Oxygen and Cognitive Abilities:

The Effect of Oxygen Percentage on Reading Comprehension

1. Abstract

In order for the brain to maintain proper functionality, a consistent intake of oxygen is essential as energy production for neural tissues is heavily reliant on oxygen. However, this poses the question of whether different levels of oxygen have any sort of effect on cognitive function or if it does not matter what concentration of oxygen one inhales as long as it is "enough". Our study aims to determine if different oxygen concentrations seem to have an effect on cognitive functionality as well as if different inhalation periods of this oxygen has any effect. In order to do this, we used a Two-Way Randomized Block design and measured the reading comprehension scores of 198 Islanders directly after inhaling different oxygen percentages (15%, normal, and 40%) for their assigned duration (10 minutes, 20 minutes, and 30 minutes). We also blocked by gender as previous studies had differing conclusions on if there is a significant difference in reading comprehension between these two genders. Using a significance level of 0.05, we concluded that oxygen concentration was the only significant predictor of reading comprehension score. These results indicate that it may be worthwhile for schools and workplaces to make efforts to maintain proper ventilation in order to maintain optimal mental performance.

2. Introduction

It has been well established that despite only constituting 2% of the average person's body mass, the brain consumes about 20-30% of the total energy used by the person as a whole. The energy required by the brain is reliant on the oxygen-dependent breakdown of glucose, and one must maintain a constant intake of oxygen in order for the brain to stay electrically active. Additionally, previous research has indicated that as brain activity increases during mentally challenging tasks, neural tissues demonstrate an increase in metabolic demands. Understanding this link between oxygen, brain activity, and cognitive ability could prove advantageous as it may help to make clear ways to optimize mental performance, which could be beneficial to many throughout their day-to-day lives.

Hypoxia is the condition in which the body does not have enough oxygen to maintain homeostasis. Numerous studies have made it abundantly clear that hypoxia impairs mental function as without enough oxygen, ATP production slows down, which results in the brain lacking the necessary energy to operate normally. However, further studies of hypoxia indicate that acute hypoxia has a larger negative impact on mental functioning than long-term exposure to hypoxic conditions (Ho-Jun Seo et al.).

Conversely, hyperoxia is the condition in which bodily tissues have an excess oxygen supply. Not only have studies indicated that highly concentrated oxygen has positive effects on the cognitive processes of healthy young adults, but later studies have also indicated that a similar effect can be seen in elderly adults as increased oxygen concentration resulted in slower heart rates and faster reaction times in elderly participants (Kim, Hyun-Jun et al.). Even intellectually and developmentally disabled individuals have displayed positive reactions to high concentrations of oxygen, which is a particularly notable result as improved cognitive function

could significantly benefit the lives of such individuals (Kim, Hyung-Sik et al.). Though some studies have even indicated that cognitive function increases not only at very high oxygen concentrations but also at slightly elevated concentrations of around 30%, it must be noted that the mental functionality these studies tend to measure are in terms of attention and long-term memory, so they do not necessarily indicate improvement in working memory. Additionally, researchers have suggested that the benefits these participants demonstrated were dependent on the duration of their exposure to increased oxygen, but many studies did not deeply investigate this potential relationship.

Based on the large body of information on the relation between oxygen concentration and cognitive function as well as the substantial benefits understanding this association could pose, this study aims to assess how different oxygen concentrations (both lower and higher than normal) affect mental functionality. Additionally, since some studies indicated that duration of inhalation may also affect any shifts in cognitive performance, we wanted to incorporate different durations of exposure into our study. Through this study, we specifically aimed to investigate if oxygen concentration, duration of inhalation, and the interaction between the two had a statistically significant effect on reading comprehension.

