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The Effect of Psychomotor Performance, Cerebral and Arterial Blood Saturation between African-American and Caucasian Males Before, During and After Normobaric Hypoxic Exercise

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ABSTRACT

International Journal of Exercise Science 10(5): 655-665, 2017. To further elucidate physiological and cognitive performance differences between African-American (AA) and Caucasian individuals (CAU) before, during or after hypoxic and normoxic exercise. Twelve college aged (18-25) apparently healthy African-American (six volunteers) and Caucasian (six subjects) males took part in two trials consisting of normobaric normoxia and normobaric hypoxia (12% oxygen). Each subject cycled at 50% of their altitude adjusted VO_{2max} (-26% of normoxia VO_{2max}) for one hour after a two-hour baseline. Subjects were monitored for cerebral and arterial O_2 saturation, as well as the Trail Making Test A and B (TMT) psychomotor performance. Arterial saturation proved to be significantly higher in AA (86.0±4.7) compared to CAU (79.5±4.8) during the first 60 minutes of exposure to hypoxia at rest (p=0.039), but not during exercise. However, cerebral oxygenation to the left frontal lobe was decreased near the conclusion and in 30 minutes after normoxic exercise. TMT B data revealed that CAU (79±12.7) had faster scores than the AA subjects (98±25.1) at all time points and was significantly different at the 115-minute time point of the hypoxic trial (p=0.024). The data suggests that before, during and after normobaric normoxia and hypoxia trial there is a differential response between AA and CAU in regards to arterial and cerebral oxygenation, as well as psychomotor tests.

KEY WORDS: Ethnic differences, hypoxic exercise, arterial saturation, cerebral blood flow

INTRODUCTION

Hypoxia is a physiological state defined as a reduction in the ability of oxygen to reach the tissues of the body. Preservation of adequate oxygen supply is critical for physiological and psychological functions of the human body (4). The cells of the human body are dependent on oxygen for energy utilization, thus sufficient oxygen supply is critical for survival. Oxygen delivery can be altered by pathological (chronic obstructive pulmonary disease, sleep apnea)

or environmental (changes in altitude or inhaled oxygen concentrations) factors. Hypoxia is a potent stimulus that induces neuropsychological and physical impairments in humans (8).

The brain utilizes limited sources (i.e., oxygen and glucose), to maintain homeostasis, and thus it is the highly dependent upon oxygen and its supply. Decreases in cerebral oxygenation are present during hypoxic conditions. A decrease in brain oxygenation promotes a decrease in executive function (13). This decrease in oxygenation is the result of a decreased PaO_2 and SaO_2 (Saturation of Oxygen) in the arterial system. Furthermore, there is little research in the area of hypoxemia evaluating African-Americans physiological and cognitive alterations while hypoxic. The overwhelming majority of research has studied the effects of Caucasian populations, specifically males.

Evidence does support physiological differences between Caucasian and African-American populations. Prior research in this area has demonstrated muscle fiber type, hematological, baroreceptor sensitivity and endocrinological variances across ethnicities (2, 9, 21). Previous literature supports that there are physiological variations; however, there are gaps in the knowledge concerning cognitive performances across ethnicities. The present investigation aims to further elucidate physiological and cognitive performance differences between African-American (AA) and Caucasian individuals (CAU) before, during or after hypoxic and normoxic exercise.

METHODS

Participants

All methods and forms were approved by the Institutional Review Board at Kent State University.

Twelve college aged (18-25) apparently healthy African-American (six volunteers) and Caucasian (six subjects) males were recruited to participate in the study via direct contact with the principal investigator. Participants were all non-smokers. Due to the nature of the trials, the subjects were low altitude residents and that had not been exposed to normobaric hypoxia of altitudes above 2500 meters within two months prior to the study. Participants were excluded from the study if they; 1) possessed signs and symptoms or were known to have cardiovascular, metabolic, or respiratory disease, 2) experienced syncope, anemia, or fainting while exercising or immediately following exercise.

Table 1. Subject Characteristics.

Variable	All Subjects	AA	CAU
N	(12)	(6)	(6)
Age (yrs)	22.08	22	22.2
Height (cm)	178.3	181.2	175.3
Weight (kg)	88.4	85.5	91.4
$VO_{2\,max}$ (ml.kg.min)	47.06	51.6	43

Protocol

Participants completed a VO_2 max test via a Parvo metabolic cart to volitional fatigue using a progressive intensity protocol performed on a cycle ergometer. Following completion of the VO_2 max test and health history questionnaire, participants were then counterbalanced for two additional testing sessions (hypoxia with exercise and normoxia with exercise).

