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STAT 404 Project: The Influence of Sensory and Environmental Conditions on Human Reaction Times

Abstract

The objective of this experiment is to investigate how hand dominance, visual distractions, and auditory distractions individually and collectively impact reaction time in a simple colour-change response task. By examining these factors, this study aims to identify any significant main effects and potential interactions, contributing to a deeper understanding of how attentional demands and sensorimotor performance are affected by controlled distractions.

Introduction

Under typical conditions, performance differences between the dominant and non-dominant hands are well-documented, suggesting that sensorimotor tasks, including reaction time measures, may exhibit variations depending on hand preference. Research suggests that dominant hand bias can influence reaction times, often resulting in faster responses when using the dominant hand (Dexheimer, B., Przybyla, A., Murphy, TE., Akpinar, S., Sainburg, R., 2023). While this effect is typically studied in more complex tasks, it may also be relevant in simple reaction-time tasks, depending on the hand used.

Beyond hand dominance, other factors such as visual and auditory distractions are known to influence reaction time, potentially increasing cognitive load and affecting response performance. These distractions can alter attentional demand, which in turn may significantly affect individuals performing a simple reaction time test.

The research report by the Texas Office of Safety studies how the presence of visual distraction affects the reaction time in a simulated traffic environment. The findings showed a higher mean of reaction time for an increased number of the distracting backgrounds to traffic regulatory devices. Through these observations, the presence of visual distraction may increase the reaction speed in a colour-change response task.

Auditory noise can enhance reaction times through stochastic resonance—where adding an optimal level of noise improves sensory detection, suggesting that rather than always being disruptive, noise can actually boost reaction performance when optimally tuned (Pérez-Pacheco, A., Rodríguez Morales, F. Y., Misaghian, K., Faubert, J., & Lugo Arce, J. E., 2024). For this experiment, these findings indicate that certain noise levels might enhance reaction speed, highlighting the potential role of controlled noise in improving performance in tasks requiring quick responses.

In more challenging tasks, noise tended to increase cognitive load, though without a significant change in performance (Smucny, J., Rojas, DC., Eichman, LC., Tregellas, JR., 2013). For this experiment, which tests reaction times under controlled noise and visual distractions, these findings imply that noise could affect cognitive load differently based on task complexity. With added visual distractions, noise may increase cognitive load, potentially slowing responses. This insight helps frame the potential joint effects of noise and distractions on reaction time in this study.

The objective of this experiment is to investigate how controlled noise and visual distractions influence reaction time in a simple color-change response task, examining the individual and combined effects of these factors based on hand dominance and task complexity. This leads to the main research question of this report: ***is there a significant difference in reaction time when performing a colour-change response task with the dominant versus non-dominant hand under varying levels of noise and visual distractions?***

The remainder of the report will be structured as follows: details of the experimental plan and variables in *Experimental Design*, model and data findings in *Statistical Analysis*, summary of results in *Conclusion and Discussion*, *Tables and Figures,* and lastly, *References* and *Appendix*.

Experimental Design

This experiment consists of 3 treatment factors, 1 blocking factor and the response variable. Further details on the variables can be referred to in **Table 1** below. A factorial design with lighting as a blocking factor to investigate how our treatments affect reaction time will be conducted for this report. To ensure independence of observations, trial order will be randomized within each lighting block by picking a number randomly corresponding to one of the 12 unique treatments, and a brief gap will be placed between trials to prevent fatigue and adaptation. Data will be analyzed using an ANOVA model. The main effects and interactions of our treatment factors will be analyzed, while lighting will control for environmental variability but will not be a focus of interpretation. This model allows us to assess if each factor or combination of factors significantly impacts reaction time. Statistical significance will be evaluated at $\alpha = 0.05$.

For each level of room lighting condition: dark (absence of light), dim (low-level illumination) and bright (high-level illumination), 2*2*3=12 different combinations of hand dominance, visual distraction and audio distraction will be conducted. The subject will perform trials using either their dominant and non-dominant hand to assess whether or not dominant hand bias can influence reaction times. The screen of the device will be split between a plain background (no visual distraction) or the distractor video, and the reaction performance platform. In addition, participants will be exposed to no background auditory distraction, moderate distraction (mid-neutral volume) and high distraction (maximum volume) utilizing consistent headphones and audio source throughout all trials.

