Does Intermittent Hypoxia Elicit Dose-Dependent Strength and Neuromuscular Responses in Healthy Adults?

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Introduction

Acute intermittent hypoxia (AIH) is a novel therapy that can enhance strength and neuromuscular function in individuals, particularly those with neurological deficits. Research has shown that a hypoxic dosage equivalent to 9% fraction of inspired oxygen (FiO_2) can increase strength and neuromuscular activity in clinical cases like Spinal Cord Injuries (SCIs). While the exact mechanisms underlying AIH-induced strength gains and functional improvements in neuromuscular responses are not well understood, it is believed that these improvements may be linked to a sympathoexcitatory release of serotonin near motor neurons and the activation of cellular cascades that enhance motoneuron activity. Finding the optimal therapeutic dosage to enhance strength gains while minimizing the adverse effects of hypoxia is crucial to understand the acute and prolonged effects on strength and neuromuscular function. This study, is the first to combine dose-dependent AIH protocols and measure time course of strength and neuromuscular function, which has important implications to recreationally healthy and clinical populations.

Purpose

The purpose of this study was to examine the dose-dependent influence of a Low Dose (LD) and High Dose (HD) acute intermittent hypoxia (AIH) protocol on handgrip strength and neuromuscular function.

Methods

Twelve healthy subjects (mean ± SD; age: 25.5 ± 7.4 yrs.) were randomized to perform three AIH protocols consisting of:

1. Sham [SH] (21% Fraction of Inspired Oxygen [FiO_2])
2. Low dose [LD] (15% FiO_2)
3. High dose [HD] (9% FiO_2)

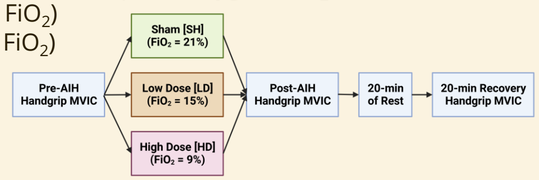

Figure 1. *Study Visit Timeline*

AIH Protocol (30 min, 1:1 Hypoxia/Normoxia Ratio):

- Participants laid in a supine position while being exposed to 15 brief (60-sec) periods of hypoxic air exposure interspersed with 60-sec of normoxic air exposure at a 1:1 ratio for a total of 30 min.
- A commercial hypoxic generator was used to adjust the FiO_2 dosage for each condition (HYP123, Hypoxico Altitude Training Systems, New York, NY, USA).
- An oro-nasal mask connected with a two-way non-rebreathing valve (7400 Series Silicone VmaskTM, Hans Rudolph Inc. Shawnee, KS, USA) was manually secured over the participant's nose and mouth during the hypoxic period and removed during the normoxic period.

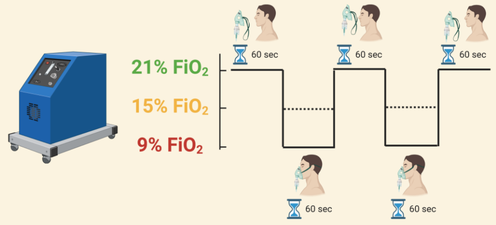

Figure 2. *AIH Protocol*

Maximal Isometric Handgrip Protocol & Electromyography:

- A calibrated handgrip dynamometer (TSD121C – BIOPAC System Inc., Goleta, CA, USA) was used to collect maximal voluntary isometric contraction (MVIC) force at three separate time points (Figure 1).
- Three 6-sec long MVIC handgrip contractions were performed with the participant's dominant arm flexed at a 90° angle.
- Each MVIC was separated by 60-sec of rest, and the contraction that generated the highest force output was used for data analysis.
- A bipolar surface electrode arrangement was used to record electromyographic amplitude (EMG_{AMP}) and electromyographic frequency (EMG_{FC}) signal parameters from the muscle belly of the flexor digitorum superficialis muscle during the handgrip MVICs.

Force and Neuromuscular Signal Analysis:

- Both force and the electromyographic signal were simultaneously collected using a BIOPAC MP150 data acquisition device (BIOPAC System Inc., Coleta, CA, USA).
- Electromyographic signals were zero-meaned and bandpass filtered at 10-500Hz & Handgrip was set to a sampling frequency of 1,00Hz
- The middle 33% of each 6-sec handgrip MVIC was used to determine the HG_{MAX}, EMG_{AMP}, and EMG_{FC}.

Statistical Analysis

- All independent variables were normalized to the Pre time point during the SH protocol.
- Three, 3 (Protocol: SH, LD, and HD) x 3 (Time: Pre, Post, and Recovery) two-way repeated measure ANOVAs (RM-ANOVAs) were performed with an alpha of $p \leq 0.05$ considered statistically significant for all statistical analyses.