All subjects participated in two counterbalanced testing trials. Each trial consisted of a two hour baseline, one hour of exercise, and one hour of recovery. Additionally a one week washout period between the two trials for each subject was utilized. During the hypoxia trial, the partial pressure of the inspired oxygen was 91.2. torr (760 mmHg pressure x 12% oxygen) within the altitude simulation chamber. The inspired oxygen during the normoxia trial was 152 torr (760 mmHg pressure x 20% oxygen). The 12% oxygen exposure is similar to that of an altitude of 4300 meters (14,110 feet).

Participants reported to the Exercise Physiology Lab at Kent State in the mornings during the post-absorptive state. The subjects then entered the hypoxic chamber. During the first two hours, the subjects were seated to collect baseline data. Following the rest period, the participants then exercised on a cycle ergometer (Excalibur 1300w) at 50% of VO_{2max} for one hour. Following the exercise, the subjects were again seated for a one hour recovery period.

During each four hour trial, blood oxygen levels (% O_2 saturation), cerebral blood flow, and cognitive performance were monitored continuously by way of a pulse-oximeter, Near Infrared Spectroscopy, and a trail making test, respectively. Expired air data was collected every 30 minutes via a Parvo Metabolic Cart, Sandy, Utah.

Figure 1. Schematic of Trials.

The CAT (Colorado Altitude Training, Louisville, CO) system was used for the simulation of altitude for the study. This system controlled the altitude setting automatically by sensing oxygen, carbon dioxide, and atmospheric pressure within the chamber. CAT has been applied

to various research related to exercise training, aviation, military, and altitude application (18, 23).

Near-Infrared Spectroscopy (NIRS) (Somanetics, Troy, MI) was utilized noninvasively to monitor hemodynamics and tissue oxygenation of cerebral tissue (3). This system has been used to measure cerebral blood flow and oxygenation (16, 17, 20). Also, Henson et al. (12) and Tran (22) validated that NIRS was correlated with oxygen consumption by muscle and cerebral tissue.

Pulse-Oximeter (Oxi-Go, Roslyn, NY) was used as a noninvasive way to measure oxygen saturation in the arterial blood. Identifying the arterial saturation of oxygen is an important marker for determining alterations of the metabolic use of oxygen. Cornolo et al. (6), Peltonen et al. (17), and Ainslie et al. (1) used the device within their respective studies. Martin et al. (14) reported that the pulse-oximeter is more accurate than an ear probe and that it is a valid predictor of arterial oxygen saturation during exercise. Gehring (9), however, showed that the manufacturer's guidelines for placement of the device should be followed for an accurate measurement.

Parvo metabolic measurement system (Parvo, Metabolic Cart; Sandy, Utah) were used to analyze and monitor air samples by way of an indirect automated open circuit system to determine oxygen consumption. This system has been commonly used in current research as it provides accurate and reliable data for gas exchange (5, 7). The accuracy of the CO_2 and O_2 analyzer is 0.1% (Parvo, Metabolic Cart; Sandy, Utah). This was used in the preliminary VO2 max testing to assess fitness level of the participants and to determine workloads for the trials.

An Excalibur 1300W magnetically braked cycle ergometer (Lode Excalibur Sport, Lode, Groningen, The Netherlands) was used in the collection of $VO_{2\ max}$ as well as for the cycling exercise during trials.

A computerized version of Trail Making Test (TMT) was applied to measure cognitive performance. TMT is a well-established and a widely used psychological test that can measure cognitive flexibility (19). TMT consists of two tests, A (TMTA) and B (TMTB). While TMTA measures visual searching and motor speed, TMTB measures visual searching, executive function and cognitive function because it examines the ability to mentally maintain two sequences, numbers and letters, at the same time. The dependent variable of intent was the time to completion. To minimize a learning effect, different formats of test were used for every measurement, and subjects underwent practice test sessions to familiarize themselves with the test before participating in the study.

