Tempearature on Cognitive Performance

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Abstract

Cognitive performance is central to academic achievement and occupational productivity, yet it may be more vulnerable to environmental conditions than previously assumed. Research from the MIT Climate Portal estimates that even a 1°C increase in temperature results in a 0.13% decrease in cognitive function, emphasizing the urgency of understanding how rising global temperatures can impair mental performance. In this study, we conducted a controlled experiment to assess the effect of room temperature on short-term arithmetic performance across individuals with differing cognitive baselines. We are analyzing the disproportionate impact of thermal stress on more vulnerable populations and offer insight into how climate regulation may be essential in educational and professional settings amid ongoing climate change.

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1 Introduction

As climate change intensifies, so too does the frequency of extreme temperature exposures in our daily environments. While the physiological consequences of heatwaves are well documented, their effects on psychological and cognitive processes are only beginning to receive serious attention. Recent studies, including those from the MIT Climate Portal and UCLA's Luskin Center, reveal that even small increases in ambient temperature can disrupt mental functioning.

Understanding how temperature influences cognition is particularly urgent in academic and workplace contexts, where focus, memory, and mental agility are routinely demanded. Schools, offices, and testing centers often lack standardized temperature controls or do not consider the differential effects that climate may have on individuals.

This paper seeks to explore the impact of the thermal environment on arithmetic performance while accounting for individual cognitive capacity. In doing so, it contributes to a growing body of research at the intersection of environmental science, psychology, and education, aiming to inform policies that prioritize both comfort and cognitive equity.

2 Methods

2.1 Participants

The participants in this study are residents of the islands. We began by generating a randomized list of households using a random number generator. From each selected household, we invited a single individual to participate, and only those who were willing were included in the study. While this means the sample is not purely random, the initial random selection process helps reduce selection bias. After determining each participant's IQ level, we randomly assigned them to one of the treatment groups. We did not control for gender or age, as our goal was to include a wide range of individuals to reflect the diversity of the island population.

2.2 Design

The study will be set up as a 2 x 3 between-subjects factorial experimental design with random assignment. The parameters for the design will be:

- Response Variable: Mental Arithmetic Difficult Test Score
- Factor 1: Room Temperature (Control, Hot (40°C), Cold (-20°C))
- Factor 2 (Blocking Factor): IQ Level (< 100, ≥ 100)
- Interactions: Control + < 100, Hot + < 100, Cold + < 100, Control + ≥ 100, Hot + ≥ 100, Cold + ≥ 100

The factor diagram is detailed below:

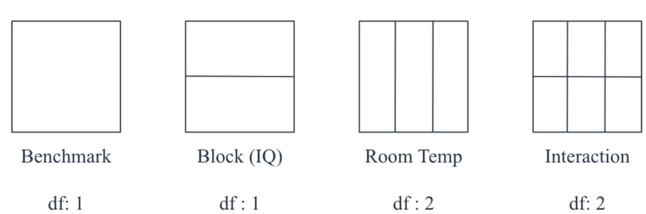

Figure 1: Factor Diagram. These show the factors and degrees of freedom of our experiment.

We chose to focus on temperature and IQ based on their established influence on cognitive performance through distinct physiological and psychological pathways. Our goal is to determine whether short-term exposure to extreme temperatures alters cognitive thinking and whether this effect is moderated by IQ level. We focus on direct short-term exposure because both cold and heat are known to cause immediate physiological stress responses, which may impair performance on tasks requiring concentration and mental arithmetic. We treat IQ as a categorical independent variable (IQ < 100 vs. IQ ≥ 100) to explore how baseline cognitive ability interacts with environmental stressors in shaping cognitive outcomes.

2.3 Instruments

For each randomly selected participant, we first administered a standardized 20-minute IQ assessment to categorize individuals into either the IQ < 100 or IQ ≥ 100 group. To evaluate short-term cognitive performance, we employed a challenging mental arithmetic test as the primary outcome measure. This test was chosen for its ability to assess a participant's capacity for logical reasoning and concentration under pressure. It allows us to directly observe the immediate cognitive effects of brief exposure to extreme temperature conditions.

