International Journal of EXERCISE SCIENCE

*Original Research*

# Cognitive Function is Unaffected during Acute Hypoxic Exposure but was Improved Following Exercise

JASMIN R. JENKINS†[1], OWEN F. SALMON†[2], and CORY M. SMITH‡[2]

[1]Interdisciplinary Health Sciences PhD Program, College of Health Sciences, University of Texas-El Paso, El Paso, TX, USA; [2]Department of Health, Human Performance, and Recreation, Robbins College of Health and Human Sciences, Baylor University, Waco, TX, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

***International Journal of Exercise Science 15(5): 1481-1491, 2022.*** To investigate the effects of two levels of acute hypoxic exposure and exercise compared to normoxia on the Stroop color word test. A total of 14 (4 females and 10 males) active participants with a self-reported (mean±SEM) 8.54±1.44 h/week of physical activity, performed a 3-repetition maximum hex/trap bar deadlift, Hand-Release Push-Up, and Leg Tuck events from the Army Combat Fitness Test at normoxia and normobaric hypoxia of fraction of inspired oxygen ($FiO_2$) of 16% and 14.3%. The Stroop color-word test was administered on a touch screen device before and after the exercise battery, where participants were given congruent (word and ink color matching) and incongruent (non-matching) prompts. Peripheral oxygen saturation ($SpO_2$) and heart rate were recorded at pre- and post-exercise. Variables obtained from the Stroop color word test were not influenced as a result of acute hypoxic exposure but did improve after an exercise battery. Peripheral oxygen saturation was greater during normoxia compared to acute hypoxic exposure which indicated a systemic change in oxygenation. The results of the present study indicated that the Stroop color-word test is not influenced by an $FiO_2$ 16% or 14.3%, however, exercise did improve Stroop score and response time.

KEY WORDS: Stroop Color Word Test, cognition, high altitude

## INTRODUCTION

Humans are highly susceptible to oxygen deprivation, making hypoxia a major concern in modern aviation affecting the physiological processes and cognitive function in the human body (8, 18). A hypoxic environment lacks sufficient oxygen to sustain normal physiological function, in which the severity of oxygen deprivation can be influenced by the duration and the degree of reduction of ambient pressure or gasses concentration (20). In the ascent to altitude there is a progressive decline in the partial pressure of oxygen; such that a reduction in atmospheric pressure allows atmospheric gasses to expand creating a diluted concentration at altitude and decreasing oxygen availability to sustain normal homeostatic function (16, 20, 21, 24). As a result of the decrease in arterial oxygen saturation ($SpO_2$), hypoxia becomes much more severe and can induce headaches, nausea, and insomnia (9, 10, 12, 13, 16).

A number of essential physiological responses are required to maintain tissue oxygen supply in response to hypoxia (20). Kon, et al., (2010) reported elevations in blood lactate, epinephrine, and norepinephrine concentrations after resistance exercise while breathing 13% fraction of inspired oxygen ($FiO_2$) (12,500 ft or 3800 m) compared to Normoxia, indicating an increase in overall metabolic stress (17). This is further supported by Rasmussen, et al., 2010, who reported an increase in cerebral metabolic rate during maximal exercise to maintain brain oxygen supply, but this same maximal exercise induced increase in cerebral metabolic rate was not sustainable in an $FiO_2$ 10% (19,000 ft or 5800 m) (27). Such that exercise and hypoxia are both contributors to cerebral metabolic stress. In addition, these cerebral metabolic changes are reported to alter cerebral activation during exercise but have also been suggested to affect cognitive function as a result (27). A review of literature by Taylor, et al., (2016) supported the idea that affected cognitive processes may also be hypoxic severity dependent, such that the higher the altitude the more complex of a task is affected (32). As of current, there is only an estimate of altitudes that affect certain cognitive processes, therefore, the gap in knowledge of reduced cerebral blood flow affecting cognitive processes requires further investigation (11, 22, 32, 33).

The Stroop task assesses executive function through the ability to cause cognitive interference, which occurs when the processing of a stimulus affects the simultaneous processing of another of the same stimulus (28, 29). The Stroop task functions by requiring participants to actively perform a less automated task (identifying the color of the text) while inhibiting the process of a more automatic task (reading the word), the challenge of inhibiting the automated task is termed the Stroop effect (29). This cognitive inhibition mimics the high stress environments servicemembers experience during mission deployment such that several stimuli (i.e., mission goal, auditory cues, visual cues, physical exertion) in the presence of hypoxic and fatigued conditions, may cause a series of impulsive or erratic behavior (2, 11, 19, 36). The combined effects of hypoxia and exercise have the potential to worsen the already negative individual effects on cognitive function (4, 5, 14, 15). Therefore, investigating the effects of acute hypoxic exposure combined with combat related physical tasks is crucial for the military population. The purpose of this study was to investigate whether executive function as assessed by scoring of the Stroop color-word test, is decreased during moderate and severe hypoxic exposure and in combination with exercise. (18, 24, 25).