Statistical Analysis

The study included two treatments (normoxia with exercise and hypoxia with exercise). The study also consisted of two groups categorized by ethnicity (African-Americans and Caucasians). Therefore, a 2 condition (hypoxia and normoxia) x 2 group (African-American and Caucasian) x time points on dependent variables with repeated measures on condition

and time was utilized with post-hoc analyses when applicable. The data collected will be analyzed using SPSS program and, more specifically the data will be analyzed using an analysis of covariance (ANCOVA). The level of significance was set a priori at $p \leq 0.05$. T-tests were utilized for post-hoc analysis and to examine the main effects of time, condition and ethnicity.

RESULTS

The analysis yielded no significance interactions across time, condition and ethnicity ($p = 0.140$), however during the hypoxia trial, significance ($p < 0.05$) was demonstrated during the initial exposure of the stimulus between AA and CAU. Figure 2 depicts the time points for the hypoxia trial(s). At the 30-minute and 60-minute time points during exposure to hypoxia, SAO_2 was significantly lower in the CAU subjects when compared to the AA subjects; with subsequent p values of 0.05 at 30 minutes and 0.039 at 60 minutes of exposure respectively.

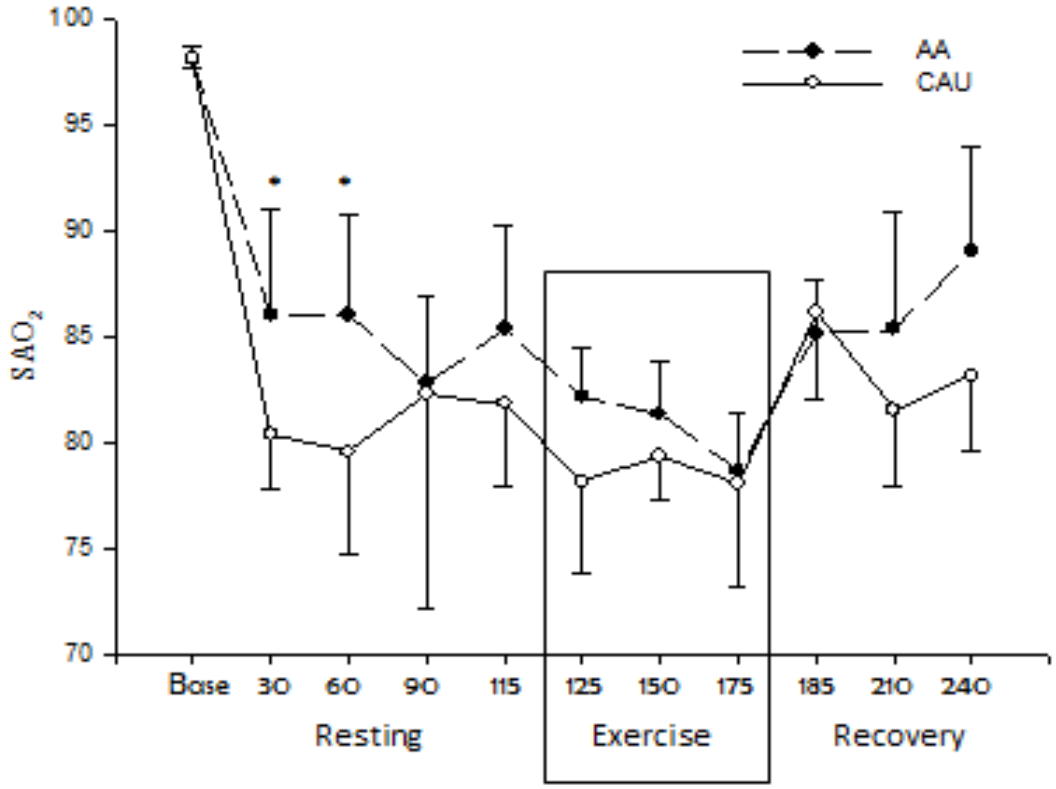
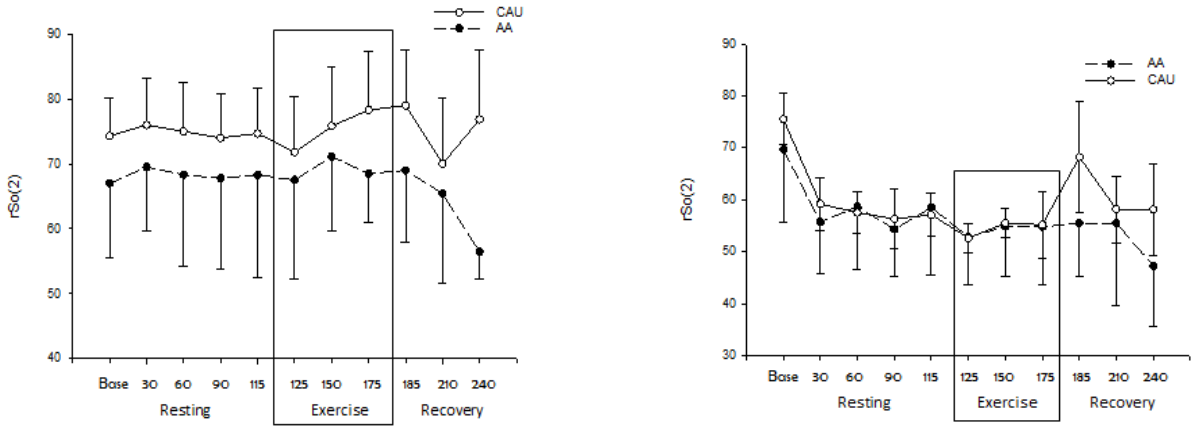