3. Methods

a. *Participants*

The participants will be individuals from The Islands. We will randomly select one of the three islands by assigning a number to each island and using a random number generator to pick one of the three numbers. Then, we will select four cities by assigning a number to each city and using a random number generator to pick four cities. We will then use a random number

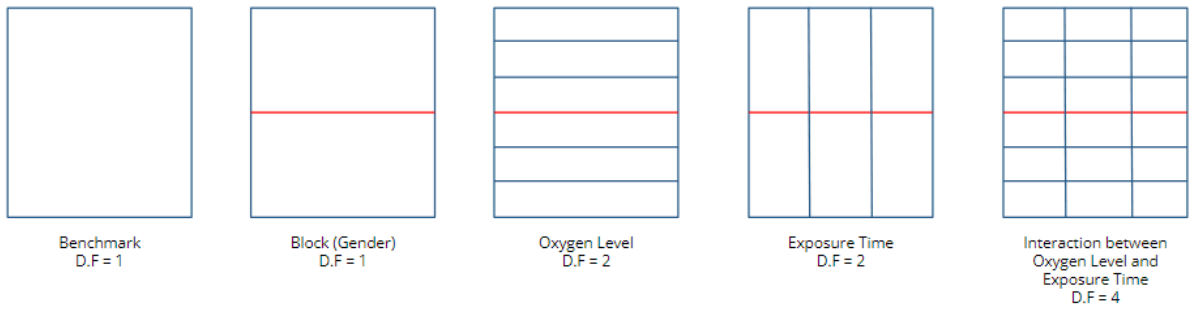
generator to select a house within the city. Then, we randomly select of-age individuals within a selected house. We will repeat the last two steps until we achieve the desired sample size.

b. Design

The study will be conducted using a Two-Way Randomized Block Design. The variables of interested are outlined here:

Response	Reading Comprehension Score		
Treatment 1 (Oxygen Level)	15%	Normal	40%
Treatment 2 (Exposure Time)	10 minutes	20 minutes	30 minutes
Block (Gender)	Male		Female

The factor diagram is also included below:



We focused on oxygen level because of previous literature showing a physiological and neurological reaction to differing levels of oxygen. We decided to use a reading comprehension test score to explore any possible effects. We also focused on oxygen level exposure time as previous literature indicates that the effects of hypoxia and hyperoxia may be dependent on exposure time. Finally, we will block based on gender to account for the biological variation between males and females.

c. Instruments

In order to perform this study, the Island, a virtual world and tool, was used so that tasks may be assigned to and data may be collected from its virtual residents. The Island was used to

gather the participants for this study as detailed throughout this paper, and several of the built-in tasks were assigned to different participants in order to investigate the research questions. Specifically, the tasks assigned to the participants included “Oxygen 40% 10 mins”, “Oxygen 15% 10 mins”, and “Comprehension Test 10 mins”. Additionally, Google Sheets was used to store and organize data during the collection period, and in order to analyze the data, create models, and produce our graphs, we used base R as well as RStudio.

d. Procedure

Step 1: Gather 99 males and 99 females from the Island using the sampling methods detailed above.

Step 2: Using R, randomly assign the groups into the 9 different treatments. The treatment groups are:

1) 15% oxygen level at 10 minutes, 15% oxygen level at 20 minutes, 15% oxygen level at 30 minutes
2) 40% oxygen level at 10 minutes, 40% oxygen level at 20 minutes, 40% oxygen level at 30 minutes
3) Normal oxygen level at 10 minutes, normal oxygen level at 20 minutes, normal oxygen level at 30 minutes

Step 3: Apply the assigned treatment by having them breathe air at the assigned oxygen level for the prescribed amount of time.

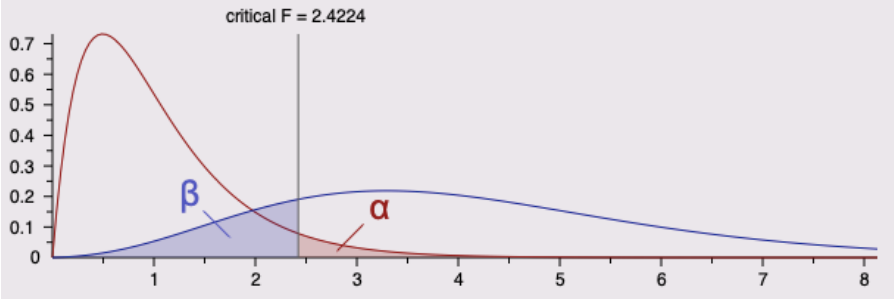
Step 4: Measure the reading comprehension level immediately after oxygen treatment.

4. Data Analysis

a. Type of Statistical Analysis

In order to test whether oxygen level and exposure time have an effect on the comprehension score, we will run an ANOVA using R. This will include F-tests for the differences in oxygen levels and exposure times, as well as for their interaction and for the blocking.

