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ORIGINAL INVESTIGATION

Manuscript Title: Physical performance during high-intensity resistance exercise in normoxic and hypoxic conditions

Short Title: Performance during hypoxic resistance exercise

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ABSTRACT

This study aimed to determine whether different levels of hypoxia affect physical performance during high-intensity resistance exercise, or subsequent cardiovascular and perceptual responses. Twelve resistance-trained young men (age: 25.3 ± 4.3 yr; height: 179.0 ± 4.5 cm; body mass: 83.4 ± 9.1 kg) were tested for 1-repetition maximum (1RM) in the back squat and deadlift. Following this, participants completed three separate randomized trials of 5 x 5 repetitions at 80% 1RM, with 3 minutes rest between sets, in either normoxia, (NORM; fraction of inspired oxygen [F_IO_2] = 0.21), moderate-level hypoxia (MH; F_IO_2 = 0.16), or high-level hypoxia (HH; F_IO_2 = 0.13) via a portable hypoxic unit. Peak and mean force and power variables were monitored during exercise. Arterial oxygen saturation (SpO_2), heart rate (HR), and rating of perceived exertion (RPE) were assessed immediately following each set. No differences in force or power variables were evident between conditions. Similar trends were evident in these variables across each set and across the exercise session in each condition. SpO_2 was lower in hypoxic conditions than in NORM, whereas HR was higher following sets performed in hypoxia. There were no differences between conditions in RPE. These results indicate that a hypoxic stimulus during high-intensity resistance exercise does not alter physical performance during repetitions and sets, or affect how strenuous exercise is perceived to be. This novel training strategy can be used without adversely affecting the physical training dose experienced, and may provide benefits over the equivalent training in normoxia.

Keywords: Strength; force; power; hypoxia; intermittent hypoxic resistance training

INTRODUCTION

Resistance training using loads of 20-50% of 1-repetition maximum (1RM) combined with blood flow restriction (BFR) to working muscles has been demonstrated to rapidly increase muscle size and strength in athletic populations (4,34). These responses are likely related to an increase in localized hypoxia during BFR, which effects beneficial acute changes in the intramuscular environment (28,31). For example, limited oxygen availability increases the reliance on anaerobic metabolism during exercise, augmenting intramuscular metabolic stress (30). The resultant accumulation of metabolic by-products is proposed to increase muscle cell swelling (36), hypertrophic signalling (9), and motor unit recruitment (31), which are all likely to benefit muscular development. Furthermore, localized hypoxia may increase the activation and proliferation of satellite cells, further enhancing muscular hypertrophy (24). Increased concentrations of systemic hormones have also been observed (31), though the role of exercise-induced hormonal responses in resistance training adaptation has been recently questioned (33).

Recently, researchers have begun to investigate whether resistance exercise performed while breathing normobaric hypoxic air can augment muscular development, similarly to BFR exercise (17,18,21,22,25). Manimmanakorn et al. (21) investigated the adaptive responses to 5 weeks of low-intensity intermittent hypoxic resistance training (IHRT; 20% 1RM), with the fraction of inspired oxygen (F_IO_2) being adjusted to maintain arterial oxygen saturation (SpO_2) at ~80%. The IHRT elicited similar increases in the combined cross-sectional area of the knee extensor and flexor muscles to work-matched BFR training, and greater increases than the equivalent training in normoxia in netball athletes. Substantially greater increases in strength and muscular endurance were also reported following the IHRT and BFR training when compared to the control group. Additionally, Nishimura et al. (25) reported that 6 weeks of moderate-intensity IHRT (70% 1RM;

F_IO_2=0.16) resulted in significant hypertrophic gains in untrained males, despite no change after matched training in normoxia. Muscle strength was also found to increase significantly after only 3 weeks of IHRT, whereas significant strength increases in the normoxia group required 6 weeks (25).

Evidence indicates that improvements in muscular strength following BFR training result primarily from increases in muscular size (35). This suggests that neuromuscular adaptations do not contribute strongly to augmented strength levels following BFR training, which is likely related to the low-intensity of training. It is widely accepted that optimal training for maximal strength requires high-intensity resistance exercise (1-6RM) to facilitate substantial neuromuscular development (32). Therefore, an interesting question that remains unanswered is whether the addition of systemic hypoxia to high-intensity training can enhance the hypertrophic response to a form of training which largely targets neuromuscular development. As many athletes are required to develop both muscular size and strength, the potential to optimize the development of these characteristics together via IHRT would be of great interest.