## METHODS

*Participants*

Fourteen participants (mean ± SEM; females $n$ = 4, 26.75 ± 1.32 yrs, 160.7 ± 4.32 cm, 64.97 ± 3.16 kg; males $n$ = 10, 27.60 ± 1.51 yrs, 175.8 ± 2.44 cm, 191.5 ± 9.81 kg) recreationally active (self-reported 8.54 ± 1.44 h of physical activity per week) were recruited to participate in the study. Participants were excluded if they presented with any musculoskeletal, neurological, or cardiovascular disorders. The present study was approved by the University's Institutional

Review Board and all participants (4 females, 10 males) signed an informed consent and completed a health history questionnaire to identify any exclusion criteria prior to participation. This research was carried out in accordance with the ethical standards of the International Journal of Exercise Science (23).

*Protocol*

Executive function was assessed using the Stroop color-word test before and after exercise (29). The Stroop test required participants to select the font color the prompt was displayed in, not what the word read. The test was administered using a mobile smart device (Galaxy Note20 Ultra 5G, Samsung Electronics Co., Ltd, Suwon-si, South Korea) and participants were instructed to respond as quickly as possible and score as many points within a 5-min time frame. The test included prompts that were displayed in the same ink color as the word that was displayed. The prompts included the words *red, blue, green,* or *yellow*, with the ink color matching (congruent) or different (incongruent). The Stroop test was administered at Normoxia and Post-Exercise at all normal and hypoxic conditions. The total score, total responses, percent accuracy, average Time per Score (Time/Score), and average Time per Response (Time/Response) were displayed at the conclusion of the test.

Participants came to the lab on five different occasions with 48h between visits, study design is presented in Figure 1. Participants performed a series of three exercises in accordance with the United States Army Combat Fitness Test (ACFT) to examine the effect of exercise on cognitive executive function during normobaric hypoxic exposure (1). Visit 1 consisted of a familiarization session in normoxia, where participants 1 repetition maximum (1RM) trap/hex bar deadlift was obtained (3). On the same visit, participants were instructed on proper technique and form for each of the exercises. In sequence, participants performed a three repetition maximum trap/hex bar deadlift (3RM deadlift), two-minute hand-release push-ups (HRP), and two-minute leg tuck (LTK) tests in accordance with the U.S. Army Field Testing Manual (1). Visit 2 was performed identical to Visit 1 in order to verify 1RM and reduce any possible learning effects on the Stroop color-word test.

Hypoxic testing occurred on visits 3-5, where normoxic and the two hypoxic visit order was randomized. All participants were exposed to each hypoxic condition for the entire duration of the 1h visit. Prior to the 3RM deadlift, participants performed a warmup set of 8-10 repetitions with the 27.2 kg (60lb) trap/hex bar alone, followed by a single set of 3-5 repetitions with approximately a quarter of the weight of their calculated 3RM (93% of 1RM). The 3RM deadlift event required participants to perform three complete repetitions at 93% of their 1RM with an allotted three attempts. The HRP were performed according to the field manual guidelines, where participants were allotted two minutes to perform as many repetitions as possible (1). The LTK event was performed on a standard pull-up bar according to the manual's procedures, where participants performed as many repetitions as possible in two minutes (1). An approximate two-to-three-minute rest between events was given while heart rate and finger pulse oximetry measures were taken before and after exercise at each condition (Oxi-Go™Pulse Oximeter, QuickCheck Pro, Oximeter Plus, Inc. Roslyn Heights, NY).