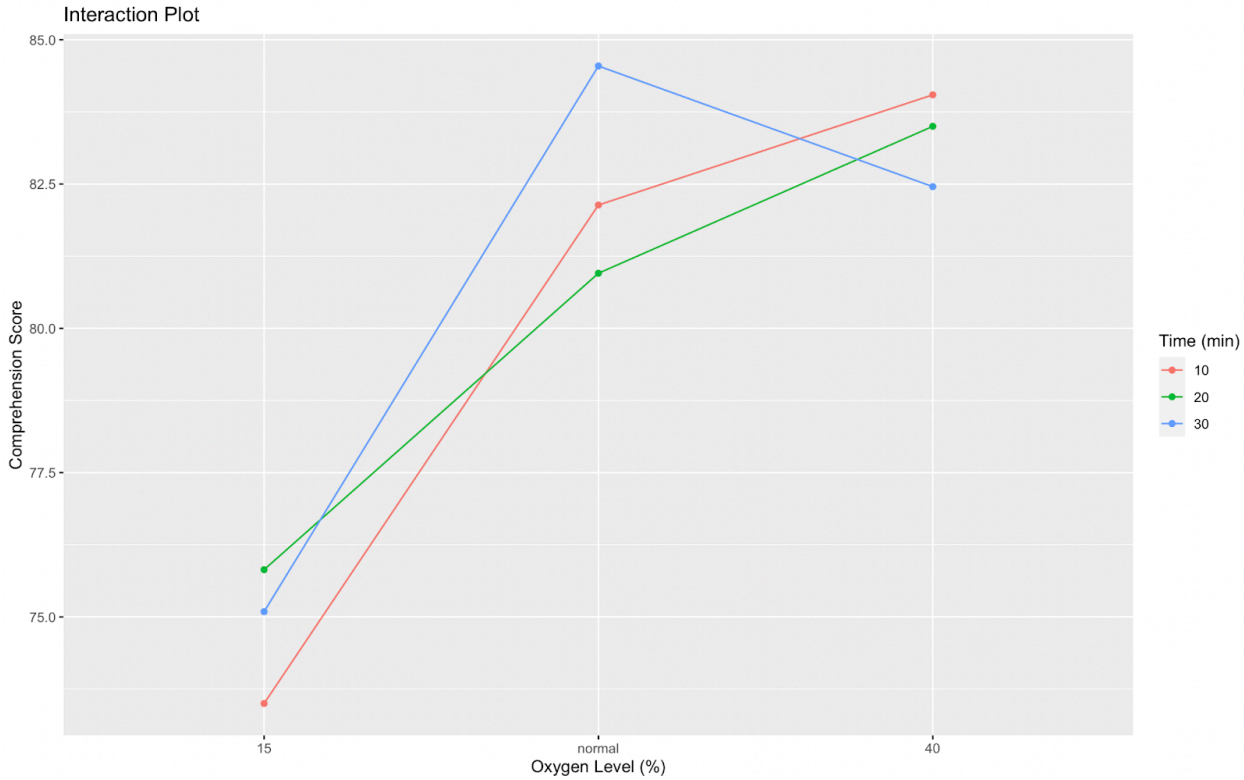
b. Sample Size Determination



For our sample size, we utilized GPower to determine the minimum sample size needed. We decided to use a power level of 80%, alpha level of 0.05, and an effect size of 0.25. After plugging in these values to GPower, it resulted in a minimum sample size of 197. We decided to round up to 198 so we can have a balanced design of 18 treatment groups of 11 individuals.