During low- and moderate-intensity resistance training, the primarily goal is to elicit physiological responses conducive to muscular adaptation. Therefore, relatively brief inter-set rest periods are often employed to elicit substantial metabolic stress (19), meaning that the actual weight lifted and the concentric power produced during training may be compromized. In contrast, high-intensity training places greater emphasis upon lifting heavy loads and attempting to complete the concentric phase of each repetition as powerfully as possible to provide a potent neuromuscular stimulus. It stands to reason that if high-intensity IHRT is to be beneficial for enhanced hypertrophic and strength development, it is important that the addition of hypoxia does not adversely affect physical performance during training. If resistance exercise performance is impaired by additional hypoxia, it is likely that the training dose experienced will be substantially decreased, limiting the practical applications of high-intensity IHRT.

Evidence suggests that supplemental hypoxia during repeated sprints (10 s cycling sprints with 30 s recovery between efforts) can profoundly affect cerebral oxygenation, which may result in decreased central nervous system motor output (29). Therefore, it is plausible that hypoxia-related central fatigue might impact on performance of high-intensity resistance exercise under systemic hypoxic conditions. Furthermore, hypoxia has been demonstrated to impair anaerobic performance during 15 s repeated sprints (15-45 s recovery between efforts) in elite female road cyclists (3), and to decrease peak speed during 6 s repeated sprints on a non-motorised treadmill (30 s recovery between efforts) in male athletes (2). Both repeat sprint activities and resistance exercise are characterised by repeated short-duration high-intensity efforts that are fuelled largely by anaerobic metabolism. However, these forms of exercise are inherently different and thus may produce dissimilar responses with the addition of hypoxia.

While research suggests that low-moderate load IHRT can offer hypertrophic and strength benefits above the equivalent normoxic training (21,22,25), the efficacy of high-intensity IHRT has not yet been examined. However, due to the demanding nature of high-intensity resistance exercise and the importance placed on physical performance during training, it is important to first consider whether additional hypoxia might impact negatively on participants' ability to perform adequately during training. Despite the potential anabolic benefits of IHRT, if force and power output is decreased during training, or if the exercise is perceived to be much more difficult by participants, the applications of such protocols may be limited. It is also not known whether the degree of hypoxia can influence the magnitude of these physical performance indicators. Therefore, the purpose of this study was primarily to assess whether physical performance (measured via concentric force and power variables) during high-intensity resistance exercise is affected by the addition of moderate or high levels of hypoxia. Secondly, the project aimed to examine whether common cardiovascular and perceptual measures of intensity are altered during high-intensity IHRT under different oxygenation conditions.

METHODS

Experimental Approach to the Problem

To examine whether additional hypoxia affects high-intensity resistance exercise performance, we recruited subjects to perform a high-intensity resistance exercise protocol in normoxic and hypoxic conditions, following a single-blind, randomized crossover design. The exercise protocol was comprised of 5 sets of 5 repetitions of both back squats and deadlifts at 80% 1RM, with 3 minutes recovery between sets. During these trials, subject's breathed air via a hypoxic generator (ATS-HP-Hyperoxic, Altitude Training Systems, Lidcombe NSW, Australia), under one of three conditions; 1) normoxia (NORM; fraction of inspired oxygen [F_IO_2] = 0.21); moderate-level hypoxia (MH; $F_IO_2 = 0.16$); and high-level hypoxia (HH; $F_IO_2 = 0.13$). Force and power variables were monitored during each set via a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) that was attached to the bar. Arterial oxygen saturation (SpO_2), heart rate (HR) and rating of perceived exertion (RPE) scores were also obtained immediately following each set to quantify the cardiovascular demands and perception of exercise intensity.

Subjects

Twelve healthy male subjects (age: 25.3 ± 4.3 yr; height: 179.0 ± 4.5 cm; body mass: 83.4 ± 9.1 kg) volunteered to participate in this study. All subjects had at least two years resistance training experience and were free of any musculoskeletal disorders. Prior to the commencement of the study, subjects were informed of the purpose and requirements of the research, provided written consent and were screened for medical contraindications. The study and its methods were approved by the institutional Human Ethics Committee.

