 19%, p < 0.01) compared to session 1, irrespective of condition (Figure 2A). Perceived motivation was lower prior to session 2 (75 ± 12%), 3 (69 ± 20%), 4 (69 ± 14%), 5 (77 ± 16%), 7 (73 ± 17%) and 8 (71 ± 20%) compared to session 1, irrespective of condition (p < 0.04, Figure 2B). Perceived breathlessness, limb discomfort and pleasure did not change with condition or time (*p* > 0.05, Figure 2C–E; Table 2).

Body mass, body mass index, systolic and diastolic blood pressures and functional fitness did not change with condition or time (*p* > 0.05, Table 1). Exercise self-efficacy (+7 ± 5%, *p* = 0.03) improved from pre- to post-tests, irrespective of condition (*p* > 0.05). Despite failing to reach statistical significance, perceived mood state (+12 ± 2%, *p* = 0.06) followed a similar trend.

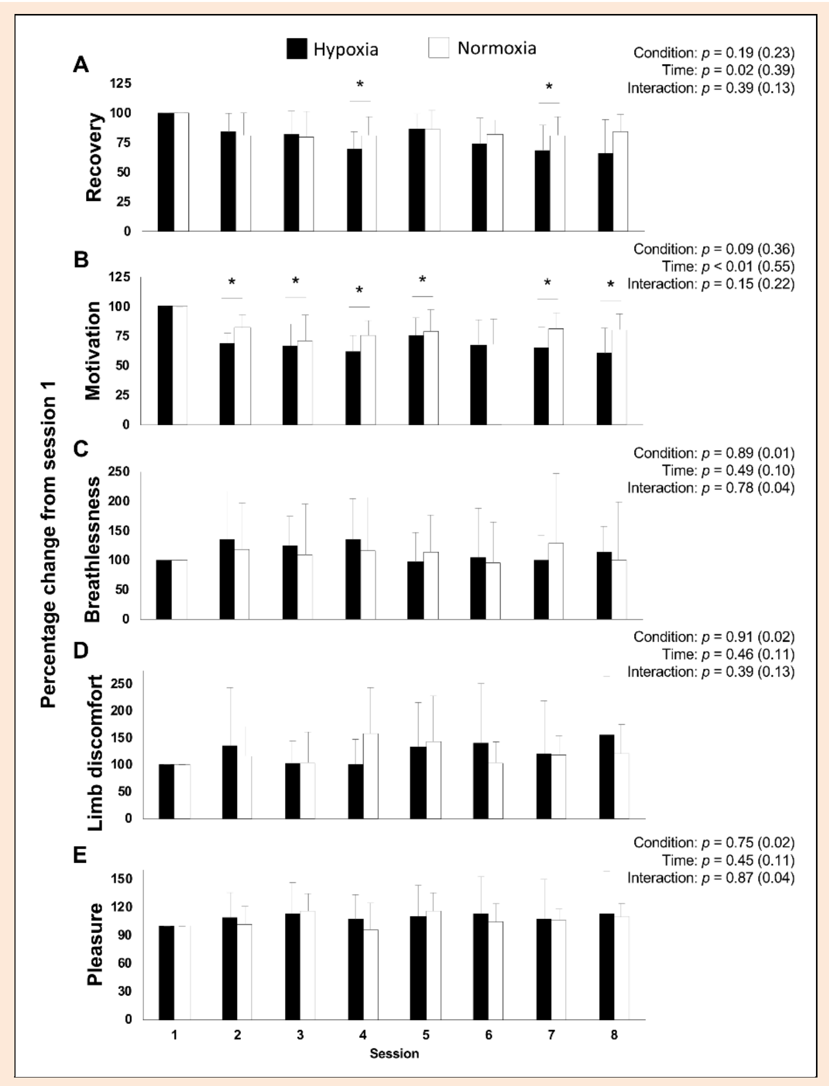

Figure 2. Changes in perceived recovery (A) and motivation (B), breathlessness (C), limb discomfort (D) and pleasure (E) assessed before and after the interval walking workouts. Data from sessions 2–8 are calculated as a percentage difference from session 1 (100%) and presented as mean ± SD. ANOVA main effects of time, condition and interaction are stated along with partial-eta squared into brackets. * denotes a statistically significant difference (p < 0.05) for a given session in reference to session 1.