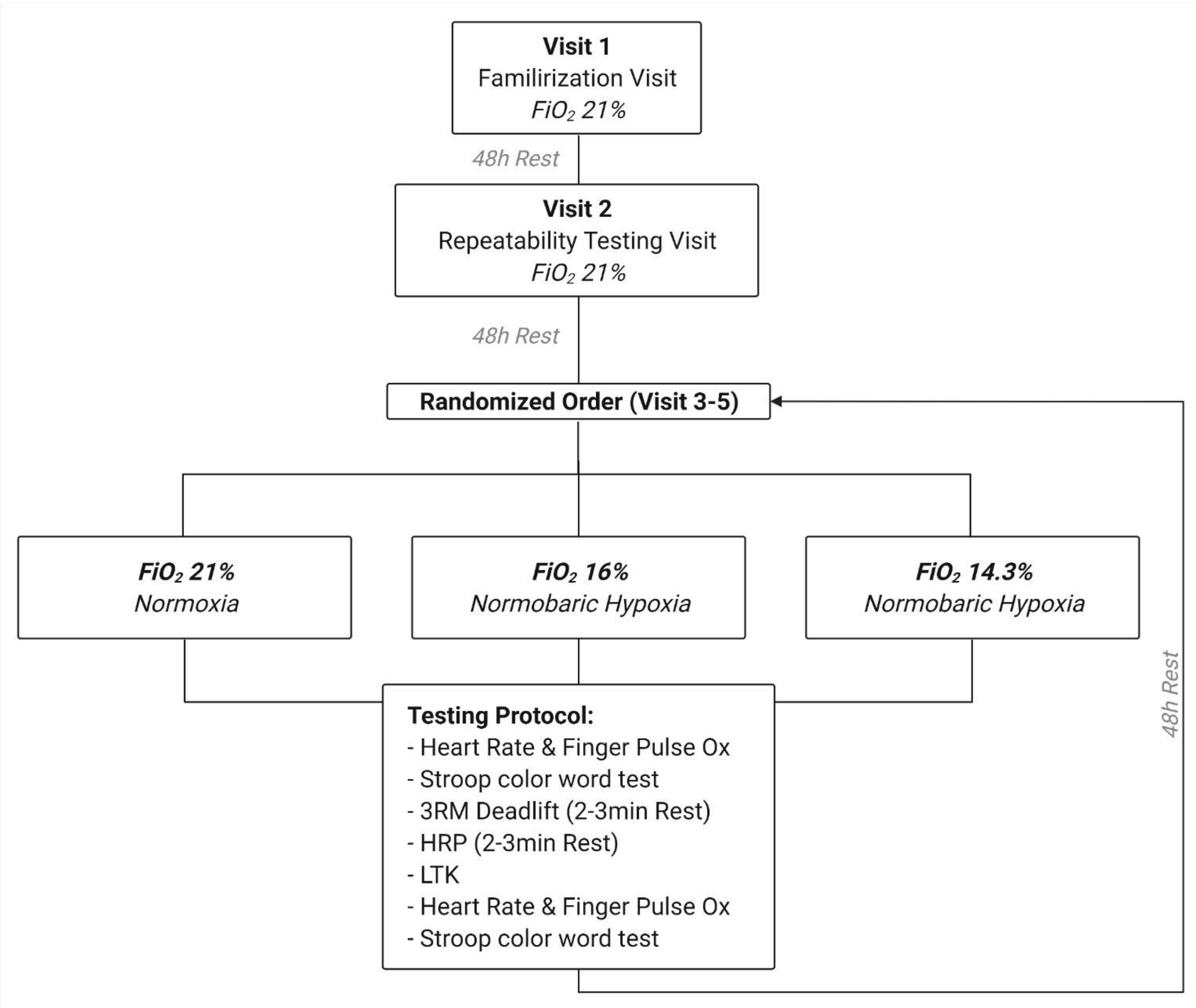


**Figure 1.** Presents study design order, where main study variables were collected on Visits 3-5 after two 'practice' visits. FiO2 – Fraction of Inspired Oxygen, 3RM – Three repetition maximum, HRP – Hand-release push-up, LTK – Leg tuck. Created with BioRender.com

All participants were exposed to normobaric hypoxia, to simulate altitude-induced hypoxia, through a Hans Rudolph Oro-Nasal mask and connected to a two-way non-rebreathing valve (7400 Series Silicone Vmask™, Hans Rudolph Inc. Shawnee, KS, USA). A HYP 123 Altitude generator (Hypoxico Altitude Training Systems, New York, NY, USA) was used to alter the $FiO_2$ from ambient room air (9, 12, 18). A 120L Douglas bag was used to store normobaric hypoxic air at the corresponding $FiO_2$ to allow subjects to breathe freely. Oxygen content was continuously monitored using the MySign®O (EnviteC by Honeywell, Wismar, Germany). Fraction of inspired oxygen was altered from ambient room air at Normoxia to $FiO_2$ 16% (7,000 ft or 2133 m), and 14.3% (10,000 ft or 3048 m).

*Statistical Analysis*
The Shapiro-Wilk normality test and the central limit theorem were used with no missing data to retain the assumption of normality (13, 19, 39). Data were analyzed by each variable (Stroop test variables, SpO2, and HR) using a 3 (Hypoxia: Normoxia, 16%, 14.3%) by 2 (Time: Pre, Post) repeated measures analysis of variance (ANOVA) accordingly. Follow up one-way ANOVAs and paired samples t-tests were performed when appropriate. Post-hoc least significant difference was used when appropriate with significant alpha set at $p \leq 0.05$. Should sphericity not be met according to Mauchly's Test of Sphericity, Greenhouse-Geiser corrections were applied, and partial eta-squared effect sizes were calculated. All statistical calculations were carried out using IBM SPSS v. 27 (Armonk, NY, USA).

**RESULTS**

There was no Hypoxia by Time interaction for Total Score ($p$ = 0.656, $\eta_p^2$ = 0.032) and no main effect for Hypoxia ($p$ = 0.580, $\eta_p^2$ = 0.041). There was, however, a significant main effect for Time, indicating Stroop Scores were greater following exercise across all Hypoxic conditions ($p$ = 0.003, $\eta_p^2$ = 0.505) (Figure 2a). In addition, there was no Hypoxia by Time interaction for Accuracy ($p$ = 0.234, $\eta_p^2$ = 0.106), as there was no main effect for Hypoxia ($p$ = 0.339, $\eta_p^2$ = 0.080) nor Time ($p$ = 0.203, $\eta_p^2$ = 0.121) (Figure 2b).