Procedures

Subjects reported to the laboratory on four occasions, each separated by at least one week. During the first visit, subjects underwent 1RM testing for the back squat and deadlift exercises. Visits 2-4 entailed a high-intensity resistance exercise protocol, in one of three experimental conditions. All sessions were conducted at the same time of day do account for diurnal variations in exercise performance, and subjects were required to abstain from alcohol and caffeine for at least 24 hours prior to each testing session, and strenuous activity for 48 hours. Subjects were also instructed to replicate their dietary consumption for each testing day.

1RM Testing

During the first visit, subjects performed 1RM testing of the back squat and deadlift exercises. Subjects completed a general warm-up (five minutes on a cycle ergometer at a moderate intensity), before performing three specific warm-up sets of the back squat. These were comprised of 10 repetitions at 50% of predicted 1RM weight (as estimated by the subject), 5 repetitions at 70%, and 1 repetition at 90%. Following this, the weight was increased by ~5% and subjects performed a single repetition. This process continued until the subjects were unable to successfully perform a lift, with three minutes rest between attempts. Subjects' 1RM was defined as their heaviest completed repetition, and was determined within 3-6 sets. Following the back squat 1RM assessment, subjects rested for 10 minutes before completing specific warm-up sets and progressing through the same 1RM testing protocol for the deadlift.

During the back squat, subjects supported the bar on the superior trapezius at the base of the neck, and flexed at the knees and hips to descend until the front of the thighs were parallel with the ground. A customized elastic stringline was set so that subjects' superior hamstrings came in contact with the stringline at this bottom position to signal that appropriate depth had been reached (5,26). This was visually confirmed by members of the research team positioned adjacent to the participant. Subjects were also given verbal cues on when they were to halt the down phase, and begin the up phase, of the squat (6). For the deadlift, conventional technique was used (rather than sumo or Romanian variations), and subjects were required to maintain the spine in a neutral position throughout the lift. A successful repetition was completed once the subject was standing with their shoulders positioned behind the vertical orientation of the bar, which was assessed by a member of the research team positioned adjacent to the subject. If the subject failed to adhere to these performance criteria during a repetition, the lift was deemed unsuccessful.

Experimental Trials

For experimental trials, subjects were fitted with a face mask connected to a hypoxic generator, and afforded 10 minutes to acclimate to the oxygenation condition. During this time, subjects were encouraged to perform any specific mobility or flexibility activities that they use prior to high-intensity squatting and deadlifting exercise. Subjects then performed two warm-up sets of the back squat (10 repetitions at 50% 1RM and 7 repetitions at 65% 1RM), which were separated by 90 s. After 3 minutes rest, subjects commenced the first of 5 sets of 5 repetitions at 80% 1RM, which were each separated by 3 minutes recovery. Following the final set of back squats, subjects again rested for 3 minutes before beginning the same warm-up and exercise protocol for the deadlift exercise. Immediately following each set, SpO_2 and HR were monitored via a pulse oximeter (Rossmax Innotek Corp. Taipei, Taiwan), and Category Ratio-10 RPE (1) scores were obtained, to reflect the blood oxygenation status and cardiovascular demand across each condition. During each visit, subjects were blinded to both oxygenation condition and SpO_2 measures at all times.

During each 5-repetition set, the displacement of the bar and time between data points was recorded via a linear position transducer, sampling at up to 50 Hz. This device has previously been demonstrated as a valid and reliable tool to quantify force and power variables during resistance exercise (8,27). Data were collected and stored on an iPad device (Apple Inc., Cupertino, USA), before being uploaded to an online database for analysis following each experimental trial. The concentric phase of each repetition was automatically identified by the linear position transducer. *Post hoc* analysis determined measures of peak and mean force and power across the concentric phase of each repetition. To assess changes in performance across a set, mean values of force and power variables were calculated for repetitions 1-5. Furthermore, to assess performance across the exercise protocol, force and power variables were calculated for the first and fifth set of each exercise, to report the percentage change across the five sets.

Statistical Analyses

Data were tested using a Shapiro-Wilks test, and were found to be normally distributed. All data were analysed using a 2-way analysis of variance with repeated measures. If significant differences were noted, a Bonferroni *post hoc* analysis was performed to assess where differences existed. All analyses were performed using Statistical Package for the Social Sciences (v20.0, IBM Corporation, Somers, New York, USA). The level of statistical significance was set at $P \leq 0.05$. Data are expressed as mean ± standard deviation (SD).