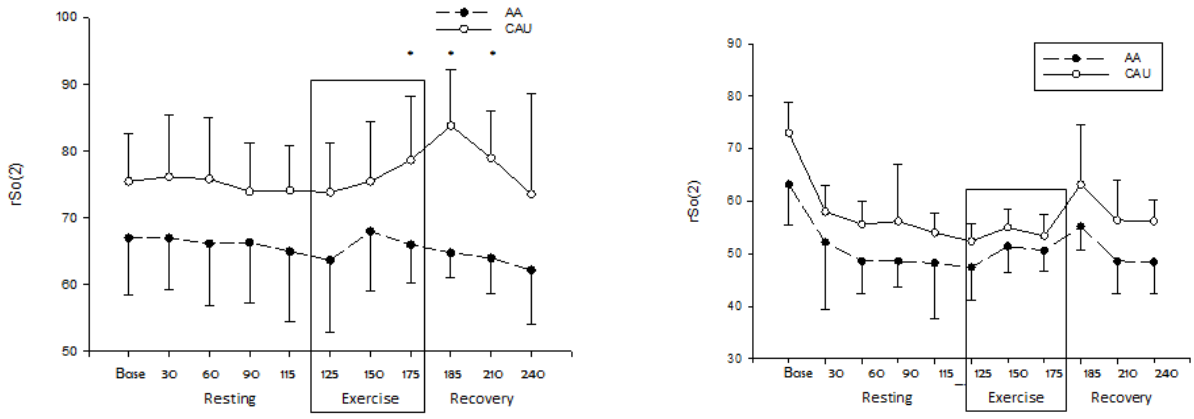
Figure 2. Arterial Saturation during Hypoxic Trial between groups. (*) Denotes significance between AA and CAU.

Right Frontal Lobe: Cerebral oxygenation to the right frontal lobe showed no significant interactions across time, condition and ethnicity ($p=0.708$). Figures 3 and 4 depict the oxygenation via NIRS to the right frontal lobe during the normoxia and hypoxia trials.



Figures 3 and 4. Right Frontal Lobe Oxygenation (via NIRS) during Normoxia (Figure 3) and Hypoxia (Figure 4).

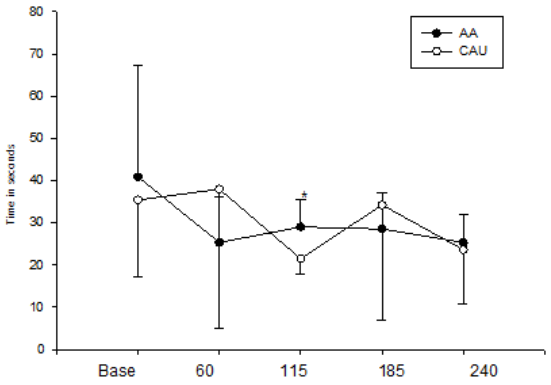
Left Frontal Lobe: Similar to the right frontal lobe, the left frontal lobe also demonstrated no significant interaction across time, condition and ethnicity (p= 0.926), but AA demonstrated lower cerebral oxygen concentration than CAU. However, unlike the right, the left frontal lobe oxygenation demonstrated significant differences between the two ethnic groups. This was only seen in the normoxia trial(s). Near the end of the exercise bout and during the first 30 minutes of recovery AA demonstrated significant reductions in oxygenation to the left frontal lobe. Figures 4 and 5 depict these results. The significant differences were noticed at the 55-minute time point of exercise (p= 0.021), immediately after (p= 0.001) and 30 minutes (p=0.004) into the recovery phase of the trial. Interestingly, there were no significant differences during the hypoxia trial(s), although CAU individuals continuously demonstrated higher oxygenation values than the AA subjects.