Discussion

The aim of this study was to investigate whether the addition of hypoxia during a short-term, perceptually regulated (RPE = 14) interval walking training program in adults with obesity leads to similar (or superior) improvements in psycho-physiological responses. During the training, treadmill velocity and perceptual responses did not differ between conditions, despite hypoxia-induced elevations in physiological strain (i.e., higher heart rate and lower SpO_2). From pre- to post-training perceived mood state improved in both groups. However, body mass, BMI, blood pressure and functional fitness did not change.

Over the course of our intervention, treadmill velocity that was self-selected by our participants to maintain a RPE of 14 did not differ either between conditions or across sessions. Despite similar external workload in both groups, higher HR and lower SpO_2 were measured during session 1 in HYP *vs.* NOR, and this internal load due to hypoxia exposure persisted during all remaining sessions. When training three times per week for 3-4 weeks, lower workload (-7-28%) during cycling (Haufe et al. 2008; Pramsohler et al. 2017) or running (Wiesner et al. 2009) exercise modes in moderate hypoxia (FiO_2 = ~15.0%) produced similar HR values compared to normoxia. In the aforementioned studies, training included 30–60 min of continuous exercise at a fixed, moderate intensity. In our study, the lack of a difference for treadmill velocity between conditions may be due to our original approach of maintaining a constant RPE target during 2-min interval walking workouts.

We further observed that neither external (treadmill velocity) nor internal load (HR, SpO_2) metrics changed during the course of the eight training sessions in both conditions. Contrastingly, Fernández Menéndez et al. (2018) showed that preferred walking speed (corresponding to RPE ~10) in obese adults became progressively faster over the course of a 3-week walking intervention in both hypoxic and normoxic training groups, despite selection of a ~7% slower velocity in hypoxia than normoxia. In the present study when exercise intensity is perceptually regulated (RPE = 14) during interval walking workouts, internal and external loads metrics remained unchanged from the first to the eighth training session over the course of the 2-week intervention. The difference in our findings to those of Fernández Menéndez et al. (2018), may be explained by the interval nature of the exercise such that the rest periods allowed for appropriate recovery and initiation of exercise in the next interval at a constant perceptually regulated intensity.

Walking velocities did not differ between conditions, therefore one would expect exercise-related sensations to be negatively impacted in HYP compared to NOR in the presence of lower SpO_2 and higher HR readings. One interesting finding, however, was that none of the perceptual measures were negatively affected by the addition of moderate hypoxia. Conversely, higher difficulty breathing and limb discomfort readings were reported by Soo et al. (2020) when completing repeated cycle sprints (8 × 5-s sprints, 25 s of rest) and by Hobbins et al. (2019) during perceptually regulated (RPE = 16), high-intensity intermittent runs (4 × 4-min, 3 min of rest) in deprived-O_2 conditions (FiO_2 = 13-15%). Jeffries et al. (2019) reported progressive arterial hypoxemia (lower SpO_2) and increases in ventilation as primary cues as an explanation for a shorter time to exhaustion during a cycling task (clamped at RPE 16) in severe hypoxia (FiO_2 = 11.4%) in comparison to normoxia. This suggests that more severe hypoxia levels than those used in the current study (FiO_2 = 13.0%) may be required to observe a negative influence on exercise-related sensations. The nature of our perceptually regulated exercise, involving short (2 min) exercise intervals, followed by similar recovery duration, may also explain why we failed to observe apparent differences between conditions in perceptual variables. Importantly, decreases in perceived recovery and motivation (i.e., already visible after the initial session) occurred across sessions, irrespective of environmental condition. A possible explanation may likely be the large number of training sessions in a short-time frame. This is an important consideration for implementation since, as described by Ekkekakis and Lind (2006), exercise-related sensations are important for adherence to regular exercise training.