RESULTS

Mean and peak values of force and power variables during each repetition of the back squat exercise are presented in Figure 1. No significant differences were observed between conditions for any force or power variable. Similarly, no significant differences were observed in mean peak force between repetitions across the exercise protocol. A significant main effect was observed for mean force between repetitions ($F_{(4, 44)}=22.66$; $P<0.001$; $\eta^2=0.67$), specifically with repetition 5 being significantly lower than repetition 1 ($P<0.001$). A significant main effect was observed for peak power between repetitions ($F_{(4, 44)}=12.65$; $P<0.001$; $\eta^2=0.54$), specifically, with repetition 5 being significantly lower than repetition 1 ($P=0.023$). A significant main effect was observed for mean power between repetitions ($F_{(4, 44)}=129.00$; $P<0.001$; $\eta^2=0.92$), specifically, with repetition 1 being significantly greater than repetitions 3-5 ($P\leq0.001$).

INSERT FIGURE 1 NEAR HERE

Mean and peak values of force and power variables during the deadlift exercise are presented in Figure 2. No significant differences were observed between conditions for any force or power variable. A significant main effect was observed for peak force between repetitions ($F_{(4, 44)}=31.05$; $P<0.001$; $\eta^2=0.74$), with repetition 1 being significantly lower than repetitions 2-5 ($P=0.001$). There were no significant differences between repetitions for mean force values. A significant main effect was observed for peak power between repetitions ($F_{(4, 44)}=7.22$; $P<0.001$; $\eta^2=0.40$), specifically with repetition 1 being significantly lower than repetition 2 ($P=0.022$). A significant main effect was observed for mean power between repetitions ($F_{(4, 44)}=18.13$; $P<0.001$; $\eta^2=0.62$), with repetition 1 being significantly lower than repetitions 2, 3 and 4 ($P=0.001$, 0.003 and 0.027, respectively).

INSERT FIGURE 2 NEAR HERE

The change in force and power variables for the back squat and deadlift exercises across the 5 sets of the exercise protocol are represented in Figure 3. There were no significant main effects for between-condition differences.

INSERT FIGURE 3 NEAR HERE

Figure 4 represents the SpO_2, HR and RPE responses following each 5-repetition set for the back squat and deadlift exercises. There was a significant main effect for SpO_2 between conditions in the back squat ($F_{(2, 22)}$=400.73; *P*<0.001; η^2=0.97) and the deadlift ($F_{(2, 22)}$=212.64; *P*<0.001; η^2=0.95) exercises. More specifically, SpO_2 in NORM was significantly greater (*P*<0.001) in both exercises than in MH and HH, while MH was greater than HH (*P*<0.001). There was no difference in SpO_2 between sets in either exercise in any condition.

The HR responses during the back squat exercise demonstrated significant main effects for HR between both conditions ($F_{(2, 22)}$=7.14; *P*=0.004; η^2=0.39) and sets ($F_{(4, 44)}$=18.30; *P*<0.001; η^2=0.63). Specifically, HR was greater in HH than in NORM (*P*=0.009), and the HR following set 1 was lower than sets 2-5 (*P*≤0.003). For the deadlift, there was only a significant main effect for HR between conditions ($F_{(2, 20)}$=10.43; *P*=0.001; η^2=0.51). Again, HR during HH was greater than for NORM (*P*<0.001). No differences were found in RPE scores between conditions in either exercise. There was a significant main effect for RPE between sets in the back squat ($F_{(4, 44)}$=23.28; *P*<0.001; η^2=0.68), with RPE scores being greater than set 1 following sets 4 and 5 (*P*≤0.002). There was a significant main effect for RPE between sets in the deadlift ($F_{(4, 44)}$=13.94; *P*<0.001; η^2=0.56), with RPE scores being greater following set 5 than set 1 (*P*=0.001).

INSERT FIGURE 4 NEAR HERE

DISCUSSION

This study aimed to quantify physical performance, as well the cardiovascular and perceptual responses, during high-intensity resistance exercise under hypoxic conditions. The main findings of this investigation demonstrate that force and power variables were not affected by a hypoxic stimulus during high-intensity resistance exercise, despite an increased cardiovascular demand. While further research is required to fully elucidate the anabolic responses to high-intensity IHRT, these data highlight that the physical training stimulus is not compromised by the addition of hypoxia.