Results

Maximal Handgrip Strength (HG_{MAX})

- Significant Protocol x Time interactions for HG_{MAX} **($p < 0.01$)**
- Follow-up 1-way RM-ANOVA for HG_{MAX} indicated that handgrip strength was on average **13.2%** greater for both the LD and HD protocols relative to SH (p<0.01) (Figure 2).
- In addition, each protocol elicited differences in time course response for HG_{MAX} (Figure 3).
  - **LD: 10%** Pre-Post increase (p=0.02).
  - **HD: 14.2%** Pre-Post increase (p<0.01) & **6.2%** Post-Recovery increase (p=0.03).

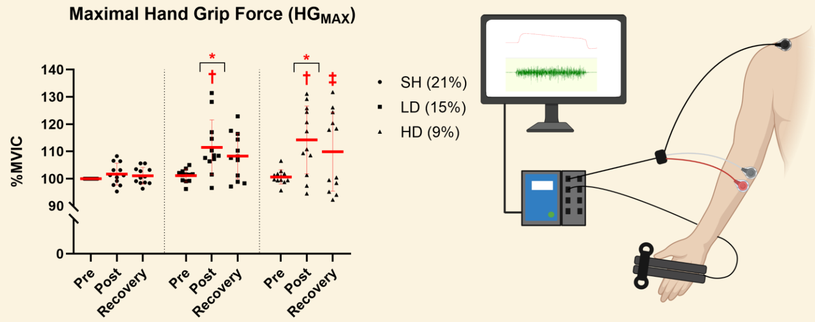

Figure 3. *Normalized isometric handgrip force across the three acute intermittent hypoxia protocols and time points (Mean ± SD). * indicates LD & HD > SH; † indicates Post > Pre; ‡ indicates Recovery > Post (p < 0.05).*

Neuromuscular Responses of Forearm (EMG_{AMP} & EMG_{FC})

- **EMG_{AMP}:** Significant Protocol x Time interaction **(p=0.02)**
- Follow-up 1-way RM-ANOVA for EMG_{AMP} indicated that muscle activation was **14.3%** greater during the HD protocol relative to SH (p=0.02) (Figure 4A).
- In addition, only the HD protocol elicited detectable differences in time course response for EMG_{AMP} (Figure 4A).
  - **HD: 11%** Pre-Post increase (p=0.03) & **8%** Post-Recovery decrease (p=0.02).
- **EMG_{FC}:** No significant Protocol x Time interaction (p>0.05) (Figure 4B).

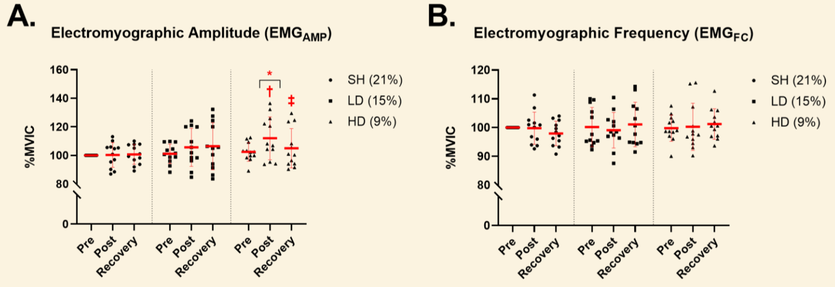

Figure 4. *Normalized electromyographic amplitude (A.) and electromyographic frequency (B.) of the flexor digitorum superficialis muscle across the three acute intermittent hypoxia protocols and time points (Mean ± SD). * indicates HD > SH; † indicates Post > Pre; ‡ indicates Recovery < Post (p < 0.05).*

Conclusions

- A 30-min AIH protocol using a FiO_2% of 15% or 9% lead to increases in isometric handgrip strength immediately following hypoxic exposure compared to a Sham condition.
- Improvements in handgrip strength (HG_{MAX}) following an AIH protocol were dose-dependent with sustained strength increases remaining for 20-min in the HD protocol exclusively, but not in the LD or SH.
- EMG_{AMP} was sensitive to the HD protocol and tracked similarly with HG_{MAX} immediately following the AIH protocol.
- Within the HD protocol, factors other than increased muscle activation or greater motor unit recruitment mediated handgrip strength gains following 20-min of rest as indicated by a lower EMG_{AMP} with sustained force (HG_{MAX}).
- Neither LD nor HD AIH protocols had any influence on motor unit action potential conduction velocity (EMG_{FC}) during handgrip MVICs.

Practical Applications

These findings suggest that a greater hypoxic dose (lower FiO_2) used during an AIH protocol can provide sympathoexcitatory increases in isometric grip strength and muscle activation, with functional strength remaining for up to 20-min following the hypoxic stimulus. These results may be important to strength and conditioning specialists who want to implement AIH as a pre-competition stimulus to improve short-term strength and power performance.

SCAN ME

All figures were created with BioRender.com or GraphPad Prism version 9.5.1