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Effects of oxygen concentration and flow rate on cognitive ability and physiological responses in the elderly☆

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Abstract
The supply of highly concentrated oxygen positively affects cognitive processing in normal young adults. However, there have been few reports on changes in cognitive ability in elderly subjects following highly concentrated oxygen administration. This study investigated changes in cognitive ability, blood oxygen saturation (%), and heart rate (beats/min) in normal elderly subjects at three different levels of oxygen [21% (1 L/min), 93% (1 L/min), and 93% (5 L/min)] administered during a 1-back task. Eight elderly male (75.3 ± 4.3 years old) and 10 female (71.1 ± 3.9 years old) subjects, who were normal in cognitive ability as shown by a score of more than 24 points in the Mini-Mental State Examination-Korea, participated in the experiment. The experiment consisted of an adaptation phase after the start of oxygen administration (3 minutes), a control phase to obtain stable baseline measurements of heart rate and blood oxygen saturation before the task (2 minutes), and a task phase during which the 1-back task was performed (2 minutes). Three levels of oxygen were administered throughout the three phases (7 minutes). Blood oxygen saturation and heart rate were measured during each phase. Our results show that blood oxygen saturation increased, heart rate decreased, and response time in the 1-back task decreased as the concentration and amount of administered oxygen increased. This shows that administration of sufficient oxygen for optimal cognitive functioning increases blood oxygen saturation and decreases heart rate.

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Key Words
neural regeneration; clinical practice; highly concentrated oxygen; cognitive task; 1-back task; cognitive ability; blood oxygen saturation; heart rate; physiological responses; elderly; grant-supported paper; neuroregeneration

Research Highlights
(1) This study investigated the effects of three different levels of oxygen (21%, 1 L/min; 93%, 1 L/min; 93%, 5 L/min) administration during a 1-back task on cognitive ability, blood oxygen saturation and heart rate of elderly subjects.
(2) Blood oxygen saturation increased, heart rate decreased, and cognitive function improved as the concentration and flow rate of administered oxygen increased.
(3) Our findings suggest that high oxygen concentrations help improve cognitive function in the elderly.

Abbreviations
HR, heart rate; SpO_2, blood oxygen saturation

INTRODUCTION

The supply of highly concentrated oxygen positively affects cognitive processes[1-13]. Highly concentrated oxygen was found to enhance cognitive performance, including memory[1-4, 13], visuospatial[10, 12], verbal[6], addition[11], and n-back tasks[7-9]. As the difficulty of the cognitive task increases, the effect of highly concentrated oxygen on the task increases[7, 11]. However, previous studies have mainly focused on healthy young adults, and few reports have studied the effect of highly concentrated oxygen administration on cognitive ability in elderly subjects.

When humans perform cognitive tasks, various physiological changes occur that increase the supply of glucose and oxygen to nervous tissues[14]. These changes include increased heart rate (HR), respiration, and oxygen consumption[15]. The supply of highly concentrated oxygen during cognitive processes induces physiological changes[1, 3, 6-7, 10-11, 13, 16-20]. Previous studies in young people showed that the supply of highly concentrated oxygen during cognitive processes increased the blood oxygen saturation (SpO_2) and reduced the increase in HR[1, 3, 6-7, 10-11, 13, 16]. This indicates that a sufficient supply of oxygen required for cognitive processes leads to an increase in SpO_2 and a blunted HR response.

Cognitive performance changes with age. Verbal and inference abilities are maintained up to the age of 60, but memory decreases from the age of 30[21]. A memory comparison study among different groups aged between 20 and 80 showed that memory decreased as age increased[22]. This suggests that the cognitive ability that declines the most with aging is memory.

It is well known that the most important dependent variables for measuring cognitive ability are speed and accuracy[23-26]. One problem with measuring cognitive ability is the speed-accuracy trade-off[25, 27], which means that the accuracy increases when a subject's response speed decreases. This will occur when the subject slows down for the purpose of emphasizing accuracy[12].

In this study, we investigated how highly concentrated oxygen affects the cognitive ability of the elderly. We also measured changes in SpO_2 and HR in response to the amount and concentration of oxygen supplied. This study focused on the speed of memory rather than the accuracy of memory. In this study, we chose to use the 1-back task as the cognitive task as it has a low level of difficulty and can be used for evaluating memory[27].