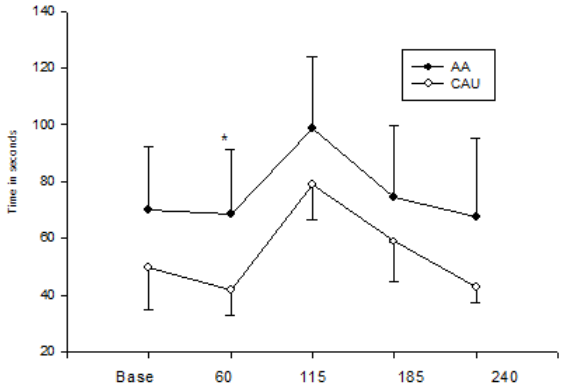


Figures 5 and 6. Left Frontal Lobe Oxygenation (via NIRS) during Normoxia (Figure 5) and Hypoxia (Figure 6). *Denotes significance between AA and CAU.

Although no significance was detected between the ethnic groups, it is interesting to note that AA individuals demonstrated lower levels of cerebral oxygenation than the CAU group, in particular during the normoxia trial. Additionally, the CAU group had a more noticeable reduction in cerebral oxygenation than the AA group between the normoxia to hypoxia trial.

In analyzing cognitive performance via the TMT A and B psychomotor tests, no interaction was demonstrated for condition, time and ethnicity (P=0.487 {A}, 0.794 {B}). However, a main effect of ethnicity was seen at the 115-minute mark of the hypoxia trial for TMT A (P=0.045) as noticed in Figure 7, as well at the 60-minute time point during the hypoxia trial for TMT B (P=0.024) as depicted in Figure 8. No significant differences were exhibited during the normoxia trials at any given time point. Additionally, there was a trend, although no significance was observed when analyzing the ratio of TMT A and B (TMT B/ TMT A) (P=0.066).





Figures 7 and 8. Trail making test A (Figure 7) and B (Figure 8) under the hypoxia condition. *Denotes significance between AA and CAU.

DISCUSSION

This study was designed to evaluate any physiological differences under the stressor of hypoxia between African-Americans and Caucasians. The investigation specifically evaluated the distribution of oxygen before, during and after exercise in normoxia and hypoxia. The experimental design allowed for this specific evaluation through the use of NIRS and the pulse-oximeter, thus allowing for the ability to discern the distribution of oxygen both in the peripheral arterial and cerebral arterial systems.

Data from the current investigation supports the hypothesis that there are varying responses due to physiological variances between the two ethnicities. As demonstrated in Figure 2, African Americans when exposed to hypoxia experienced a higher level of arterial oxygen saturation as compared to the CAU individuals. Significant differences were detected at the 30 and 60-minute time points during resting measures of the protocol. Further investigation is required to provide physiological rationale for these differences.

Data also revealed AA had on overall reduction in cerebral oxygenation as depicted in Figures 3 and 4. It is worth noting that no significance was demonstrated under the influence of a hypoxia state by either the right or left frontal lobes. Additionally, no significant differences were shown for the right frontal lobe. However, when examining the left frontal lobe

oxygenation, significance was demonstrated during normoxia, but not during hypoxia. These significant differences occurred near the end of the cycling and at the cessation of the cycling session, specifically at the 55-minute mark of the exercise session, as well as at the 10 and 30-minute time points of recovery phase. To date, no other study has suggested a possible mechanism for these findings. According Zion et al., differences exist in arterial compliance and autonomic balance in African-American males, which may contribute to the higher prevalence of hypertension in AA. However, the current subject pool was void of hypertension; therefore, this mechanism may not explain the overall reduction in cerebral oxygenation.