Total body mass, BMI and functional fitness did not change in response to either interventions. Previously, greater (Kong et al. 2014; Netzer et al. 2008) and similar improvements (Gatterer et al. 2015) in body composition have been found after training in hypoxic than normoxic conditions. Similarly, gains in functional fitness were greater after HC compared to the normoxic equivalent training (Haufe et al. 2008; Wiesner et al. 2009). In adults with obesity, a 2-week training block may not be long enough to elicit positive changes in body composition and functional fitness, unlike the aforementioned studies implementing longer training periods (4-6 weeks) yet with a similar number (8-12) of training sessions (Haufe et al. 2008; Kong et al. 2014; Netzer et al. 2008). Other anthropometric measures not assessed in the current study (i.e., waist: hip ratio, fat mass and muscle mass) that are pertinent for improved body composition should be assessed in future investigations. In our study, blood pressure remained unchanged throughout the protocol. Perhaps a greater training dose (i.e., higher intensity and/or longer training duration) may be required in normotensive individuals (as recruited here) to positively impact on exercise capacity and cardio-metabolic health when in hypoxia compared to normoxia (Navarrete-Opazo and Mitchell, 2014). That said, despite greater improvement in exercise tolerance, HC (hypobaric hypoxia with a target SpO_2 of 80%) thrice weekly for 8 weeks was not associated with larger improvement in either body composition or vascular and metabolic functions in overweight-to-obese individuals compared to normoxic equivalent (Chacaroun et al. 2020).

Irrespective of condition, perceived mood change and exercise self-efficacy improved from pre- to post-tests. To our knowledge, no investigation exists that has compared exercise-related sensations before and after HC in a similar population. In obese individuals, fixed-intensity interval training (60 × 8-s sprint at 90% $\dot{V}O_{2max}$/12 s recovery) including 20 sessions over 5 weeks in normoxia was perceived as being more enjoyable and easier to complete compared to moderate-intensity, continuous training (40 min at 65% $\dot{V}O_{2max}$) (Kong et al. 2016). In our study, implementation of interval exercise at a perceptually regulated intensity, causing higher internal but similar external load levels between conditions, may have mitigated the potential onset of hypoxic-induced negative mood (Lane et al. 2004). Overall, similar improvements in perceived mood change and exercise self-efficacy result from perceptually regulated interval walking in HYP and NOR.

Limitations

Limitations of this study include both the relatively small sample size and the approach to simple randomization increasing the likelihood of unequal distribution of participants (Kim and Shin 2014). This appears evident in both the mean age of the participants in the hypoxic and normoxic groups (32.1 and 41.1 years, respectively) and the assessment of baseline functional fitness (670 *vs*. 613 m, respectively). That being said, changes in functional fitness from pre- to post- the intervention did not differ between groups (hypoxic: >1.5% and normoxic: 1.0%). This implies that the ability to determine the impact of age on change in functional fitness is not evident. Rather the duration of the intervention was the key limiting factor in determining the impact of training under hypoxic compared to normoxic conditions. This suggests that adherence to exercise for longer than a 2-week period would be required if the beneficial effects of exercise in hypoxia *vs*. normoxia are to be realized.

Conclusion

In overweight adults, or those with obesity, eight perceptually regulated interval-walk sessions over 2-week training period led to similar treadmill velocity and perceptual responses between HYP and NOR, despite hypoxia-induced elevations in physiological strain (i.e., higher heart rate and lower SpO_2). While both interventions improved exercise-related sensations, there were no significant differences in weight loss, blood pressure and functional performance from either training condition. Hypoxic conditioning does not appear to modify some cardiometabolic risk factors and improve exercise tolerance in overweight-to-obese adults, at least over a short training period.

Acknowledgements
The authors have no conflicts of interest, source of funding, or financial ties to disclose and no current or past relationship with companies or manufacturers who could benefit from the results of the present study. The authors report no conflict of interest. The present study complies with the current laws of the country in which the study was performed.

References

Burgess, E., Hassmén, P. and Pumpa, K. (2017) Determinants of adherence to lifestyle intervention in adults with obesity: a systematic review. *Clinical Obesity* **7**, 123-135.

Chacaroun, S., Borowik, A., Vega-Escamilla Y Gonzalez, I., Doutreleau, S., Wuyam, B., Belaidi, E., Tamisier, R., Pepin, J-P.,Flore, P. and Verges, S. (2020) Hypoxic exercise training to improve exercise capacity in obese individuals. *Medicine and Science in Sports & Exerc*ise **52**,1641-1649.