RESULTS

Quantitative analysis of subjects

Eighteen elderly subjects aged 72.9 ± 4.5 years were recruited and included in the final analysis. The experiment consisted of three phases, which included an adaptation phase after the start of the oxygen administration (3 minutes), a control phase to allow the subjects' condition to stabilize before the task (2 minutes), and the task phase in which the 1-back task was performed (2 minutes). Three levels of oxygen were administered throughout the three phases (7 minutes).

Changes in cognitive performance

Mean 1-back task response time and accuracy rates under the three conditions are shown in Figure 1A. There was a trend towards a decrease in response time as oxygen supply increased, but the statistical significance was weak (P = 0.053). As a result of Bonferroni's posteriori tests, the mean response time of 93% (5 L/min) oxygen administration decreased significantly, compared to that of 21% (1 L/min) oxygen administration (P < 0.05). Accuracy rates were constant regardless of the condition.

Changes in physiological signals

Mean SpO_2 values during the control and task phases at the three different levels of oxygen administration are presented in Figure 1B. There was a significant difference in SpO_2 among the three conditions (Table 1).

From the results of Bonferroni's posteriori tests, the SpO_2 of 93% (1 L/min) and 93% (5 L/min) oxygen administration increased significantly, compared to that of 21% (1 L/min) oxygen administration (P < 0.001). The SpO_2 of 93% (5 L/min) oxygen administration increased significantly, compared to that of 93% (1 L/min) oxygen administration (P < 0.01). In other words, higher concentrations and flow rates of oxygen administration were associated with greater increases in SpO_2. However, there were no significant differences in SpO_2 between the control and the task phase at any level of oxygen administration.

Mean HR values during the control and task phases at the three different levels of oxygen administration are presented in Figure 1C. There were statistical differences in HR among the three conditions and between the two phases (Table 2).

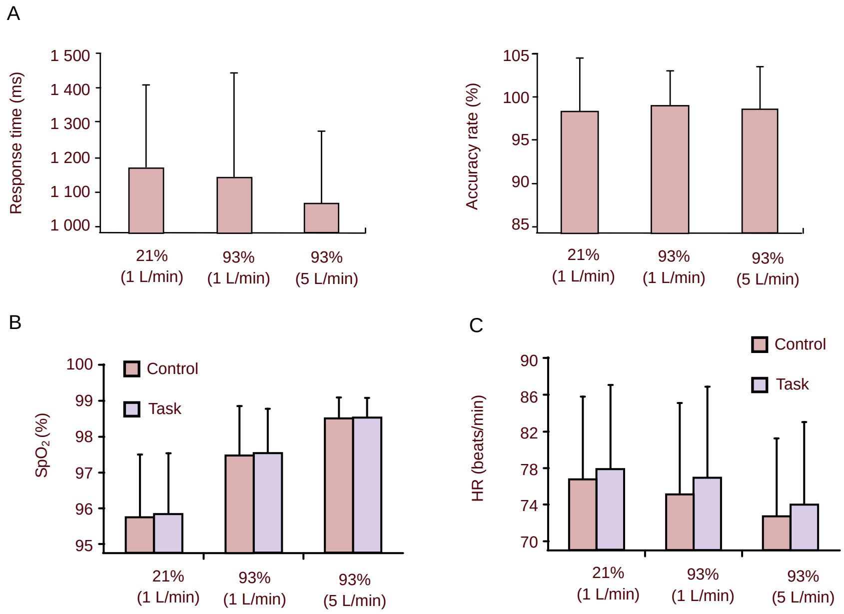

Figure 1 Cognitive performance and physiological signals at three different levels of oxygen administration in 18 elderly subjects.

(A) Mean response time (left panel) and accuracy rates (right panel) in 1-back task.

(B) Blood oxygen saturation (SpO_2) during the control and task phases of the 1-back task under the three conditions.

(C) Heart rate (HR) during the control and task phases of the 1-back task under the three conditions.

Table 1 Results of the repeated measures analysis of variance of blood oxygen saturation using condition and phase as independent variables

Source	Type III sum of squares	*df*	Mean square	*F*	*Sig.*
Condition	136.942	2	68.471	70.838	0.000
Phase	0.079	1	0.079	1.095	0.310
Condition × phase	0.025	2	0.013	0.224	0.800

Table 2 Results of the repeated measures analysis of variance of heart rate using condition and phase as independent variables

Source	Type III sum of squares	*df*	Mean square	*F*	*Sig.*
Condition	300.472	2	150.236	12.238	0.000
Phase	52.892	1	52.892	7.979	0.012
Condition × phase	2.476	2	1.238	0.549	0.582

From the results of Bonferroni's posteriori tests, the HR of 93% (5 L/min) oxygen administration decreased significantly, compared to that of 93% (1 L/min) oxygen administration ($P < 0.05$) and compared to that of 21% (1 L/min) oxygen administration ($P < 0.01$). The HR of 93% (1 L/min) oxygen administration decreased significantly, compared to that of 21% (1 L/min) oxygen administration ($P < 0.05$). As the amount and concentration of oxygen supply increased, HR decreased. Furthermore, HR was higher during the task phase than during the control phase at any level of oxygen administration ($P < 0.05$).