Although hypoxia has previously caused performance decrements during high-intensity anaerobic exercise (2,3), the current data demonstrated no differences in performance during high-intensity resistance exercises in either moderate-level or high-level hypoxia. Furthermore, trends in force and power values across each set were consistent in all experimental conditions. For the back squat, there was a trend for both mean and peak power values to decline across the set when compared to the first repetition. This may be explained by an accumulation of neuromuscular and metabolic fatigue with each repetition across a set. Indeed, similar trends in resistance exercise sets have been previously noted, with researchers hypothesizing that performance decrements result from decreases in adenosine triphosphate and phosphocreatine (PCr) concentrations, in concert with increased metabolic stress (13). Interestingly, augmented metabolic stress has been noted in recent IHRT research, with higher blood lactate concentrations following hypoxic resistance exercise compared to the equivalent exercise in normoxia (17,18). While this might suggest that the onset of fatigue could occur more readily during resistance exercise under hypoxic conditions due to increased metabolic stress, the current data do not support this inference.

This is most likely due to the high-intensity protocol used, which employed fewer repetitions per set than previous low- and moderate-intensity IHRT research (5 versus 10-14) (17,18), and as such decreased the total time-under-tension during which fatiguing intramuscular metabolites could accumulate. Also, the longer inter-set recovery periods used in the current study (3 minutes versus 1 minute) (17,18) are likely to have facilitated greater removal of these intramuscular metabolites, further lessening metabolic stress. Additionally, these increased recovery periods may have allowed for greater resynthesis of PCr stores. Although hypoxia has been shown to slow the rate of PCr recovery following repeated submaximal plantar flexions when compared to normoxic and hyoperoxic conditions, PCr levels returned close to resting levels within two minutes (14). It is therefore likely that the three-minute inter-set recovery employed in the current study was sufficient to allow near-complete PCr resynthesis. To this point, a recent investigation using moderate-intensity IHRT (10RM) with longer inter-set rest periods than typically used at that intensity (120 s) has demonstrated no added hypertrophic or strength benefit for IHRT (15). These results contrast those of Nishimura et al. (25), and could indicate that longer inter-set rest intervals attenuate any hypoxia-mediated increases in metabolic stress, and subsequent downstream anabolic responses. It is therefore important to acknowledge that while additional hypoxia does not appear to affect physical performance during high-intensity resistance exercise in hypoxia, these findings may not translate to low- or moderate-intensity exercise using more repetitions per set and shorter inter-set recovery periods. Future research should aim to clarify the impact of hypoxia on low- and moderate-intensity resistance exercise performance, as well as the acute metabolic and potential anabolic responses to high-intensity resistance exercise with hypoxia.

Similar trends were also evident in each condition for force and power variables for the deadlift exercise, though these were somewhat disparate from those observed for the back squat. For peak force and power, as well as mean power, the first repetition of each set demonstrated lower physical performance than each subsequent repetition. There are two likely explanations for this. Firstly, deadlifts commence with the barbell on the floor, and as such the exercise is initiated with a concentric contraction. In contrast, the back squat is initiated with an eccentric contraction where the participant lowers the weight to the bottom position. As such, the first repetition of a set of deadlifts is unable to take advantage of a preceding eccentric phase, and thus does not benefit from the stretch-shortening cycle, which has previously been shown to enhance contractile force in a subsequent concentric contraction (16). Secondly, subjects were instructed to perform the deadlift in a 'touch-and-go' fashion, meaning that each eccentric contraction ended when the barbell came in contact with the floor, and subjects were to immediately initiate the concentric phase of the next repetition. In doing this, it is likely that the barbell itself underwent a positive change in momentum, which decreased the inertial forces that subjects were required to overcome in the subsequent concentric phase.

As expected, the HH condition resulted in the lowest SpO_2 values, whereas NORM resulted in the highest SpO_2 values. The inverse of this trend was observed when examining the HR values following each set, with HH producing significantly greater responses than NORM. Furthermore, HR values for MH tended to lie between NORM and HH values following each set. These findings likely reflect an increased cardiac output which occurs in response to hypoxia, and may mitigate muscular oxygen deprivation (12). Importantly, increased cardiac output, and resultant oxygen delivery, can benefit the aerobic resynthesis of PCr (11), which is crucial to the production of power during subsequent bouts (23). However, despite the increase in cardiovascular demand during MH and HH, subjects did not perceive the exercise to be any more difficult than the NORM condition. While RPE scores following sets four and five of the back squat and the set five of the deadlift were significantly higher than after the first set of each exercise, there were no differences observed between conditions.