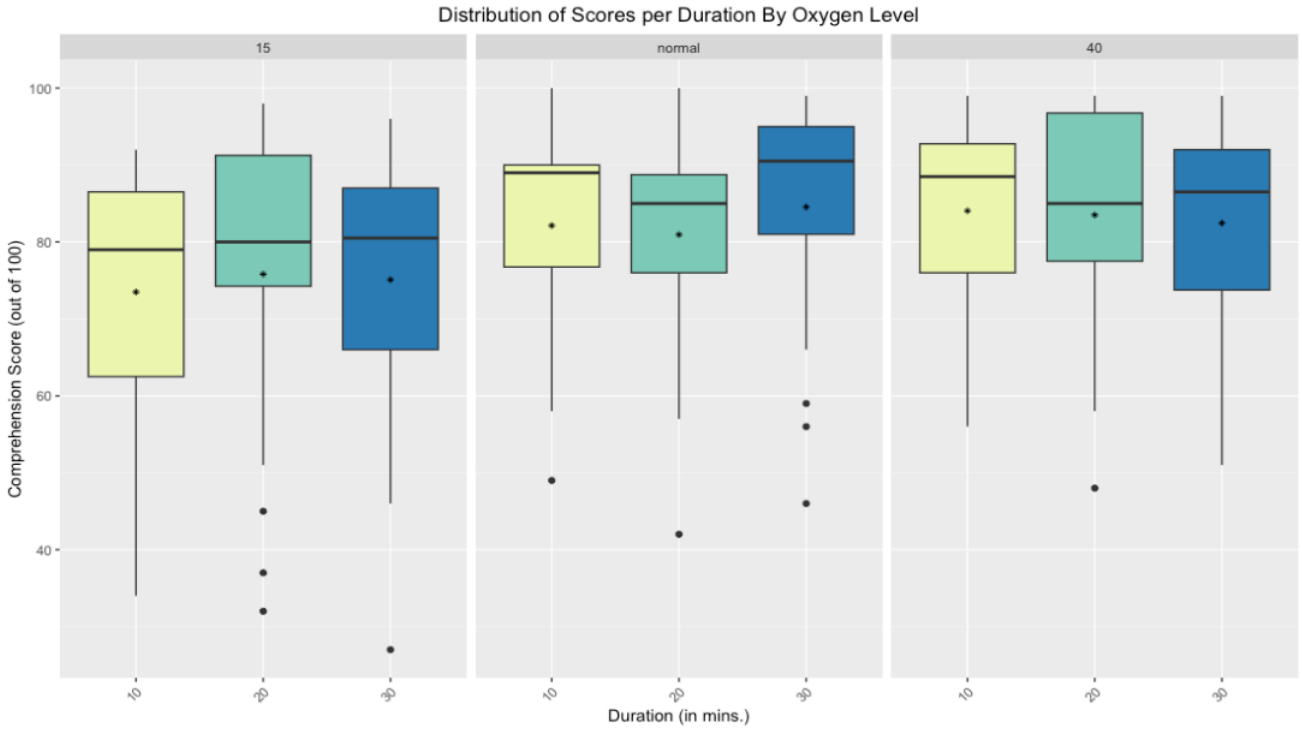
5. Results

a. Interaction Plot

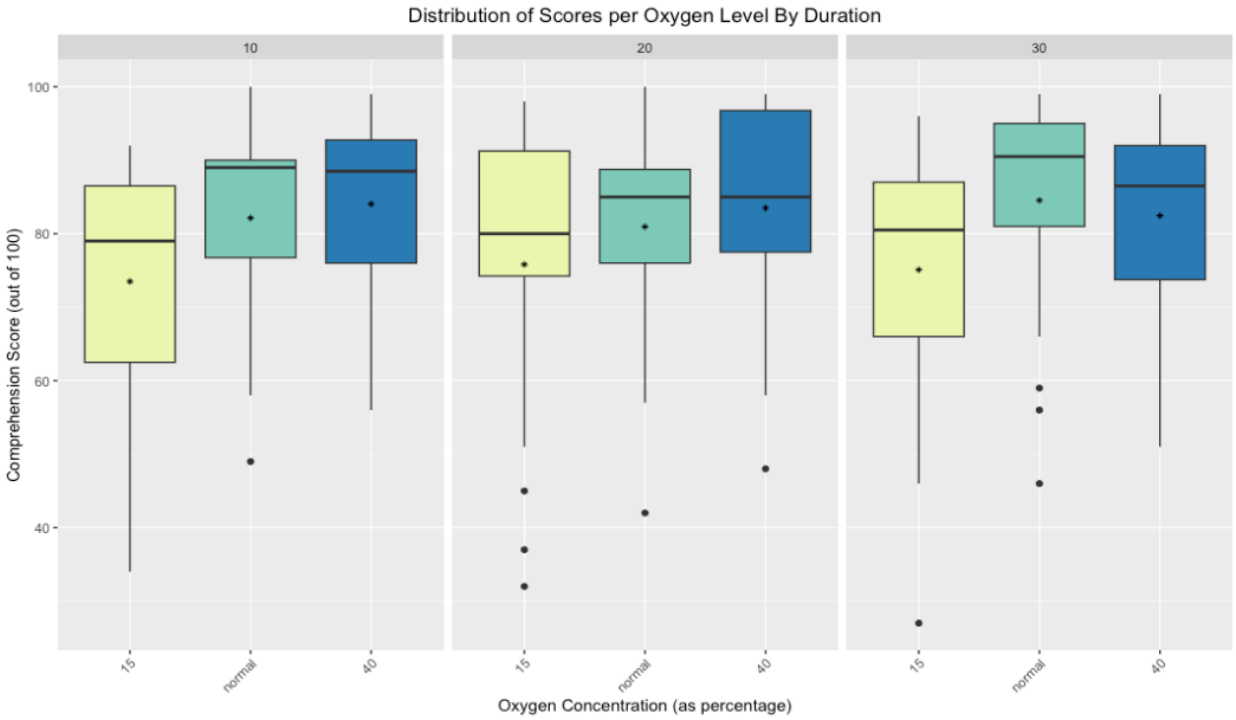


The above interaction plot shows some potential for interaction, especially within the 30 minute treatment. While both the 10 minute and 20 minute treatments showed an increasing trend as the oxygen level increased, the comprehension score actually decreased from the normal oxygen level to the 40% oxygen level for the 30 minute treatment.

b. Boxplots



The above boxplots show the distribution of comprehension scores for each duration of inhaling oxygen clustered by oxygen concentration. While the distributions vary slightly, they remain relatively similar with the means of each group (indicated by the black star within the box) being almost equivalent across the different durations.