Using a web application, reaction time will be recorded for each trial, which begins with a red screen that changes to green after a random delay, prompting the subject to click as quickly as possible. The time from the green screen's appearance to the click is recorded as the reaction time. This process is repeated across all factor combinations with replication, using the same computer and mouse for reliability.

Statistical Analysis

Through the exploratory data analysis in **figure 1** and summary statistics found, we observe the following:

1) Hand Used
   Median reaction time for the dominant hand (1) is lower than that of the non-dominant (0) hand, however the range is much larger, suggesting greater variability. Through the summary statistics, the average reaction time for the non-dominant hand was 278 milliseconds and dominant was 273 milliseconds.

2) Visual Distraction
   Reaction time with no visual distraction (0) appears faster than that with (1), with a narrower interquartile range. The average reaction time for no visual distraction was 269 milliseconds, and with distraction was 281 milliseconds.

3) Audio Distraction
   High decibel distraction (-1), has the smallest interquartile range, but an outlier is present. We observe the median reaction time for no audio distraction (0) is the lowest, but the observations were the most inconsistent, with the greatest range. Low decibel (moderate) distraction (1) has the slowest median reaction time out of the three levels. The average reaction time was the highest for moderate audio distraction, at 281 milliseconds, followed by high distraction with 276 milliseconds and the lowest for no audio at 269 milliseconds.

4) Lighting Condition
   The observed reaction times are distinct between each lighting condition. We observe the quickest reaction time in a dim-lit room, and the slowest in a dark one. The range between each level of lighting was relatively similar.

Before fitting the ANOVA model, we assessed whether the response variable (average reaction time) required a transformation to satisfy the assumptions of normality and homoscedasticity. Using the Box-Cox procedure, we tested a range of λ values to determine the optimal power transformation. The resulting Box-Cox plot shown in **figure 2** indicated that $\lambda=1$ (no transformation) lies well within the 95% confidence interval, suggesting that the data does not require a transformation. As a result, we proceeded with the untransformed data for subsequent analyses.

To analyze the effects of experimental factors and their interactions on reaction time, we fit a factorial ANOVA model with the blocking variable (Lighting) included to control for environmental variability. Thus, the model can be written as:

$$Reaction\ Time_{ijklm} = \mu + \tau_i + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + \delta_m + \epsilon_{ijklm}$$

Where:

- μ: Overall Mean
- τ_i: Effect of the blocking factor Lighting (i = 1, 2, 3 representing Dark, Dim and Bright)
- α_j: Effect of Hand Used (j = 0: Non-Dominant, 1: Dominant)
- β_k: Effect of Visual Distraction (k = 0: None, 1: Distraction)
- γ_l: Effect of Auditory Distraction (l = 0: None, 1 = Moderate, -1: High)
- Interaction Terms:
    - $(\alpha\beta)_{jk}$: Interaction between Hand Used and Visual Distraction
    - $(\alpha\gamma)_{jl}$: Interaction between Hand Used and Auditory Distraction
    - $(\beta\gamma)_{kl}$: Interaction between Visual and Auditory Distraction
    - $(\alpha\beta\gamma)_{jkl}$: Three-way interaction among all treatment factors
- δ_m: Random effect of the m-th block (Lighting) to account for variability
- ϵ_{ijklm}: Residual error term, assumed to be independently and normally distributed $N(0, \sigma^2)$

To ensure the reliability of the fitted ANOVA model, model assumptions are checked through diagnostic plots, given in **figure 3.** The assumption of normality is satisfied as the histogram of residuals is approximately symmetric with a slight bell-curved shape, and the points of the QQ plot follow a linear relationship, with no deviations that are of significant concern. The residuals vs. fitted plot displays a random scatter of points, symmetric around 0 and no apparent pattern, therefore the assumption of a linear relationship and homoscedasticity is satisfied.