The examination of cognitive performance did reveal significant differences between the two groups, however only at two time points for each of the tests (TMT A and B). Although differences were reported, these differences did not coincide with the significant decrease demonstrated in left frontal lobe oxygenation seen in the AA volunteers during the normoxia trial. The significant differences in cognitive performance were noticed during the hypoxia trial. This data partially supports the findings of Kurihara et, al., which found a decrease in brain oxygenation promotes a decrease in executive function (13). This is partially supported by the data that demonstrated that the decrease in cognition (increase time of task) which was seen during the hypoxia trials; however there was no statistical variability between the ethnic groups (cerebral oxygenation). It should be noted that there was a noticeable overall reduction in executive function across ethnicity when analyzing TMT B. Although significance was noticed in neurocognitive tests, the results are not unequivocal to support a statement of cognitive decrements across ethnicity or condition.

Left frontal lobe oxygenation did provide significant differences between ethnicities. This significant decrease in oxygen demonstrated by the AA individuals of the left frontal lobe could lend itself to detrimental performance with regards to cognitive ability during times of moderate oxygen demand. Examples of this could be in the realm of athletic performance or in military maneuvers. Although this is one possible mechanism, still other mechanisms exists that also need further exploration such as the plasticity of the red blood cell and its role in vascular responsiveness. Other unique physiological differences may also play a role in the reduction of cerebral oxygenation. These include hematological variances between AA and CAU. These differences include a reduced hematocrit, hemoglobin and mean corpuscular volume in AA when compared to CAU (2). Again, the mechanism that supports this variation of reduced cerebral oxygen saturation is not fully understood.

Further research is needed to help provide a rationale for the results elucidated by this investigation. Such research could involve examining the mechanism by which AA display an overall reduction in oxygen saturation and the ramifications that can result from such reductions. If there is a better understanding perhaps, then it may be possible to start to control and/or reduce some of the consequences associated with reduced cerebral oxygen in this population.

Furthermore, this may also be the result of perhaps a problem with the deformability of the ability of the red blood cell to accept oxygen. Beutler and West reported that the AA population has a decrease in serum transferrin saturation (2). This may be a contributing mechanism to sickle cell trait. Although all subjects were excluded with a self-report of sickle cell trait, the higher incidence found AA could contribute to a unique response to hypoxia. Further research may also consider evaluating red blood cell mass and number to elucidate the circulatory response as well. It is evident that the current investigation has brought to light some very specific physiological, psychomotor and cognitive function differences between CAU and AA populations. The results yielded from this data warrants further investigations into the mechanisms that can further explain the variability of responses.

Although, the AA participants exhibited a greater relative $VO_{2\ max}$ arterial O_2 concentration as compared to their CAU counterparts, they also demonstrated lower cerebral O_2 (Fig. 5). Prospective studies are needed to expand upon the data put forth from this investigation. The potential investigations in this domain could include, but are not limited to examining a-v O_2 difference, oxidative capacity of the working skeletal muscle and overall blood flow dynamics, both to cerebral tissue and also to skeletal muscle.

Subjects were not homogenous in the area of $VO_{2\ max}$ or body mass (Table 1) and therefore only generalizations can be made from the current data. Additionally, the sample size was relatively small (Table 1. n=12, AA=6, CAU= 6). Furthermore, the cognitive tests (TMT A and TMT B) were explained and subjects had a brief familiarization with the tests; however a lengthier familiarization period would behoove the investigators for future inquiries. It is also worth noting that additional cognitive tests (i.e. Stroop Test) would be a welcomed addition to a data set as a means of further examining cognitive abilities. There is also no data to represent any hematocrit variances or corpuscular volume. As a consequence of these limitations, further testing is needed in order to help substantiate some of the results discerned.

REFERENCES

1. Ainslie PN, Barach A., Murrell C, Hamlin M, Hellemans J, Ogoh S. Alterations in cerebral autoregulation and cerebral blood flow velocity during acute hypoxia: rest and exercise. Am J Physiol Heart Circ Physiol 292(2): H976-H983, 2007.

2. Beutler E, West C. Hematologic differences between African-Americans and whites: the roles of iron deficiency and α-thalassemia on hemoglobin levels and mean corpuscular volume. Blood 106(2): 740-745, 2005.

3. Brazy JE. Near-infrared spectroscopy. Clin Perinatol 18(3): 519-534, 1991.

4. Cheung SS. Advanced environmental exercise physiology. Champaign, IL: Human Kinetics; 2010.

5. Cooper J, Watras A, O'Brien M, Luke, A, Dobratz J, Earthman C, Schoeller D. Assessing validity and reliability of resting metabolic rate in six gas analysis systems. J Am Diet Assoc 109(1): 128-132, 2009.