2.4 Procedure

Step 1: We began by assigning numerical identifiers to each island and city involved in the study. Within these areas, we randomly selected households and then recruited willing participants from each selected household.

Step 2: We assessed the IQ levels of each willing participant and continued sampling until we obtained an equal number of participants in both IQ categories: IQ < 100 and IQ ≥ 100.

Step 3: Participants were then randomly assigned to one of three experimental treatment groups:

- Control Group: Participants took a difficult mental arithmetic test immediately after being in their usual room-temperature environment. This condition was designed to simulate the participants' baseline or most common mental state.
- Hot Condition: Participants were exposed to a high-temperature room (40°C) before immediately taking the same arithmetic test.
- Cold Condition: Participants were exposed to a low-temperature room (-20°C) before immediately taking the arithmetic test.

Step 4: Each participant underwent the treatment condition to which they were randomly assigned.

Step 5: Immediately following the treatment, participants completed the difficult mental arithmetic test. Their performance scores were recorded.

Step 6: Finally, we compared arithmetic test scores across the treatment groups, with cognitive performance (test score) serving as the response variable. The analysis aims to identify any statistically significant effects of temperature and IQ level on cognitive functioning.

3 Data Analysis

3.1 Type of Statistical Analysis

We will perform a two-way analysis of variance (ANOVA) using R to evaluate the effects of temperature and IQ level on cognitive performance. The analysis will employ F-tests to examine both main effects and the interaction effect between the two independent variables: ambient room temperature (cold, room, hot) and IQ category (IQ < 100 vs. IQ ≥ 100). The dependent variable is participants' mathematical test scores, which serve as a proxy for short-term cognitive performance.

A randomized complete block design will be used, with IQ level treated as a blocking factor to control for inter-individual variability. The room temperature condition will be the primary treatment factor. We will include a control group for each IQ group with room temperature IQ testing to establish a statistical baseline against which the treatment conditions can be compared. The full design consists of six groups:

- Room Temperature – IQ < 100
- Cold – IQ < 100
- Hot – IQ < 100
- Room Temperature – IQ ≥ 100
- Cold – IQ ≥ 100
- Hot – IQ ≥ 100

This design enables us to test for significant differences in mean test scores attributable to temperature, IQ level, and their interaction.

3.2 Sample Size Determination

We chose a power level of 0.95, meaning there is a 95% probability of correctly rejecting a false null hypothesis. We set the alpha level at 0.05, which represents the probability of a Type I error, which is falsely rejecting the null hypothesis. Based on an expected average effect size of 0.40, which quantifies the magnitude of the difference between groups, we used G*Power to calculate the required sample size for our study. Given our two-way complete block design and the interaction term with the highest degree of freedom (df = 5), the required sample size was estimated to be 130. However, to maintain a balanced design across all completely crossed groups, we increased the total sample size to 132, ensuring that each group includes exactly 22 participants.

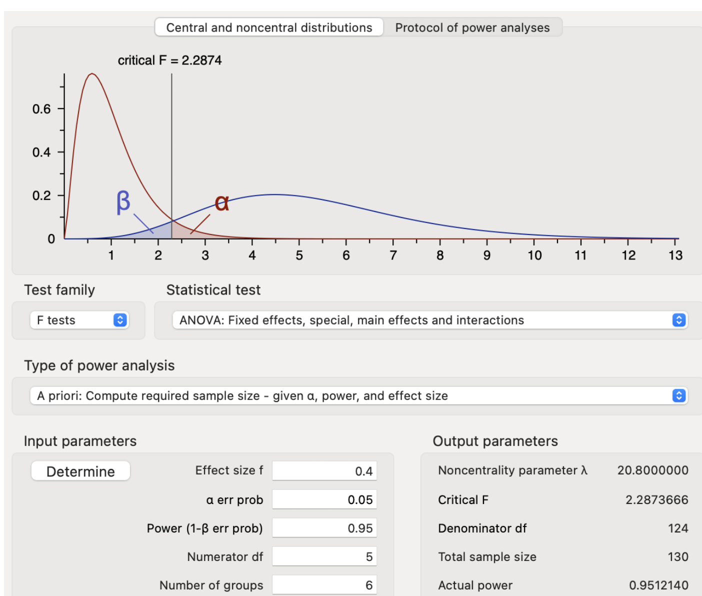

Figure 2: G*Power Sample Size Determination. This shows the parameters we used to calculate the required sample size.