Crewther, B., Carruthers, J., Kilduff, L., Sanctuary, C. and Cook, C. (2016) Temporal associations between individual changes in hormones, training motivation and physical performance in elite and non-elite trained men. *Biology of Sport* ***33***, 215-221.

De Groote, E., Britto, F., Bullock, L., François, M., De Buck, C., Nielens, H. and Deldicque, L. (2018) Hypoxic training improves normoxic glucose tolerance in adolescents with obesity. *Medicine and Science in Sports & Exerc*ise **50**, 2200-2208.

Ekkekakis, P. and Lind, E. (2006) Exercise does not feel the same when you are overweight: the impact of self-selected and imposed intensity on affect and exertion. *International Journal of Obesity* **30**, 652-660.

Fernández Menéndez, A., Saudan, G., Sperisen, L., Hans, D., Saubade, M., Millet, G. P. and Malatesta, D. (2018) Effects of short-term normobaric hypoxic walking training on energetics and mechanics of gait in adults with obesity. *Obesity* **26**, 819-827.

Gatterer, H., Haacke, S., Burtscher, M., Faulhaber, M., Melmer, A., Ebenbichler, C., Strohl, KP., Hogel, J. and Netzer, N. C. (2015) Normobaric intermittent hypoxia over 8 months does not reduce body weight and metabolic risk factors - a randomized, single blind, placebo-controlled study in normobaric hypoxia and normobaric sham hypoxia. *Obesity Facts* **8**, 200-209.

Gibson, O., Richardson, A., Hayes, M., Duncan, B. and Maxwell, N. (2015) Prediction of physiological responses and performance at altitude using the 6-minute walk test in normoxia and hypoxia. *Wilderness and Environmental Medicine* **26**, 205-210.

Hardy, C. J. and Rejeski, W. J. (1989) Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport and Exercise Psychology* **11**, 304-317.

Haufe, S., Wiesner, S., Engeli, S., Luft, F. and Jordan, J. (2008) Influences of normobaric hypoxia training on metabolic risk markers in human subjects. *Medicine and Science in Sports & Exerc*ise **40**, 1939-1944.

Hobbins, L., Hunter, S., Gaoua, N. and Girard, O. (2017) Normobaric hypoxic conditioning to maximize weight loss and ameliorate cardio-metabolic health in obese populations: a systematic review. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* **313**, R251-R264.

Hobbins, L., Gaoua, N., Hunter, S. and Girard, O. (2019) Psycho-physiological responses to perceptually-regulated interval runs in hypoxia and normoxia. *Physiology & Behavior* **209**, 112611.

Jeffries, O., Patterson, S. and Waldron, M. (2019) The effect of severe and moderate hypoxia on exercise at a fixed level of perceived exertion. *European Journal of Applied Physiology* **119**, 1213-1224.

Kim, J. and Shin, W. (2014) How to do random allocation (randomization). *Clinics Orthopedic Surgery* **6**, 103-109.

Kong, Z., Fan, X., Sun, S., Song, L., Shi, Q. and Nie, J. (2016) Comparison of high-intensity interval training and moderate-to-vigorous continuous training for cardiometabolic health and exercise enjoyment in obese young women: a randomized controlled trial. *Plos One* **11**(7):e0158589.

Kong, Z., Zang, Y. and Hu, Y. (2014) Normobaric hypoxia training causes more weight loss than normoxia training after a 4-week residential camp for obese young adults. *Sleep and Breath* **3**, 591-597.

Lane, A., Terry, P., Stevens, M., Barney, S. and Dinsdale, S. (2004) Mood responses to athletic performance in extreme environments. *Journal of Sports Sciences* **22**, 886-897.

Laurent, C., Green, J., Bishop, P., Sjökvist, J., Schumacker, R., Richardson, M. and Curtner-Smith, M.A. (2011) Practical approach to monitoring recovery: development of a perceived recovery status scale. *Journal of Strength and Conditioning Research* **25**, 620-628.

Morishima, T., Hasegawa, Y., Sasaki, H., Kurihara, T., Hamaoka, T. and Goto, K. (2015) Effects of different periods of hypoxic training on glucose metabolism and insulin sensitivity. *Clinical Physiology and Functional Imaging* **35**, 104-109.