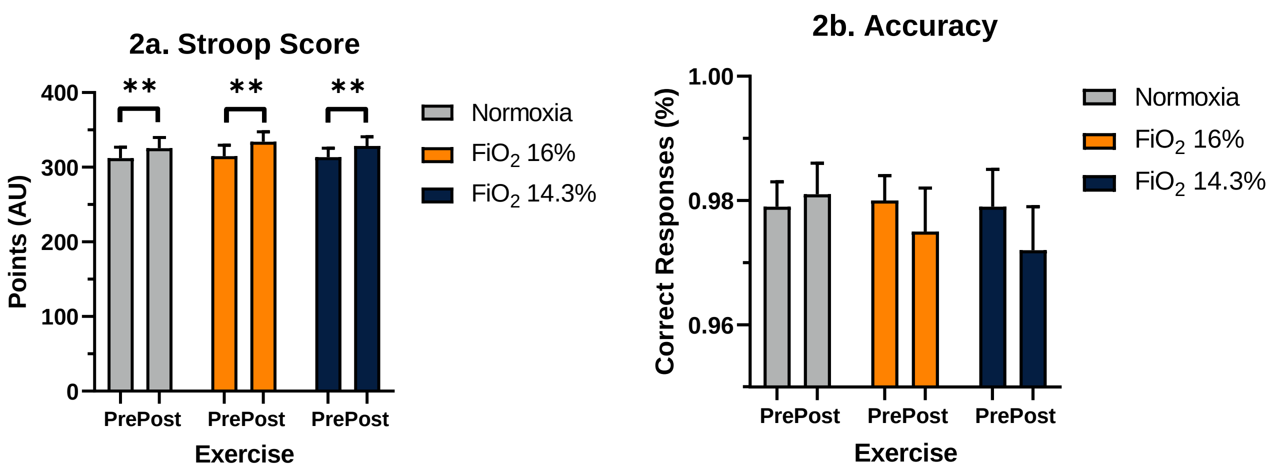


**Figure 2**. Presents executive function measures of Total Score (a) and Accuracy (b) stratified by hypoxia. All data bars display sample means and error bars indicate standard error of mean. **indicates a significant difference between pre- and post-exercise where $p < 0.001$.

There was no Hypoxia by Time interaction for Time/Score (p=0.618, $\eta_p^2$=0.036). There was, however, main effect for Time on Time/Score (p=0.006, $\eta_p^2$=0.449), where Time relative to Stroop Score was significantly faster following exercise (Figure 3a). Furthermore, there was no Hypoxia by Time interaction ($p$ = 0.618, $\eta_p^2$ = 0.036) or main effect for Hypoxia ($p$ = 0.581, $\eta_p^2$ = 0.041) for the Time/Response. There was, however, a significant main effect for Time ($p$ = 0.034, $\eta_p^2$ = 0.303), which indicates that the Time/Response was significantly lower following exercise independent of Hypoxic condition (Figure 3b).

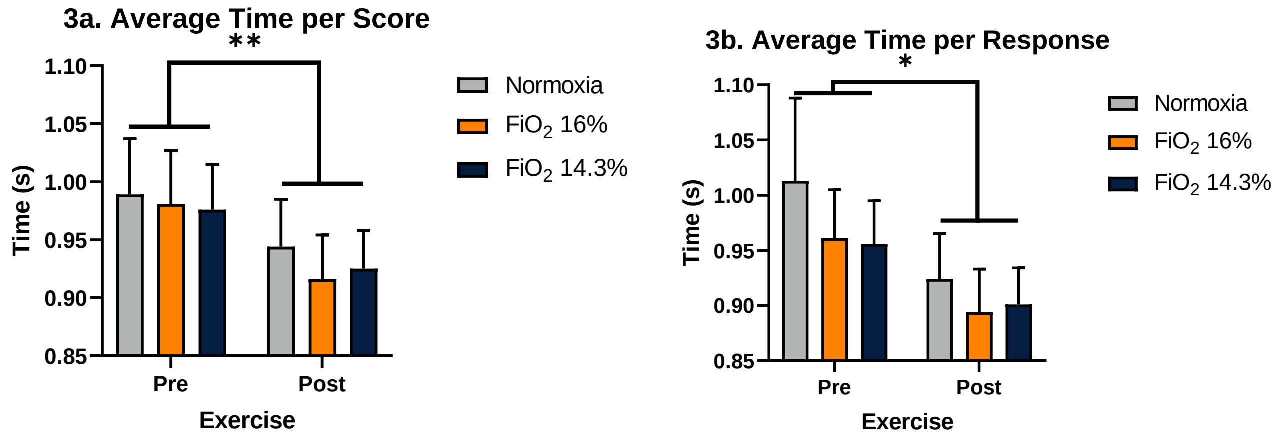


**Figure 3.** Presents reaction time (s) by average Time per Score (a) and average Time per Response (b) at each hypoxic condition. All data bars display sample means and error bars indicate standard error of mean. *indicates a significant difference pre- and post-exercise where $p$ < 0.05; **indicates a significant difference pre- and post-exercise where $p$ < 0.001.