<u>Anova Results</u>

Hand Used

While the dominant hand (1) exhibited a slightly faster average reaction time (273 ms) compared to the non-dominant hand (0, 278 ms), this difference was not statistically significant ($F = 2.166$, $p = 0.155 > 0.05$). Moreover, the dominant hand showed greater variability in reaction times, as indicated by a wider range in the data.

Visual Distraction

The presence of visual distractions significantly slowed reaction times ($F = 11.006$, $p = 0.003 < 0.05$). On average, reaction times were faster with no visual distraction (0, 269 ms) compared to trials with distractions (1, 281 ms). The interquartile range for trials without visual distraction was narrower, indicating greater consistency in performance.

Auditory Distraction
The level of auditory distraction also had a statistically significant effect on reaction times ($F = 3.493$, $p = 0.048 < 0.05$). Trials with no auditory distraction (0) exhibited the fastest average reaction time (269 ms) but showed the greatest variability. High decibel distractions (-1) led to slightly slower reaction times (276 ms) with greater consistency, while moderate distractions (1) resulted in the slowest average reaction time (281 ms).

Lighting Condition
Lighting condition, included as a blocking factor in the ANOVA model, was the most statistically significant factor ($F = 33.461$, $p < 0.001$). Its primary purpose in the model was to control for environmental variability across trials, ensuring that any observed differences in reaction time could be more accurately attributed to the treatment factors rather than lighting inconsistencies. Despite being a blocking factor and not a treatment, the substantial variation in reaction times across the three lighting conditions—where the dim condition produced the fastest average reaction times and the dark condition the slowest—highlights its influence on the response variable. By accounting for lighting in the model, we reduced residual variance, improving the overall model's precision and robustness.

Interaction Effects
None of the interaction terms in the ANOVA model were statistically significant ($p > 0.05$); however, some trends were noted. The dominant hand appeared slightly less affected by visual distractions compared to the non-dominant hand, while auditory distraction levels showed minimal variability in reaction times without a clear pattern. Combined visual and auditory distractions showed a slight increase in reaction time, though the effect was not consistent. Overall, the trends suggest largely additive effects rather than meaningful interactions, highlighting potential areas for further investigation with a larger sample size. For a deeper understanding of the behavior of the interaction effects, we assess the interaction plot, generated in **figure 4**:

1) Visual Distraction Vs. Auditory Distraction
   Non-parallel lines suggest that interaction is present but not strong. We observe that for both levels of visual distraction, average reaction time is lowest when there is no auditory distraction and highest for low decibel distraction. For a combination of no auditory and visual distraction, the quickest average reaction time is achieved.

2) Hand Used Vs. Visual Distraction
   Although lines are not parallel, this interaction plot does not indicate a strong interaction relationship between hand used and visual distraction. Average reaction time is displayed to be the slowest for presence of visual distraction for either non-dominant or dominant hand. This plot suggests that using your dominant hand with no visual distraction will minimize average reaction time.

3) Hand Used Vs. Auditory Distraction
   The estimated effect of auditory distraction depends slightly on whether you use your non-dominant or dominant hand in these tasks. Similar to 1, average reaction time is lowest when no auditory distraction is used for either hand, and highest for low decibel. However, no auditory distraction and performing with your dominant hand is optimal for the lowest average reaction speed.

Based on these findings, performing the simple color-change response task with your dominant hand, with the absence of auditory and visual distraction in a dim-lit room is recommended to achieve the quickest average reaction speed. The estimated average reaction time for the recommended levels from the ANOVA model is approximately 241.122 ms, with standard error 6.892 ms. We're 95% confident that the true average human reaction speed for the recommended levels falls between 226.829 ms and 255.416 ms.

A half normal plot was also made as shown in **figure 5**. The half-normal plot confirms Visual Distraction and Auditory distraction as the dominant contributors to reaction time variability, aligning with the ANOVA results. Hand Used and interaction terms show negligible deviations from the theoretical line, underscoring their limited impact. The results also suggest that treatment factors largely operate independently, with no strong evidence of synergistic effects. This result reinforces the observed importance of sensory distractions and lighting conditions, while indicating that hand dominance plays a minor role in reaction performance, at least for a simple colour-change test like in this experiment.