4 Results

4.1 Box Plots

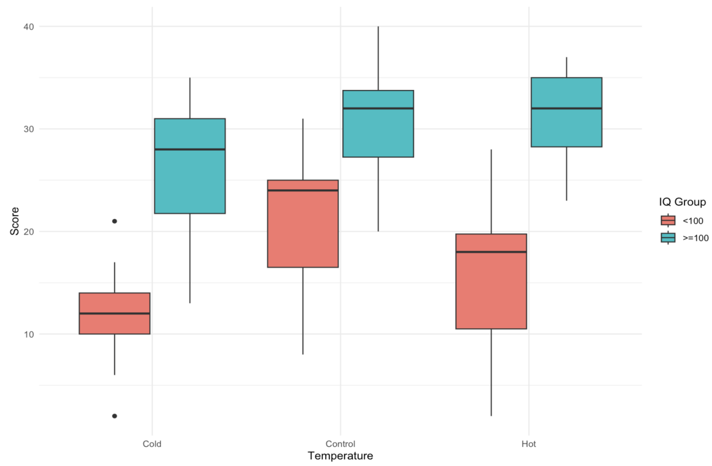

Figure 3: Box Plot Across Temperature by IQ Groups. This is a display of the scores across the different temperature levels for both of the IQ groups.

Looking at the initial box plots in Figure 3, we can see that there is a slight difference in the median scores across temperature levels, especially prominent in the <100 IQ group. Because the boxes across temperature levels are not similarly distributed, we see that temperature might have a significant effect on the score in the memory test.

4.2 Interaction Plots

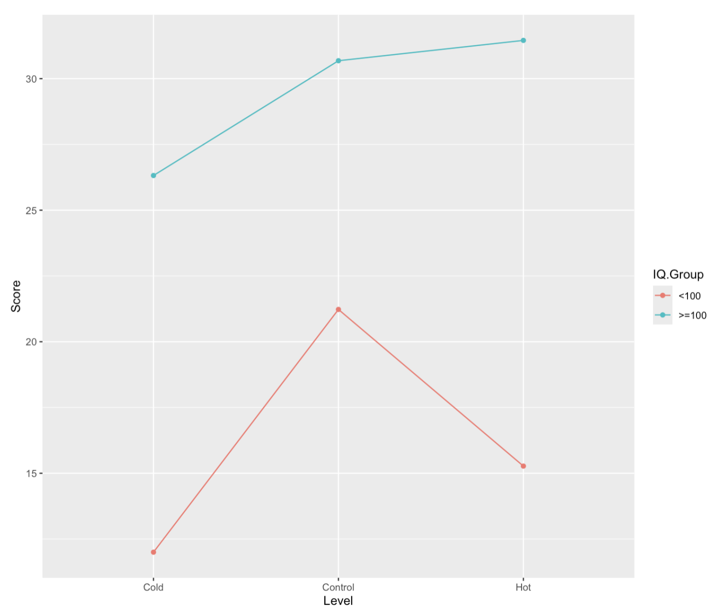

Figure 4: Interaction Plot between IQ Group and Temperature. The dots represent the average score for the people in that temperature level and IQ group.

The interaction plot in Figure 4 suggests interaction between Temperature and IQ Group, given that the lines between IQ groups are not parallel. More importantly, we can see that the effect temperature has on score seems far more prominent in the <100 IQ group, suggesting that people with higher IQ are less affected by temperature when taking the memory test, and thus more consistent in their scores.