There was no significant Hypoxia by Time interaction for $SpO_2$ ($p$ = 0.608, $\eta_p^2$ = 0.038) or main effect for Time ($p$ = 0.249, $\eta_p^2$ = 0.101). There was a main effect for Hypoxia (Figure 4a; $p$ < 0.001, $\eta_p^2$ = 0.696), indicating that $SpO_2$ was reduced at $FiO_2$ 16% (92.82 ± 0.78%; $p$ < 0.001) and 14.3% (91.61 ± 0.76%; $p$ < 0.001) compared to Normoxia (97.21 ± 0.36%). Furthermore, there was no Hypoxia by Time interaction for HR ($p$ = 0.085, $\eta_p^2$ = 0.173) or main effect for Hypoxia ($p$ = 0.440, $\eta_p^2$ = 0.061). There was a main effect for Time (Figure 4b; $p$ < 0.001, $\eta_p^2$ = 0.910), indicating HR was elevated after exercise at Normoxia ($p$ < 0.001), $FiO_2$ 0.16 ($p$ < 0.001), and $FiO_2$ 0.143 ($p$ < 0.001).

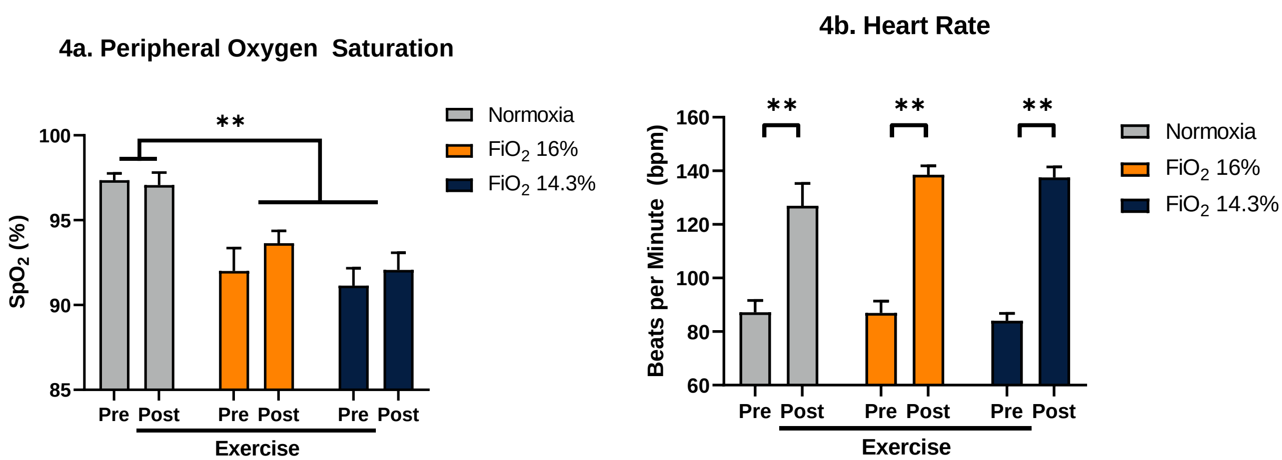


**Figure 4**. Physiological variables Peripheral Oxygen Saturation (a) and Heart Rate (b) in response to exercise and by hypoxia. All data bars display sample means and error bars indicate standard error of mean. *indicates a significant difference pre- and post-exercise where $p$ < 0.05; **indicates a significant difference pre- and post-exercise where $p$ < 0.001.

**DISCUSSION**

The present study aimed to investigate the combined effects of acute hypoxic exposure and exercise on executive function as measured by the Stroop test. The results indicated that hypoxia did not alter Stroop Score or Accuracy, however, exercise increased Stroop Score with no change in Accuracy (Figure 2a, 2b). Furthermore, there was an improved Time/Score and Time/Response due to exercise, corresponding to quicker response times (Figure 3a & 3b) independent of hypoxic exposure. Peripheral oxygen saturation was lower during hypoxic exposure ($FiO_2$ 16% or 7,000 ft or 2133 m and 14.3% or 10,000 ft or 3048 m) compared to Normoxia but did not change with exercise (Figure 4a). Heart rate was not affected by acute hypoxic exposure but did increase in response to exercise in all conditions (Figure 4b).