Studies have shown that RPE values provide an effective method of measuring exertion during resistance training (7,10), and are related to physiological measures of intensity including metabolic stress markers and the magnitude of muscle activation (20), Furthermore, RPE is sensitive to the inverse relationship between resistance exercise intensity and set volume, with heavier sets using fewer repetitions being perceived as more difficult than lifting comparatively lighter weight for more repetitions when external work is held constant (10). Considering that RPE values are easily obtained without the need for additional equipment and are non-invasive in nature, this tool would provide a practical method to monitor the intensity of resistance exercise in conjunction with a hypoxic stimulus.

In conclusion, the current study demonstrates that the addition of a hypoxic stimulus during high-intensity resistance exercise does not affect measures of physical performance. Furthermore, despite the increased cardiovascular demands associated with MH and HH, there was no perception that the resistance exercise was any more strenuous than in NORM. Taken together, these findings highlight that a matched physical training dose can be applied to individuals performing resistance exercise in either normoxia or hypoxia. While future research should examine whether the acute responses to high-intensity resistance exercise in hypoxia promote a favourable anabolic environment, the current data highlight that the training dose is not adversely affected by this novel practice.

PRACTICAL APPLICATIONS

The results of this study highlight that coupling resistance training with systemic hypoxia does not adversely impact on the imposed physical training dose. While further research is needed to elucidate the morphological and strength adaptations to high-intensity IHRT, athletes with access to hypoxic chambers and devices can employ this novel training strategy without negative impacts on their force or power output during training sessions. In addition, this research demonstrates that set RPE values are not affected by the addition of hypoxia to resistance exercise, and can therefore be used to easily and non-invasively monitor exercise intensity. It should be acknowledged that IHRT requires costly equipment to provide hypoxic air, and may therefore be limited to high-level athletes who have access to such equipment. Importantly, subjects in the current study were well experienced in resistance training, and the findings of this research are therefore applicable to athletes who regularly use resistance exercises to enhance muscular strength. The findings of this research also have implications for athletes engaged in other forms of hypoxic training. For example, team sport athletes who regularly perform intermittent hypoxic training or exposure for haematological or peripheral adaptations may be able to incorporate IHRT into their training to increase their total hypoxic dose in a given week, without sacrificing the physical training stimulus experienced. Future research should investigate the acute metabolic, endocrine and neural responses to high-intensity resistance exercise with hypoxia, in order to clarify whether this form of IHRT can promote responses conducive to hypertrophic and strength gains. In addition, researchers should also examine the intramuscular oxygenation status of agonist muscles during IHRT to ascertain the effect of systemic hypoxia on the function of exercising skeletal muscle. Such research would provide valuable information regarding the mechanisms that underpin adaptive responses to resistance exercise.

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FIGURE CAPTIONS

Figure 1 – Pooled data for (a) peak and (b) mean force as well as (c) peak and (d) mean power during the concentric phase of each repetition across five sets of the back squat. Data are mean ± SD.

NORM = normoxia; MH = moderate-level hypoxia; HH = high-level hypoxia.

*Significantly different from repetition 1 across all conditions ($p < 0.05$).

Figure 2 – Pooled data for (a) peak and (b) mean force as well as (c) peak and (d) mean power during the concentric phase of each repetition across five sets of the deadlift. Data are mean ± SD.

NORM = normoxia; MH = moderate-level hypoxia; HH = high-level hypoxia.

*Significantly different from repetition 1 across all conditions ($p < 0.05$).