Conclusion and Discussion

This study examined how hand dominance, visual distraction, auditory distraction, and lighting conditions influence reaction times in a simple color-change response task. Visual and auditory distractions were found to significantly increase reaction times, with visual distractions having a stronger effect. Lighting conditions, included as a blocking factor, had the most substantial impact, with the fastest responses observed under dim lighting and the slowest under dark conditions. Hand dominance did not significantly influence reaction times, and the absence of significant interaction effects suggests that the treatment factors operate independently rather than synergistically. The results of this experiment align with precious research indicating that visual and auditory distractions increase cognitive load, while optimal lighting conditions enhance performance. Overall, the findings highlight the independent effects of sensory distractions and environmental conditions on reaction performance, providing a foundation for future research into task complexity and individual variability.

While study effectively controls for environmental variability and assessed key factors influencing reaction time, there are areas for improvement:

1. Sample size: The limited sample size may have reduced the power of the experiment in finding significant interaction effects. Future studies could include more participants to enhance generalizability and statistical power.

2. Additional Blocking Factors: While lighting was shown to be statistically significant, additional levels or different environmental conditions (e.g., temperature) could provide additional insights

3. Task Complexity: The colour-change task is a simple reaction test. Using more complex tasks could better stimulate real-world scenarios and provide deeper insights into how distractions affect reaction performance.

4. Fatigue and Training Effects: Although measures were taken to reduce fatigue, repeated trials could still introduce fatigue or adaptation effects, where participants may become faster through familiarity with the task. Future experiments could explicitly measure or account for these effects, such as by including randomized rest periods or training blocks prior to data collection.

5. Additional Variables: Factors such as caffeine intake, sleep quality, or participant demographics (e.g., age, experience) could be included to investigate their potential influence on reaction times

In summary, the experiment successfully identified the significant main effects of visual and auditory distractions, as well as lighting conditions, on reaction times. Future studies should build on these findings by incorporating larger and more diverse participant groups and exploring additional environmental, task-related, and temporal factors such as fatigue and training effects.

Tables and Figures

Variable Name	Type of Variable	Variable Role	Units	Levels
Reaction Time	Continuous	Response	Milliseconds	N/A
Hand Dominance	Binary	Treatment factor	N/A	2 (dominant, non-dominant)
Visual Distraction	Binary	Treatment Factor	N/A	2 (yes/no)
Audio Distraction	Categorical	Treatment Factor	N/A	3 (none, moderate, high)
Lighting Condition	Categorical	Blocking Factor	N/A	3 (dark, dim, bright)