4.3 ANOVA Analysis

Term	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Signif
IQ.Group	1	5853	5853	193.920	< 2e-16	***
Level	2	1035	518	17.145	2.6e-07	***
IQ.Group:Level	2	265	133	4.396	0.0143	*
Residuals	126	3803	30			

Figure 5: Summary of Anova Results. These were the ANOVA results of our model, including the interaction term.

At the $\alpha = 0.05$ significance level, these results reveal that IQ group, temperature, and their interaction all have statistically significant effects on short-term memory performance. This indicates that temperature does influence the Islanders' short-term memory scores overall. More importantly, the significant interaction between IQ group and temperature suggests that the impact of temperature is not uniform across individuals—rather, it varies depending on the IQ group.

4.4 Tukey HSD Post-hoc

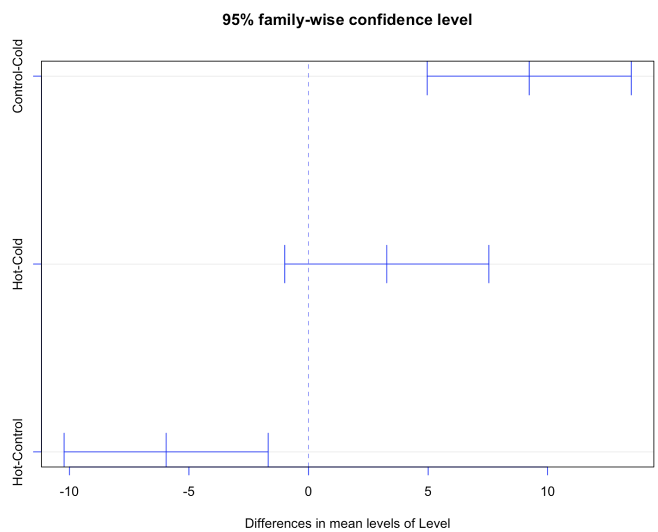

Figure 6: Tukey-HSD Confidence Intervals for IQ Group < 100. The bars represent the confidence intervals of the difference between the two temperature levels. This was only looking at the < 100 IQ Group.

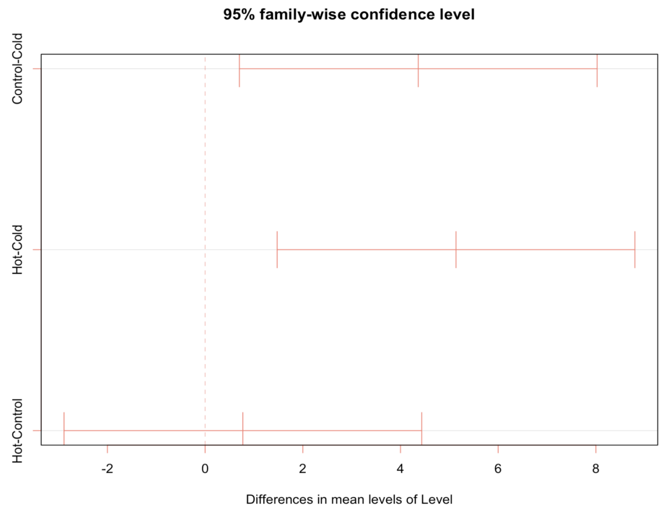

Figure 7: Tukey-HSD Confidence Intervals for IQ Group $\geq$ 100. The bars represent the confidence intervals of the difference between the two temperature levels. This was only looking at the $\geq$ 100 IQ Group.

The confidence interval plots in Figures 6 and 7 illustrate which specific temperature conditions significantly impact short-term memory. In Figure 6, which shows the results for the <100 IQ group, both 95% confidence intervals comparing the hot and cold conditions to the control do not include 0. This indicates that short-term memory scores under hot and cold temperatures are significantly different from those in the control group.

In contrast, Figure 7 displays the confidence intervals for the $\geq$100 IQ group, where the interval for the hot vs. control comparison does include 0. This suggests that, for individuals in the higher IQ group, the difference in memory performance between hot and control conditions is not statistically significant. These findings are consistent with the significant interaction effect found between temperature and IQ group: the influence of temperature on memory performance varies by IQ group. Specifically, individuals with IQ scores below 100 appear to be more negatively affected by high temperatures than those with higher IQ scores.