There were no differences in Stroop test variables of Score, Accuracy, Time/Score, and Time/Response from Normoxia to 16% (7,000 ft or 2133 m) and 14.3% (10,000 ft or 3048 m) conditions (Figure 2 & 3). These findings were in agreement with Ochi, Yamada, et al., (2018), which reported no difference in error rate (Accuracy), Time/Score, and Time/Response when exposed to normobaric hypoxia of $FiO_2$ 13.5% (11,500 ft or 3505 m) (25). In another study, Ochi, Kanazawa, et al., (2018) reported no differences at $FiO_2$ 16.5% (6,562 ft or 2000 m) and 13.5% (11,500 ft or 3505 m) in Time/Score, Time/Response, and Accuracy (24). In addition, Legg et al., (2016) reported no difference in Stroop test variables when exposed to $FiO_2$ 15.4% (8,000 ft or 2438 m) and $FiO_2$ 13.2% (12,000 ft or 3658 m) in a hypobaric chamber (18). Turner, Byblow, & Gant (2015) found similar Stroop test performance as part of a battery of cognitive tests at $FiO_2$ 10% (19,000 ft or 5800 m) and normoxia (34). These results are indicative of there being a specific cognitive process that is impaired at lower altitudes, that may be only partially depicted in the Stroop test. Present study results suggest that cognitive inhibition as measured by the variables Stroop color-word test is not affected up to altitudes of $FiO_2$ 14.3% (10,000 ft or 3048 m).

The findings of the current and previous studies (18, 24, 25) contrasted with Asmaro et al., (2013) who reported lower Stroop Scores from a cognitive testing battery, but showed 26.9% and 20.3% improved reaction times at $FiO_2$ 8.1% (25,000 ft or 7620 m) compared to Normoxic and $FiO_2$ 10.7% (17,500 ft or 5334 m), respectively (7). Furthermore, Takács, Czigler, Pató and Balázs (2017) reported similar but opposite findings of increased accuracy but an increase in reaction time of a Voice Stroop Test (subjects responded to the gender of the speaker) at $FiO_2$ 10.6% (18,000 ft or 5500m) (31). In addition, Takács et al., (2017) also reported 90.6% longer reaction times during hypoxia with no change in accuracy for a Name Stroop Task (subjects responded to the gender of presented names) in hypoxia (31). These differences in cognitive function in response to hypoxia, indicate there may be an effect related to the severity of hypoxia and type of cognitive process. Executive function as measured by the traditional Stroop Test is only impaired in extreme hypoxic environments (approximately above $FiO_2$ 10%, 19,000 ft, or 5800 m (7, 31)) (6). The differences in Stroop Test administration/test-variations like color-word (present study and previous (7, 18, 24, 25, 34)), gender response (31), or as part of a larger battery of cognitive tests (7, 18, 31, 34) all encompass basic cognitive inhibition but include other aspects of cognition in its variation. As previously mentioned, the type and severity of cognitive impairments may be hypoxic severity dependent (32). Simple and complex tasks are impaired at low to moderate hypoxia and only complex tasks at higher levels of hypoxia (22, 32, 35), which might explain the variation in findings of present and previous results (7, 18, 24, 25, 31, 34).

Physiological variables (HR and $SpO_2$) of the present study mirrored the findings of previous studies during combined fatigue and hypoxic exposure (18, 24, 25). Specifically, $SpO_2$ in the present study decreased 4.4% to 5.6% in response to the $FiO_2$ 16% (7,000 ft or 2133 m) and 14.3% (10,000 ft or 3048 m) hypoxic conditions compared to Normoxia, which mirrors the 4% to 22.7% decrease in $SpO_2$ reported by others (18, 24, 25). In contrast to the current study, the results of previous studies indicated that $SpO_2$ was dependent on the severity of hypoxic exposure with greater hypoxia resulting in lower $SpO_2$ (18, 24). The similar $SpO_2$ values observed during the $FiO_2$ 16% (7,000 ft or 2133 m) and 14.3% (10,000 ft or 3048 m) may suggest that exercise under hypoxic conditions is a more potent regulator of peripheral oxygen saturation during hypoxia maintaining blood flow to peripheral systems.

Heart rate was not changed in response to an $FiO_2$ of 16% (7,000 ft or 2133 m) and 14.3% (10,000 ft or 3048 m), suggesting that simulated altitudes of the present study had no alteration in blood flow responses. Contrasting evidence in previous literature indicates there to be a concomitant increase in HR with hypoxic exposure (24-26, 33). The disparity between present results and earlier literature can be attributed to variations in the degree of hypoxic exposure or the lengths of hypoxic exposure. For example, Ochi, Yamada et al. (2018) reported both an increased resting and exercise HR response at $FiO_2$ of 13.5% (11,483 ft or 3500 m) compared to Normoxia (25). Similarly, other literature reported an increased resting and exercise HR at $FiO_2$ ranging from 15.4% (8,000 ft or 2438m) to 10% compared to Normoxic conditions (24-26, 33). Literature that tested similar hypoxic conditions of $FiO_2$ 16.5% (6,562 ft or 2000 m) (24) and 17.3% (26) to the present study (16% [7,000 ft or 2134 m]) did not observe an increased HR response with a concomitant reduction in $FiO_2$. We can therefore hypothesize a potential threshold effect of HR in response to hypoxia, that the compensatory increase in HR (and so an increase in cardiac output shuttling oxygen-rich blood to vital areas of the body) occurs somewhere between $FiO_2$ 17.3% (5,000 ft or 1524 m)-14.3%(10,000 ft or 3048 m) and 15.4 (8,000 ft or 2438 m) -10% (19,000 ft or 5791) (24-26, 33). There is some overlap within the literature and present results, Pilmanis et al. (2016) reported an increase as early as 15.4% (8,000 ft or 2438m) whereas the present study saw none at 14.3% (10,000 ft or 3048 m) (26). Further investigation is needed to determine the existence of a so called "hypoxic threshold" and quantify at what altitude we can begin to observe such effects.