Table 1: Response Variable and Factors

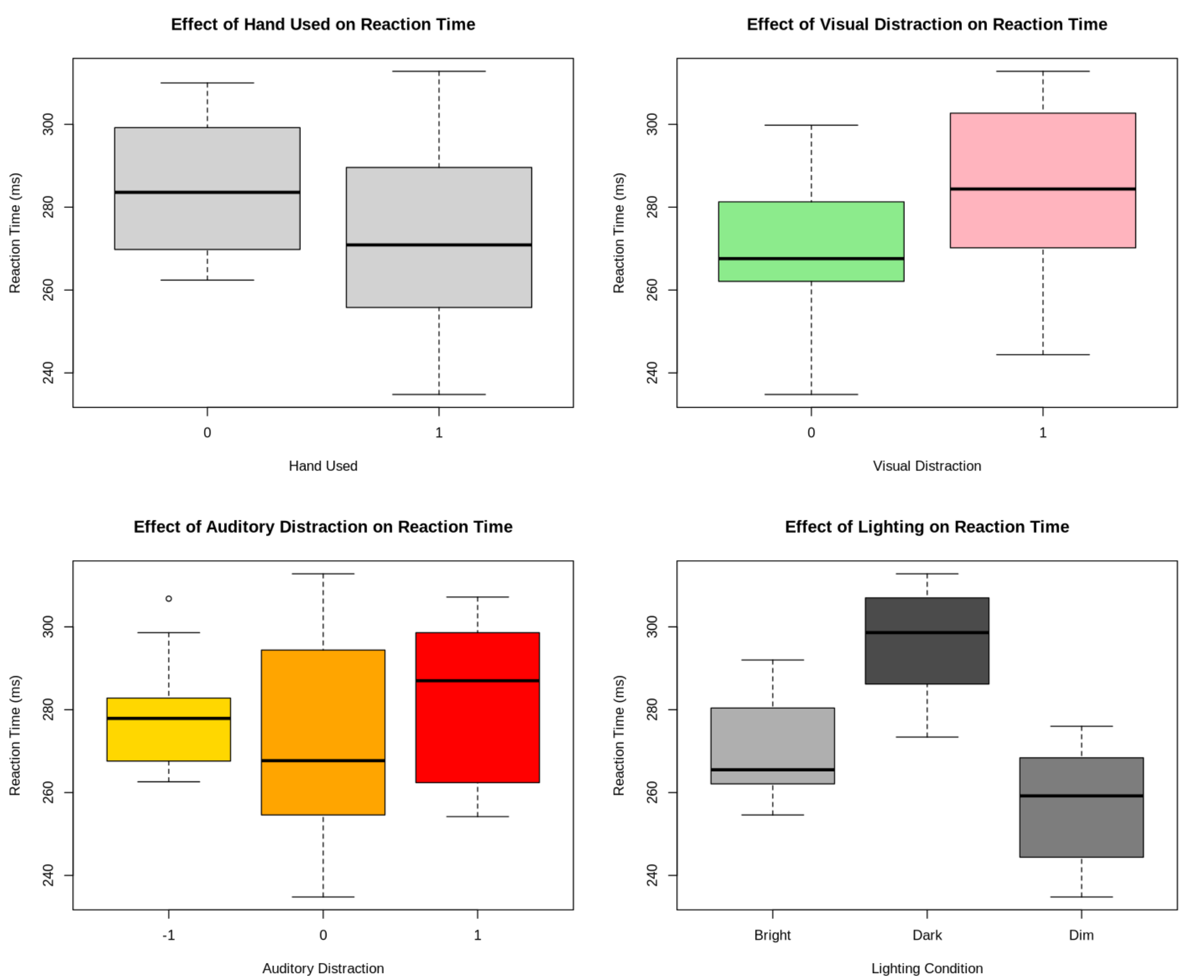

Figure 1: Boxplots illustrating the effects of Hand Used, Visual Distraction, Auditory Distraction, and Lighting Condition on Reaction Time (ms).