DISCUSSION

This study investigated performance ability in a 1-back task and changes in SpO_2 and HR in elderly subjects at three levels of oxygen administration.

Our results show that highly concentrated oxygen administration increases cognitive ability by decreasing response time in elderly subjects. As the amount and concentration of oxygen administration increased, the response time decreased. This result is consistent with those of several studies on the effects of highly concentrated oxygen on cognitive ability in healthy young adults[1-13, 16]. These studies have shown that highly concentrated oxygen administration results in improved cognitive ability as demonstrated by an increase in the percentage of correct answers[1, 3, 6-7, 10-11, 13], and a reduction in response time[1-5, 12, 13] in various cognitive tasks. As our study focused on the speed of memory rather than the accuracy, we found no effect of oxygen supply on the 1-back task accuracy rate. Our results suggest a positive relationship between the flow rate and concentration of oxygen administration and cognitive ability in the elderly.

In the present study, the SpO_2 greatly increased as the concentration and flow rate of oxygen administration increased in elderly subjects, which is consistent with results from previous studies. Oxygen concentrations of 30% and 40% were shown to increase SpO_2 compared with normal air containing 21% oxygen[1-13]. Moss *et al* [1] and Scholey *et al* [3] showed that the supply of 100% oxygen also increased SpO_2. As shown in previous studies, increased SpO_2 resulting from highly concentrated oxygen administration may have a positive effect on cognitive ability[1, 3, 6-7, 10-11, 13].

It is well understood that an increase in fuel (*e.g*. glucose) supply leads to increased ATP production at times of high demand. This increased ATP production may improve information processing during the performance of cognitive tasks, which would be manifested as enhanced cognitive ability[3]. To metabolize the fuel, the brain needs more oxygen. Thus, brain metabolism increases during cognitive processing, suggesting a need for a transient increase in oxygen supply to the brain. Previous studies showed that the SpO_2 increases during the task phase as compared with the control phase because of the increased oxygen demand for cognitive processing[1, 3, 6-7, 10-11, 13]. However, there is no difference in SpO_2 between the control and task phases in this study. This issue requires further investigation.

Many previous studies have found that HR decreases at 30% and 40% oxygen administration, compared with 21% oxygen administration[6-7, 10-11, 13]. This study showed that highly concentrated oxygen administration induced a decrease in HR in elderly subjects. The decrease in HR was greater at increasing oxygen concentrations and flow rates. We speculate that the increased supply of highly concentrated oxygen saturated the oxygen demand for cognitive processing, which resulted in decreased HR. As in previous studies[6-7, 10-11], this study also showed that HR increased during the task phase compared with the control phase. This means that the oxygen demand increased during the period of increased cognitive processing, which induced an increase in HR[6,-7, 10-11].

We found that the supply of highly concentrated oxygen induced an increase in SpO_2 and a decrease in HR in elderly subjects. Furthermore, response time in a 1-back task decreased at higher rates and concentrations of oxygen administration. Further studies are necessary to exactly examine the short- and long-term effects of highly concentrated oxygen administration on cognitive ability in the elderly. Age and gender should be taken into account.

In conclusion, administration of highly concentrated oxygen positively affects cognitive performance in the elderly and may be beneficial for elderly patients with cognitive problems.

SUBJECTS AND METHODS

Design

A block design for repeated 1-back tasks.

Time and setting

This study was performed at the Brain Science Laboratory, Department of Biomedical Engineering, College of Biomedical & Health Science, Konkuk University, between January and February 2011.

Subjects

Eighteen elderly subjects aged 72.9 ± 4.5 years were recruited by an advertisement. The subjects consisted of eight males (75.3 ± 4.3 years old) and 10 females (71.1 ± 3.9 years old) who did not have any physical or mental diseases and were normal in cognitive ability as shown by a score of more than 24 points in the Mini-Mental State Examination-Korea (MMSE-K)[28]. The experimental design controlled for external factors that could influence physiological signals (*e.g*. smoking, alcohol, coffee). The overall procedure was explained to all subjects, who subsequently gave their consent for the procedure.