Navarrete-Opazo, A. and Mitchell, G. (2014) Therapeutic potential of intermittent hypoxia: a matter of dose. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* **307**, R1181-1197.

Netzer, N., Chytra, R. and Küpper, T. (2008) Low intense physical exercise in normobaric hypoxia leads to more weight loss in obese people than low intense physical exercise in normobaric sham hypoxia. *Sleep and Breathing* **12**, 129-134.

Pramsohler, S., Burtscher, M., Faulhaber, M., Gatterer, H., Rausch, L., Eliasson, A. and Netzer, N. C. (2017) Endurance training in normobaric hypoxia imposes less physical stress for geriatric rehabilitation. *Frontiers in Physiology* **8**, 514.

Ramos-Campo, D. J., Girard, O., Pérez, A. and Rubio-Arias, J. Á. (2019) Additive stress of normobaric hypoxic conditioning to improve body mass loss and cardiometabolic markers in individuals with overweight or obesity - A systematic review and meta-analysis. *Physiology & Behavior* **207**, 28-40.

Smith, B., Sparkes, A., Tenenbaum, G., Eklund, R. and Kamata, A. (2012) Measurement in sport and exercise psychology. Making sense of words and stories in qualitative research–strategies and consideration. Champaign, IL. Human Kinetics.

Soo, J., Billaut, F., Bishop, D. J., Christian, R. J. and Girard, O. (2020) Neuromuscular and perceptual responses during repeated cycling sprints-usefulness of a "hypoxic to normoxic" recovery approach. *European Journal of Applied Physiology* **120**, 883-896.

Tucker, R. (2009) The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *British Journal of Sports Medicine* **43**, 392-400.

Ward, S. and Whipp, B. (1989) Effects of peripheral and central chem-

oreflex activation on the isopnoeic rating of breathing in exercising humans. *Journal of Physiology* **411**, 27-43.
Wiesner, S., Haufe, S., Engeli, S., Mutschler, H., Haas, U., Luft, F. and Jordan, J. (2009) Influences of normobaric hypoxia training on physical fitness and metabolic risk markers in overweight to obese subjects. *Obesity* **18**, 116-120.

Key points

- We compared the effects of a 2-week (8 sessions) perceptually regulated interval-walk intervention in hypoxia *vs.* normoxia in overweight-to-obese adults.
- Despite stronger hypoxia-induced physiological stimulus – yet essentially similar walking speeds – during training, psychological and physiological measures did not differ either between conditions or across sessions.
- Hypoxic conditioning does not appear to ameliorate exercise-related sensations, cardio-metabolic markers and functional performance, at least over a short training period.
- Adherence to exercise for longer than a 2-week period is likely required if the beneficial effects of exercise in hypoxia *vs.* normoxia are to be realized.

✉ **Dr. Olivier Girard**
School of Human Sciences (Exercise and Sport Science), The University of Western Australia, Crawley, Western Australia, Australia.

AUTHOR BIOGRAPHY

Liam HOBBINS
Employment
Journal Specialist at Frontiers (London, UK)
Degree
PhD
Research interests
Psycho-physiological responses to hypoxic conditions in healthy and obese populations.
E-mail: liam-hobbins@hotmail.co.uk

Nadia GAOUA
Employment
Associate professor in sport psychology London South Bank University (London, UK)
Degree
PhD
Research interests
Sport psychology. Effects of environmental conditions (i.e. heat stress or hypoxia) on cognitive functions and sport performance.
E-mail: gaouan@lsbu.ac.uk

Steve HUNTER
Employment
Associate Professor Sport and Exercise Physiology. London South Bank University (London, UK)
Degree
MPhil
Research interests
Environmental exercise physiology
Strength and Conditioning
Athlete testing and training
Athlete recovery strategies
E-mail: steve.hunter@lsbu.ac.uk

Olivier GIRARD
Employment
Associate Professor in Human Performance at The University of Western Australia (Perth, Australia)
Degree
PhD
Research interests
Fatigue mechanisms during high-intensity intermittent exercises performed under challenging environmental conditions (i.e. heat stress or hypoxia), with a special focus on (repeated) sprinting mechanics and underpinning neuromuscular factors
E-mail: olivier.girard@uwa.edu.au