This set of boxplots shows the distribution of reading comprehension scores for the different oxygen concentrations clustered by inhalation duration. Not only does the distribution of each group seem to vary, but the means and medians of the normal oxygen concentration and 40% oxygen concentration groups are higher for all three durations than that of the 15% oxygen concentration groups. Additionally, for the 10 minute and 20 minute durations, this plot indicates that as oxygen concentration increased, the mean reading comprehension score also increased.

c. ANOVA Results

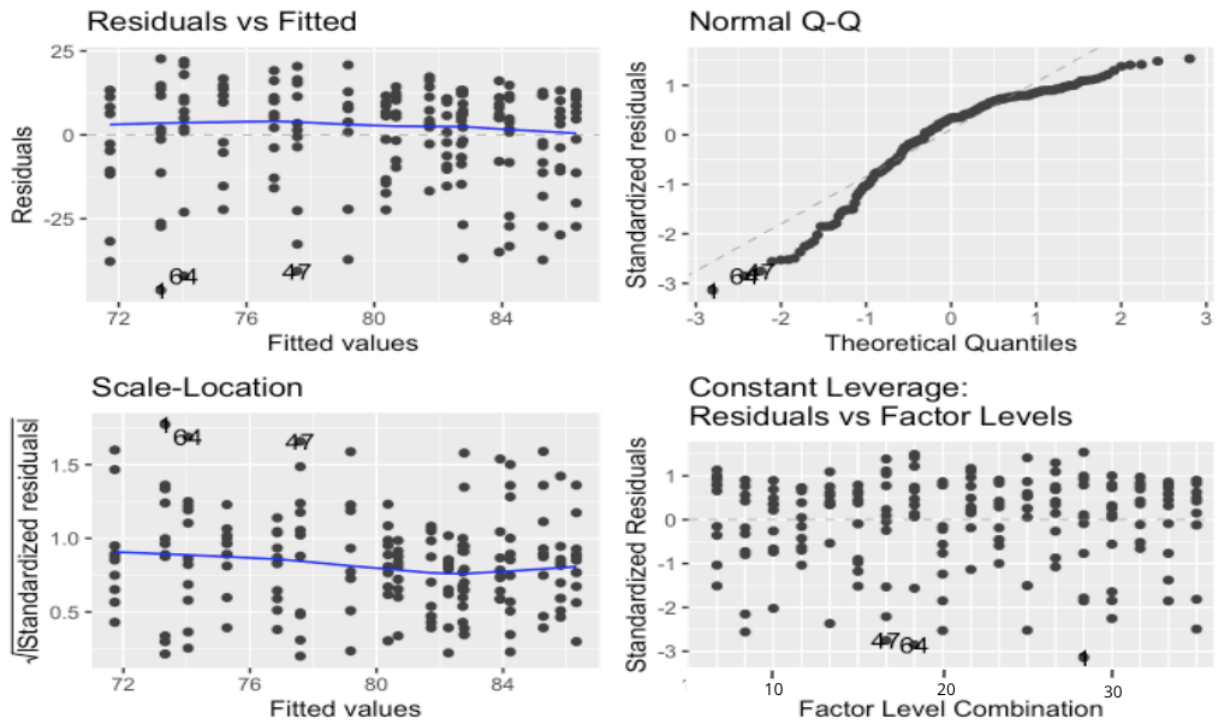
	DF	Sum Square	Mean Square	F Value	P Value
Oxygen Level	2	2,933.303	1,466.652	6.402	0.002
Time	2	23.121	11.561	0.050	0.951
Gender	1	622.227	622.227	2.716	0.101
Oxygen Level:Time	4	214.848	53.712	0.234	0.919
Residuals	188	43,067.273	229.081		