The following limitations of the present study should be noted. Present study results are only indicative of executive function, which is only one aspect of complex human cognition. The similar Stroop scores across normoxic and hypoxic conditions suggests that cognitive changes in hypoxia depend on the processing requirements of specific tasks and that greater exposure durations or cognitive demand may elicit deficits (31). In addition, in the present study design participants were blinded to the exposure condition, however, with the inclusion of exercise they were able to differentiate between a normoxic and hypoxic visits (the specific degree of hypoxia was not differentiated by subjects). Future studies should aim to examine other stressors in response to mild/moderate hypoxia that commonly affects complex cognition such as dehydration, over-the-counter stimulants/depressants, sleep loss, or long-duration tasks (18).

We hypothesized that acute hypoxic exposure in combination with exercise will decrease Stroop Task score and result in a decreased reaction time (18, 24, 25). In summary, executive function as measured by the Stroop test was not impaired by exercise or acute normobaric hypoxic exposure. The present findings were in contrast to previous literature indicating cognition was impaired in response to exercise in acute hypoxia (6, 8, 12, 25). Emerging evidence suggests that the severity of hypoxia and the type of cognitive process measured is a factor of its combined effects with exercise (6, 8, 12, 25). Additionally, the effect of exercise on cognition is primarily dependent on exercise intensity and duration (6). Specifically, in relation to the present study, high-intensity and exhaustive exercise (>80% maximal oxygen uptake) have shown inconsistent results across the literature (6-8, 12, 24-26, 30, 31). In conclusion, despite irregularities among literature investigating acute hypoxic exposure and exercise on cognition, our results indicate that acute hypoxic exposure of $FiO_2$ 16% (7,000 ft or 2133 m), and 14.3% (10,000 ft or 3048 m) and exercise did not alter cognitive performance as measured by the Stroop task. Next it may be important to discern the implications of stimulant use to combat symptoms of fatigue from physical activity or sleeplessness and their effect on cognition while hypoxic.

**REFERENCES**


1. U.S. Army ACFT field testing manual. United States Army Center for Initial Military Training; 2018.

2. Aebi MR, Bourdillon N, Noser P, Millet GP, Bron D. Cognitive impairment during combined normobaric vs. hypobaric and normoxic vs. hypoxic acute exposure. Aerosp Med Hum Perform 91(11): 845-851, 2020.

3. Alver BA, Sell K, Deuster PA. NSCA's essentials of tactical strength and conditioning. Champaign: Human Kinetics; 2017.

4. Amann M, Goodall S, Twomey R, Subudhi AW, Lovering AT, Roach RC. Altitudeomics: On the consequences of high-altitude acclimatization for the development of fatigue during locomotor exercise in humans. J Appl Physiol (1985) 115(5): 634-642, 2013.

5. Amann M, Romer LM, Pegelow DF, Jacques AJ, Hess CJ, Dempsey JA. Effects of arterial oxygen content on peripheral locomotor muscle fatigue. J Appl Physiol (1985) 101(1): 119-127, 2006.

6. Ando S, Komiyama T, Sudo M, Higaki Y, Ishida K, Costello JT, Katayama K. The interactive effects of acute exercise and hypoxia on cognitive performance: A narrative review. Scand J Med Sci Sports 30(3): 384-398, 2020.

7. Asmaro D, Mayall J, Ferguson S. Cognition at altitude: Impairment in executive and memory processes under hypoxic conditions. Aviat Space Environ Med 84(11): 1159-1165, 2013.

8. Bouak F, Vartanian O, Hofer K, Cheung B. Acute mild hypoxic hypoxia effects on cognitive and simulated aircraft pilot performance. Aerosp Med Hum Perform 89(6): 526-535, 2018.

9. Bowtell JL, Cooke K, Turner R, Mileva KN, Sumners DP. Acute physiological and performance responses to repeated sprints in varying degrees of hypoxia. J Sci Med Sport 17(4): 399-403, 2014.

10. Casey Jr. GW, Morrow JE. Altitude acclimatization and illness management. Army Publishing Directorate; 2010.

11. Denison DM, Ledwith F, Poulton EC. Complex reaction times at simulated cabin altitudes of 5,000 feet and 8,000 feet. Aerosp Med 37(10): 1010-1013, 1966.