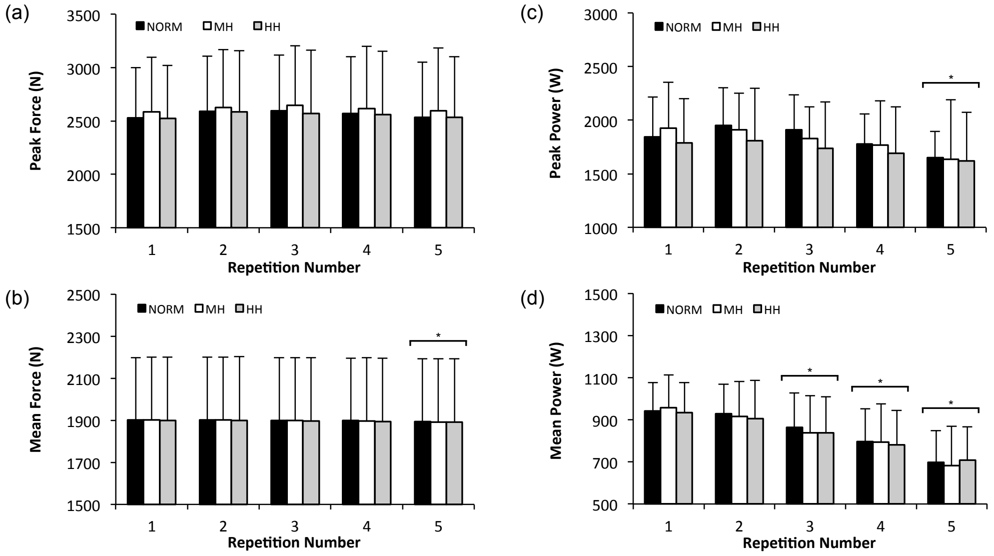
Figure 3 – Percentage change in concentric force and power from the first to the fifth set of the back squat (a and b) and the deadlift (c and d) in NORM, MH and HH.

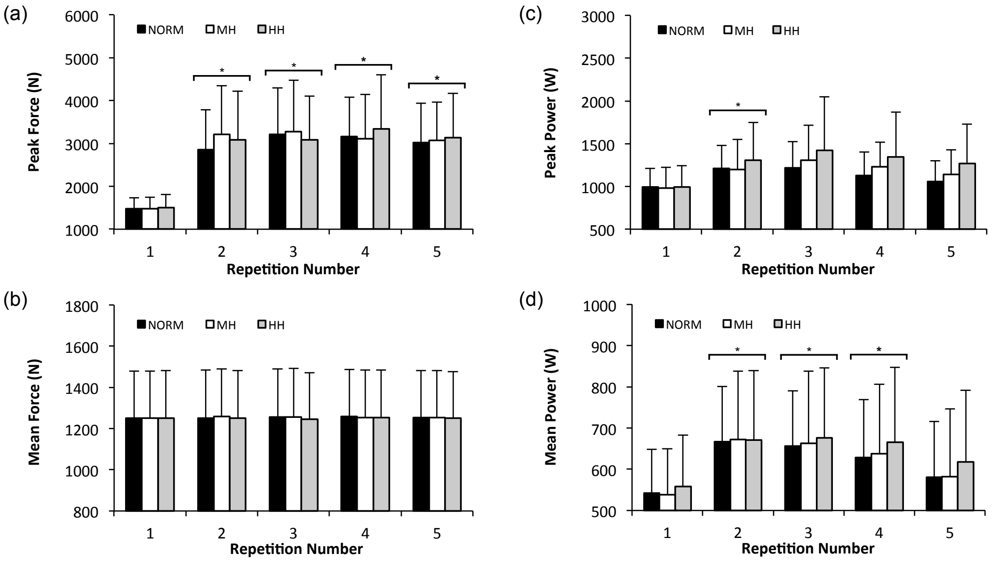
NORM = normoxia; MH = moderate-level hypoxia; HH = high-level hypoxia.

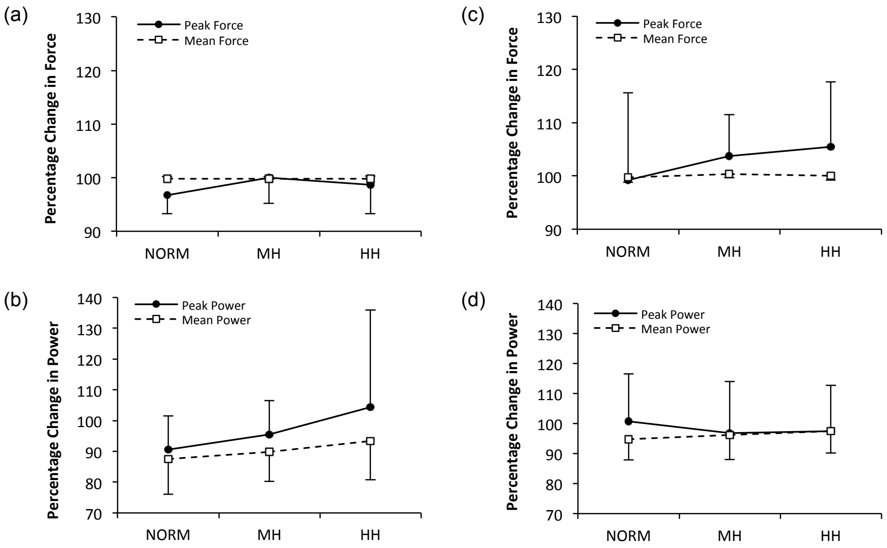
Figure 4 – Pooled data for arterial blood oxygen saturation (SpO_2), heart rate (HR) and rating of perceived exertion (RPE) immediately following each set of 5 repetitions for the back squat and deadlift exercises. Circles represent normoxia, squares represent moderate-level hypoxia and triangles represent high-level hypoxia. Data are mean ± SD.