6. Cornolo J, Mollar P, Brugniaux JV, Richalet JP. Autonomic control of the cardiovascular system during acclimatization to high altitude: effects of sildenafil. J Appl Physiol 97: 935-940, 2004.

7. Crouter SE, Antczak A, Hudak JR, DellaValle DM, Haas JD. Accuracy and reliability of the ParvoMedics TrueOne 2400 and MedGraphics VO2000 metabolic systems. Eur J Appl Physiol 98(2): 139-151, 2006.

8. Fulco CS, Cymerman A. Human performance and acute hypoxia. In Pandolf KB, Sawka MN, Gonzalez RR, Human Performance Physiology and Environmental Medicine at Terrestrial Extremes (pp. 467-495). Traverse City, MI: Cooper Publishing Group; 1987.

9. Gehring H. Pulse oximeter in a comparative test. Intensive Care Med 32(9): 1287-1289, 2006.

10. Glickman EL, Cheatham CC, Caine N, Blegen M. The influence of ethnicity on thermosensitivity during cold water immersion. Aviat Space Environ Med 72(7): 632-637, 2001.

11. He J, Watkins S, Kelley DE. Skeletal muscle lipid content and oxidative enzyme activity in relation to muscle fiber type in type 2 diabetes and obesity. Diabetes 50: 817–823, 2001.

12. Henson LC, Calalang C, Temp JA, Ward DS. Accuracy of a cerebral oximeter in healthy volunteers under conditions of isocapnic hypoxia. Anesthesiology 88: 58-65, 1998.

13. Kurihara K, Kikukawa A, Kobayashi A, Nakadate T. Frontal cortical oxygenation changes during gravity-induced loss of consciousness in humans: a near-infrared spatially resolved spectroscopic study. J Appl Physiol 103(4): 1326-1331, 2007.

14. Martin D, Powers S, Cicale M, Collop N, Huang D, Criswell D. Validity of pulse oximetry during exercise in elite endurance athletes. J Appl Physiol 72: 455-458, 1992.

15. National Center for Health Statistics. Health Data Interactive File, 1981–2006. Hyattsville, Md: National Center for Health Statistics. Available at: http://205.207.175.93/hdi/ReportFolders/ReportFolders.aspx?IF_ActivePath =P,21

16. Ogoh S, Ainslie PN. Regulatory mechanisms of cerebral blood flow during exercise: new concepts. Exerc Sport Sci Rev 37(3): 123-129, 2009.

17. Peltonen J E, Kowalchuk JM, Paterson D H, DeLorey DS, duManoir GR, Petrella RJ, Shoemaker JK. Cerebral and muscle oxygenation in acute hypoxic ventilatory response test. Respir Physiol 155: 71-81, 2009.

18. Richardson A, Twomey R, Watt P, Maxwell N. Physiological response to graded acute normobaric hypoxia using intermittent walking protocol. Wilderness Environ Med 19(4): 252-260, 2008.

19. Ridgel AL, Kim CH, Fickes EJ, Muller MD, Alberts JL. Changes in executive function after acute bouts of passive cycling in Parkinson's disease. J Aging Phys Act 19(2): 87-98, 2011.

20. Subudhi AW, Dimmen AC, Roach RC. Effects of acute hypoxia on Cerebral and muscle oxygenation during incremental exercise. J Appl Physiol 103: 177-183, 2007.

21. Tanner CJ, Barakat HA, Dohm GL, Pories WJ, MacDonald KG, Cunningham PR, Houmard JA. Muscle fiber type is associated with obesity and weight loss. Am J Physiol-Endocrinol Metab 282(6): E1191-E1196, 2002.

22. Tran TK, Sailasuta N, Kreutzer U, Hurd R, Chung Y, Mole P, Kuno S, Jue T. Comparative analysis of NMR and NIRS measurements of intracellular PO2 in human skeletal muscle. Am J Physiol 276 (6 pt 2): R1682-1690, 1999.

23. Wilber RL. Current Trends in altitude Training. Sports Med 31(4): 249-265, 2001.

24. Zion AS, Bond V, Adams RG, Williams D, Fullilove RE, Sloan RP, De Meersman RE. Low arterial compliance in young African-American males. Am J Physiol Heart Circulator Physiol 285(2): H457-H462, 2003.