Methods

Experimental setup

An oxygen supply system (OXUS. Co., Seoul, Republic of Korea) that could maintain a constant oxygen level of 21% or 93% and control a flow of 1 L/min or 5 L/min was used for the experiment. To maintain a steady flow and constant concentration, oxygen was administered to the subjects through masks.

As shown in Figure 2, the experiment consisted of three phases over a total of 7 minutes: an adaptation phase after the start of oxygen administration (3 minutes), a control phase (2 minutes), and a task phase in which the 1-back task was performed (2 minutes)[29-30]. The control phase was a 2-minute stabilization period before the 1-back task was started. The control phase was used to obtain stable baseline measurements of HR and SpO_2. The 1-back task was performed using the E-prime system (Psychology Software Tools Inc., Sharpsburg, PA, USA). During the task, 24 Arabic numbers (0–9) were presented on a monitor at 5-second intervals. If a number was repeated, participants were asked to press a response button on a keyboard as quickly as possible. The number of correct answers (repeated numbers) in each experiment was 10. All subjects performed the experiment at three different levels of oxygen 21% (1 L/min), 93% (1 L/min) or 93% (5 L/min), which were supplied throughout all three phases (7 minutes) of the experiment. All subjects participated in all three experiments with a 1-hour rest period between experiments. The order of the experiments was counter balanced.

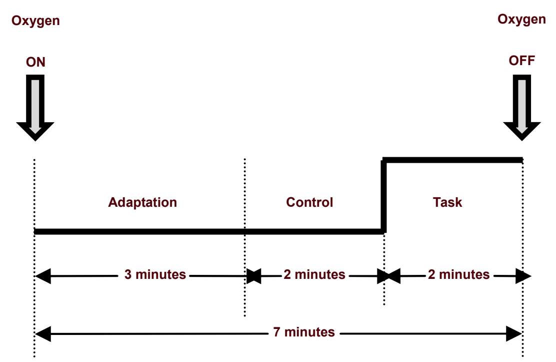

Figure 2 Experimental design.

Data analysis

The accuracy rate (the number of correct answers/total number of problems × 100) and response time of the 1-back task were calculated. The response time was recorded automatically for each experiment using the E-DataAid option in the E-prime software. SpO_2 (%) and HR (beats/min) were measured using a pulse oximeter (8600 Series, Nonin Medical, Inc., Plymouth, MN, USA) on the subject's left index finger. SpO_2 and HR were measured for all phases while the subjects sat comfortably on chairs. The mean SpO_2 and HR were calculated for each phase in each subject.

Statistical analysis

Repeated measures analysis of variance (PASW version 18.0, SPSS, Chicago, IL, USA) was used with 21% (1 L/min), 93% (1 L/min), and 93% (5 L/min) as independent variables to determine significant differences in response time and accuracy rates among the conditions. Repeated measures analysis of variance (PASW version 18.0) was used with 21% (1 L/min), 93% (1 L/min), and 93% (5 L/min) and phases (control, task) as independent variables to determine significant differences in SpO_2 and HR among conditions and phases. *Post-hoc* adjustments for multiple comparisons were made using Bonferroni's test. Since the adaptation phase was an adaptation period after the start of the oxygen supply, this phase was excluded from the analyses. The level of significance was set at 0.05 for all statistical analyses.

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Author contributions: Mi-Hyun Choi, Hyun-Joo Kim, In-Hwa Lee, Hyung-Sik Kim and Jin-Seung Choi were responsible for data acquisition. Hyun-Jun Kim, Hyun-Kyung Park, Dae-Woon Lim and Soon-Cheol Chung were in charge of the study concept and design. Hyun-Jun Kim, Hyun-Kyung Park, Gye-Rae Tack and Soon-Cheol Chung contributed to manuscript development and oversight. Dae-Woon Lim, Gye-Rae Tack and Soon-Cheol Chung provided technical help and help with data analysis. Dae-Woon Lim and Soon-Cheol Chung guided the writing of the manuscript. All authors contributed to, have read and approved the final manuscript.

Conflicts of interest: None declared.

Ethical approval: All experimental procedures were performed according to the regulations of Konkuk University Institutional Review Committee, Republic of Korea.

Author statements: This manuscript is original, has not been submitted to or is not under consideration by another publication, has not been previously published in any language or any form, including electronic, and contains no disclosure of confidential information or authorship/patent application/funding source disputations.

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