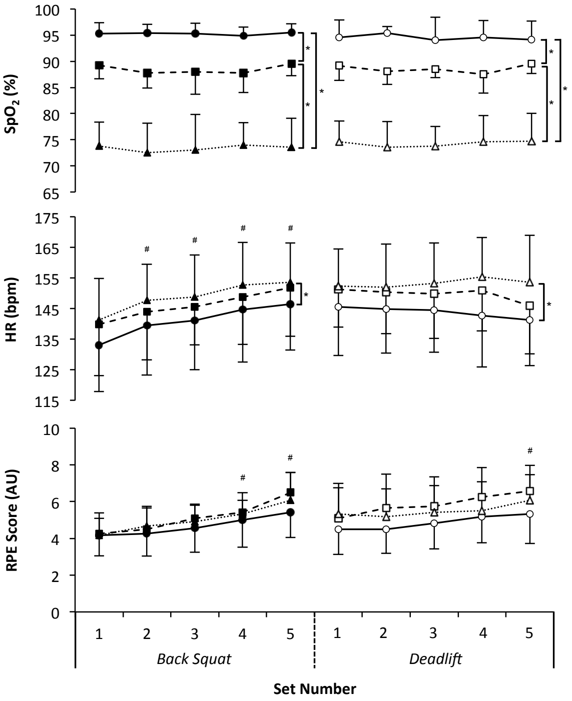
*Significantly different between conditions ($p < 0.05$).

$^{\#}$Significantly different from set 1 across all conditions ($p < 0.05$).


(a)
■NORM □MH ▨HH
Peak Force (N)
3500
3000
2500
2000
1500
1
2
3
4
5
Repetition Number
(b)
■NORM □MH ▨HH
Mean Force (N)
2500
2300
2100
1900
1700
1500
*
1
2
3
4
5
Repetition Number
(c)
■NORM □MH ▨HH
Peak Power (W)
3000
2500
2000
1500
1000
*
1
2
3
4
5
Repetition Number
(d)
■NORM □MH ▨HH
Mean Power (W)
1500
1300
1100
900
700
500
*
*
*
1
2
3
4
5
Repetition Number


(a)
Peak Force (N)
6000
5000
4000
3000
2000
1000
NORM
MH
HH
*
*
*
*
1
2
3
4
5
Repetition Number
(b)
Mean Force (N)
1800
1600
1400
1200
1000
800
NORM
MH
HH
1
2
3
4
5
Repetition Number
(c)
Peak Power (W)
3000
2500
2000
1500
1000
500
NORM
MH
HH
*
1
2
3
4
5
Repetition Number
(d)
Mean Power (W)
1000
900
800
700
600
500
NORM
MH
HH
*
*
*
1
2
3
4
5
Repetition Number


(a)
Percentage Change in Force
130
120
110
100
90
Peak Force
Mean Force
NORM
MH
HH
(b)
Percentage Change in Power
140
130
120
110
100
90
80
70
Peak Power
Mean Power
NORM
MH
HH
(c)
Percentage Change in Force
130
120
110
100
90
Peak Force
Mean Force
NORM
MH
HH
(d)
Percentage Change in Power
140
130
120
110
100
90
80
70
Peak Power
Mean Power
NORM
MH
HH


SpO$_2$ (%)
100
95
90
85
80
75
70
65
*
*
*
*
*
*
HR (bpm)
175
165
155
145
135
125
115
#
#
#
#
*
*
RPE Score (AU)
10
8
6
4
2
0
#
#
#
1
2
3
4
5
Back Squat
Deadlift
Set Number