At a significance level of 0.05, the only significant factor was the oxygen level, which had a p-value of 0.002. Exposure time and the interaction between oxygen level and exposure time both did not show statistically significant influence on the comprehension score, with p-values of 0.951 and 0.919 respectively. With a p-value of 0.101, our gender blocking factor also did not show statistically significant influence on the comprehension score, which suggests that our blocking may have been unnecessary.

d. Post-Hoc Tukey HSD

As our only significant factor was the oxygen level, we only need to do a post-hoc Tukey HSD analysis on the oxygen level. There are no other statistically significant differences in the treatments. The above Tukey HSD plot shows the confidence intervals for differences in the oxygen level treatments. Since the interval for 40% minus normal contains 0, there is not a statistically significant difference between them. However, since both the intervals between normal minus 15% and 40% minus 15% do not contain 0, there is a statistically significant difference between those treatments.

e. Residual Plots



The Residuals vs Fitted plot has a relatively straight line, which indicates that the linearity condition appears to be met. Additionally, the points of this plot seem to indicate a random, even scatter, so the constant variance condition appears to be met. The Normal QQ Plot has points that deviate from the line on both sides, which indicates a tailed distribution of the errors and a potential failure to meet the normally distributed errors condition. The Scale-Location plot has a relatively straight line and the points appear evenly spread, so it again seems that the constant variance condition is met. The Residuals vs Factor Levels plot indicates just a few potential outliers, however none of these potential outliers appear to be particularly glaring. Overall, it seems that the constant variance, linearity, and outlier conditions are met while the normality of errors condition requires further investigation.

6. Discussion

The purpose of this study was to determine the effects of varying oxygen levels and inhalation durations, as well as their interaction, on a person's cognitive functionality, specifically reading comprehension ability. This was done by randomly assigning participants to inhale 15%, normal, and 40% oxygen levels at either 10, 20, or 30 minutes prior to taking a reading comprehension test. The scores of the participants on the reading comprehension test were taken as a reflection of their reading comprehension ability during the experiment. Our results indicated that oxygen concentration had a significant effect on reading comprehension, while inhalation duration, the interaction between oxygen concentration and inhalation duration, and the blocking factor, gender, did not have a significant effect on reading comprehension.

The interaction plot revealed potential significance in the interaction between oxygen concentrations and inhalation durations. This could be seen in the plot as comprehension scores for the 10 and 20 minute treatments showed an increasing trend as oxygen levels increased, but the 30 minute treatment saw a drop in comprehension score between normal and 40% oxygen levels. However, it should be noted that the mean comprehension scores across all treatment times were relatively similar for both the normal and 40% oxygen levels so the trend change seen may be due to variability rather than interaction significance. As such, this plot alone is not enough to determine if this interaction is significant in determining comprehension scores and the significance of this interaction was further investigated in the ANOVA.

The boxplots provided insight into how reading comprehension scores were distributed across the various oxygen levels and inhalation durations. Looking at the boxplots showing the distribution of comprehension scores based on inhalation duration and separated on oxygen concentration, it can be seen that while there is some variation between the scores, the means for

each group were relatively similar, suggesting that duration of inhalation does not have a significant impact on comprehension ability. Meanwhile, looking at the boxplots showing the distribution of comprehension scores based on oxygen concentration and separated by inhalation duration, it can be seen that the means of the normal and 40% oxygen groups were consistently higher than the means of the 15% oxygen group. This suggests that oxygen concentration may have a significant effect on comprehension ability, namely that lower oxygen concentrations could have a negative impact on reading comprehension ability.