4.5 Residual Diagnostics

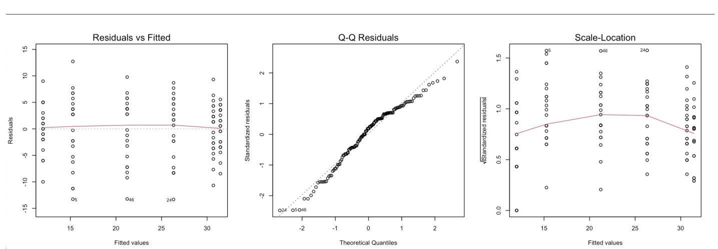

Figure 8: Residual Diagnostic Plots. These were the plots used to check our model validity.

Examining the leftmost and rightmost plots in Figure 8, we observe no clear patterns or signs of heteroskedasticity, supporting the assumption of constant variance. In the center plot, the QQ-plot, the residuals show only minor deviations from the reference line, indicating that they are approximately normally distributed. Thus, these diagnostic plots suggest that the assumptions of our model are reasonably satisfied.

5 Discussion

This study set out to examine how temperature impacts performance in a difficult arithmetic test, and whether or not its effect depends on an individual's IQ. Our results demonstrate that both temperature and IQ level significantly influence performance on mental arithmetic tasks, as well as that their interaction is also significant. These findings suggest that the effect of temperature on cognitive performance is not uniform across individuals but is moderated by a baseline cognitive ability.

Participants with IQ scores below 100 showed a steep decline in performance under both hot (40°C) and cold (-20°C) conditions compared to the neutral control group, with the hot condition having the most detrimental effect. However, in contrast, those with IQ scores of 100 or higher showed more stable performance across temperature levels, most especially between the control and the hot temperature level. This indicates that individuals with higher cognitive baseline are more resilient to environmental stressors such as thermal discomfort, in the context of demanding mental arithmetic tasks.

These results support the growing body of evidence that environmental conditions can impair cognitive functioning, particularly for individuals who may already face cognitive challenges. As climate change increases the frequency of extreme temperature exposures in academic and workplace settings, understanding these effects becomes more and more important. Our findings suggest that temperature regulation may be especially critical in environments where individuals with varying cognitive baselines are expected to perform complex tasks.

While our residual diagnostics confirmed that the ANOVA assumptions were met, our study still has several limitations. First, our measure of cognitive performance was restricted to arithmetic tasks, which, while informative, may not capture the full range of temperature-related cognitive effects, such as memory, focus, pattern recognition, etc. Second, the extreme temperature conditions used in this study may not reflect typical real-world exposures and could influence the generalizability of our results. These drastic differences in our experiment may not be applicable in the context of the slight (but still globally impactful) temperature changes due to climate change. Third, our sample of the Islanders was very broad and encompassed all ages and genders across all three islands. This could ignore the idle effects of some islanders perhaps being accustomed to hotter temperatures, and thus their cognitive performance being less affected when placed in a hotter room.

In future research, we could explore whether the impact of temperature on cognitive performance goes beyond arithmetic tasks and into other cognitive domains—such as memory, attention, or spatial awareness. This would help determine whether temperature affects cognitive functioning more broadly or if its influence is task-specific. Also, we could examine how individuals' environmental backgrounds moderate temperature effects. For example, people accustomed to harsher climates may have adapted to extreme temperatures and therefore show reduced sensitivity compared to those from milder regions. We could also look at how demographic factors such as age and gender may affect cognitive responses to temperature. Future research could also investigate the potential long-term consequences of sustained exposure to extreme temperatures, which might have a drastic effect on populations living in increasingly volatile climates due to climate change.

All in all, our study finds that room temperature significantly impacts arithmetic performance, especially for individuals with lower IQ scores. These findings emphasize the importance of considering individual differences when looking at environmental impacts on cognition, as people with a lower cognitive baseline may be more sensitive to temperature changes in their environment.

References

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