12. Dobashi S, Horiuchi M, Endo J, Kiuchi M, Koyama K. Cognitive function and cerebral oxygenation during prolonged exercise under hypoxia in healthy young males. High Alt Med Biol 17(3): 214-221, 2016.

13. Fowler B, Paul M, Porlier G, Elcombe D, Taylor M. A re-evaluation of the minimum altitude at which hypoxic performance decrements can be detected. Ergonomics 28(5): 781-791, 1985.

14. Goodall S, Twomey R, Amann M. Acute and chronic hypoxia: Implications for cerebral function and exercise tolerance. Fatigue 2(2): 73-92, 2014.

15. Goodall S, Twomey R, Amann M, Ross EZ, Lovering AT, Romer LM, Subudhi AW, Roach RC. Altitudeomics: Exercise-induced supraspinal fatigue is attenuated in healthy humans after acclimatization to high altitude. Acta Physiol (Oxf) 210(4): 875-888, 2014.

16. Hackett PH, Roach RC. High-altitude illness. N Engl J Med 345(2): 107-114, 2001.

17. Kon M, Ikeda T, Homma T, Akimoto T, Suzuki Y, Kawahara T. Effects of acute hypoxia on metabolic and hormonal responses to resistance exercise. Med Sci Sports Exerc 42(7): 1279-1285, 2010.

18. Legg S, Gilbey A, Hill S, Raman A, Dubray A, Iremonger G, Mündel T. Effects of mild hypoxia in aviation on mood and complex cognition. Appl Ergon 53(Pt B): 357-363, 2016.

19. Legg S, Hill S, Gilbey A, Raman A, Schlader Z, Mündel T. Effect of mild hypoxia on working memory, complex logical reasoning, and risk judgment. Int J Aviat Psychol 24(2): 126-140, 2014.

20. Mazzeo RS. Physiological responses to exercise at altitude: An update. Sports Med 38(1): 1-8, 2008.

21. McArdle WD, Katch FI, Katch VL. Exercise physiology. 7th ed. Philadelphia: Lippincott Williams & Wilkins; 2010.

22. McMorris T, Hale BJ, Barwood M, Costello J, Corbett J. Effect of acute hypoxia on cognition: A systematic review and meta-regression analysis. Neurosci Biobehav Rev 74 (Pt A): 225-232, 2017.

23. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

24. Ochi G, Kanazawa Y, Hyodo K, Suwabe K, Shimizu T, Fukuie T, Byun K, Soya H. Hypoxia-induced lowered executive function depends on arterial oxygen desaturation. J Physiol Sci 68(6): 847-853, 2018.

25. Ochi G, Yamada Y, Hyodo K, Suwabe K, Fukuie T, Byun K, Dan I, Soya H. Neural basis for reduced executive performance with hypoxic exercise. Neuroimage 171: 75-83, 2018.

26. Pilmanis AA, Balldin UI, Fischer JR. Cognition effects of low-grade hypoxia. Aerosp Med Hum Perform 87(7): 596-603, 2016.

27. Rasmussen P, Nielsen J, Overgaard M, Krogh-Madsen R, Gjedde A, Secher N, Petersen N. Reduced muscle activation during exercise related to brain oxygenation and metabolism in humans. J Physiol 588(11): 1985-1995, 2010.

28. Scarpina F, Tagini S. The stroop color and word test. Front Psychol 8: 557, 2017.

29. Stroop JR. Studies of interference in serial verbal reactions. J Exp Psychol 18(6): 643, 1935.

30. Sudo M, Komiyama T, Aoyagi R, Nagamatsu T, Higaki Y, Ando S. Executive function after exhaustive exercise. Eur J Appl Physiol 117(10): 2029-2038, 2017.

31. Takács E, Czigler I, Pató LG, Balázs L. Dissociated components of executive control in acute hypobaric hypoxia. Aerosp Med Hum Perform 88(12): 1081-1087, 2017.

32. Taylor L, Watkins SL, Marshall H, Dascombe BJ, Foster J. The impact of different environmental conditions on cognitive function: A focused review. Front Physiol 6: 372, 2016.

33. Turner CE, Barker-Collo SL, Connell CJ, Gant N. Acute hypoxic gas breathing severely impairs cognition and task learning in humans. Physiol Behav 142: 104-110, 2015.

34. Turner CE, Byblow WD, Gant N. Creatine supplementation enhances corticomotor excitability and cognitive performance during oxygen deprivation. J Neurosci 35(4): 1773-1780, 2015.

35. Virués-Ortega J, Buela-Casal G, Garrido E, Alcázar B. Neuropsychological functioning associated with high-altitude exposure. Neuropsychol Rev 14(4): 197-224, 2004.

36. Wei X, Ni X, Zhao S, Chi A. Influence of exposure at different altitudes on the executive function of plateau soldiers—evidence from ERPs and neural oscillations. Front Physiol 12: 632058, 2021.