In order to validate the trends seen in the boxplots and interaction plot, an ANOVA was run in R. Using $\alpha = 0.05$, the ANOVA confirmed that oxygen, with a p-value of 0.002, was a significant predictor of reading comprehension scores which is reflective of what was suggested in the boxplots. Oxygen exposure time and the interaction between oxygen concentration and exposure time did not show significant effects on reading comprehension scores, with p-values of 0.951 and 0.919 respectively. For the exposure times, this was also reflective of what was seen in the boxplots, however, for the interaction between oxygen concentrations and inhalation durations, this contradicted the potential interaction significance suggested by the interaction plot. The blocking factor of gender did not show significant effects on reading comprehension scores either, with a p-value of 0.101. Overall, the ANOVA table suggests varying oxygen levels was the only factor in this study which had a significant effect on reading comprehension.

In order to better understand how oxygen concentration affected comprehension scores, a post-hoc Tukey HSD analysis was conducted. The analysis revealed that the 15% oxygen group had significantly lower reading comprehension scores when compared with both the normal oxygen and 40% oxygen groups. The difference found in reading comprehension scores between the normal and 40% oxygen groups was found to not be statistically significant. These findings

are reflective of what was seen in the boxplots as the 15% oxygen group tended to have lower means than the normal and 40% oxygen groups. These results suggest that a lower than normal oxygen concentration is correlated with a lower comprehension ability, however, a higher oxygen concentration than normal does not have a significant effect on comprehension ability.

The residual plots provided insight into the validity of our model. The Residuals vs Fitted plot displayed a relatively straight line with the points being relatively evenly distributed across the line, suggesting that both the assumptions of linearity and homoscedasticity were met. This was further backed by the Scale-Location plot which showed a similar trend throughout. The Normal QQ plot has multiple points on both tail ends straying from the normality line, with all of these points falling to the right side of the normality line, suggesting that the normality assumption was violated, and the residuals displayed a left-skewed distribution.

7. Conclusion

The results of our study showed that lower than normal oxygen levels negatively impacted reading comprehension ability, while higher than normal oxygen levels did not have a significant impact on reading comprehension. These findings align with previous research on the negative effects of hypoxia on cognitive ability, namely that of acute hypoxia as participants were exposed to 15% oxygen levels for a short duration. However, these findings contradict previous research which suggested that hyperoxia had a positive effect on cognitive ability as participants exposed to 40% oxygen did not have significantly higher comprehension scores than participants exposed to normal oxygen levels.

Our results also showed that the duration of exposure to the various oxygen levels did not have a significant impact on cognitive ability. However, it should be noted that the exposure times of 10, 20, and 30 minutes used in this study are short-term exposures and relatively similar

in the grand scale of a lifetime, as such, longer-term exposures to the various oxygen and the interaction between the longer-term times and oxygen levels could have a significant impact on comprehension ability.

Further research will need to be conducted in order to address the various shortcomings of our study. One shortcoming was the violation of the normal residual assumption seen in the Normal QQ plot, which could have an impact on the generalizability of our study. Another shortcoming of this experiment was that the exposure times of the experiment were all relatively short. Future experiments should look into the long-term implications of oxygen level changes on cognitive ability. Such an experiment could look into the cognitive ability of those living in regions far above sea level, at sea level, and below sea level as the relative amount of oxygen decreases as altitude increases. Additionally, this research was conducted with English reading comprehension as the measure for cognitive functionality, as such, future experiments could delve into the impacts of oxygen concentration on the reading comprehension of other languages, such as Spanish or Chinese, and into the effects of oxygen concentration on other cognitive domains, such as attention and motor function.

In conclusion, our study showed that differing oxygen concentrations has a significant effect on reading comprehension, suggesting a significant effect on cognitive ability, with lower than normal oxygen levels showing a negative effect on reading comprehension while higher than normal oxygen levels did not show an effect on reading comprehension. These findings highlight the importance of maintaining adequate oxygen levels, especially in places where cognitive ability is of importance, such as schools and workplaces. Nevertheless, our study has various limitations and future research should work to build on these limitations in order to

provide a better understanding of the complex interactions between oxygen levels and cognitive ability.

8. References

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