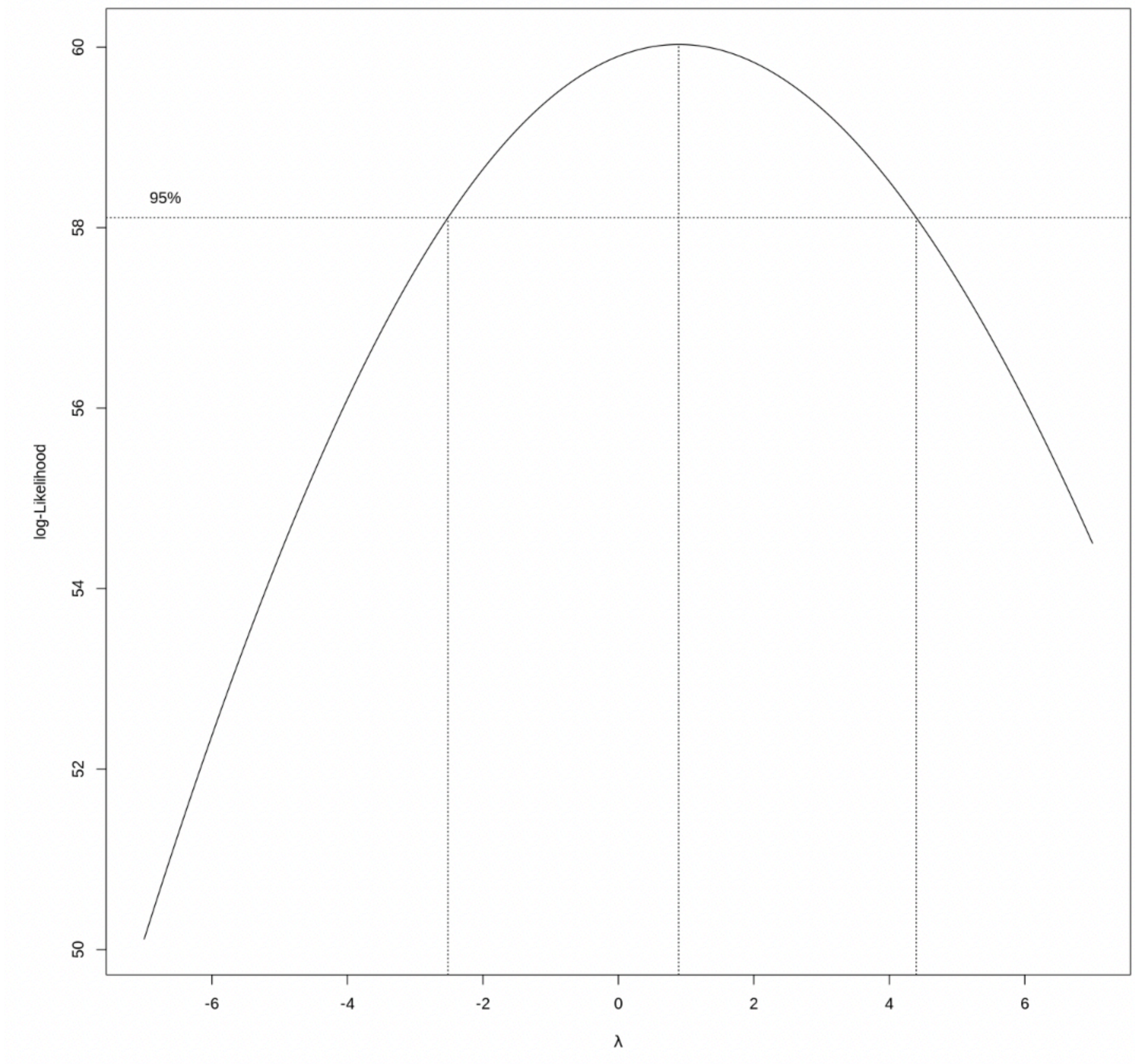

Figure 2: Box Cox Plot for Potential Model Transformation

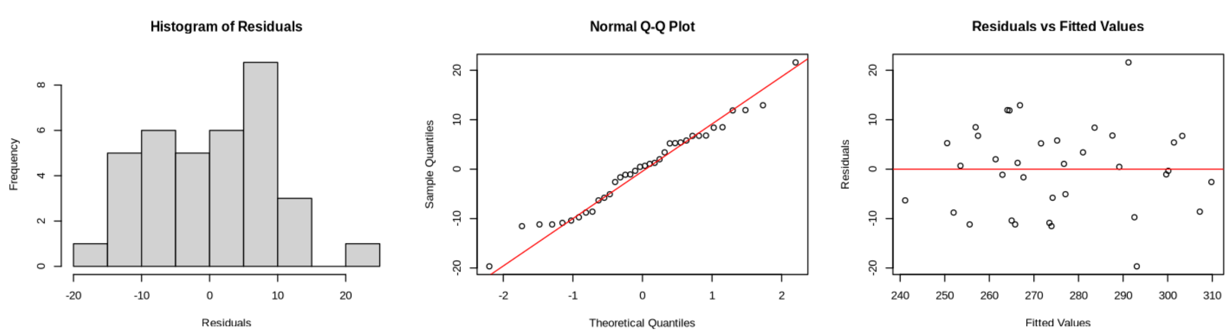

Figure 3: Diagnostic plots for assessing model assumptions.

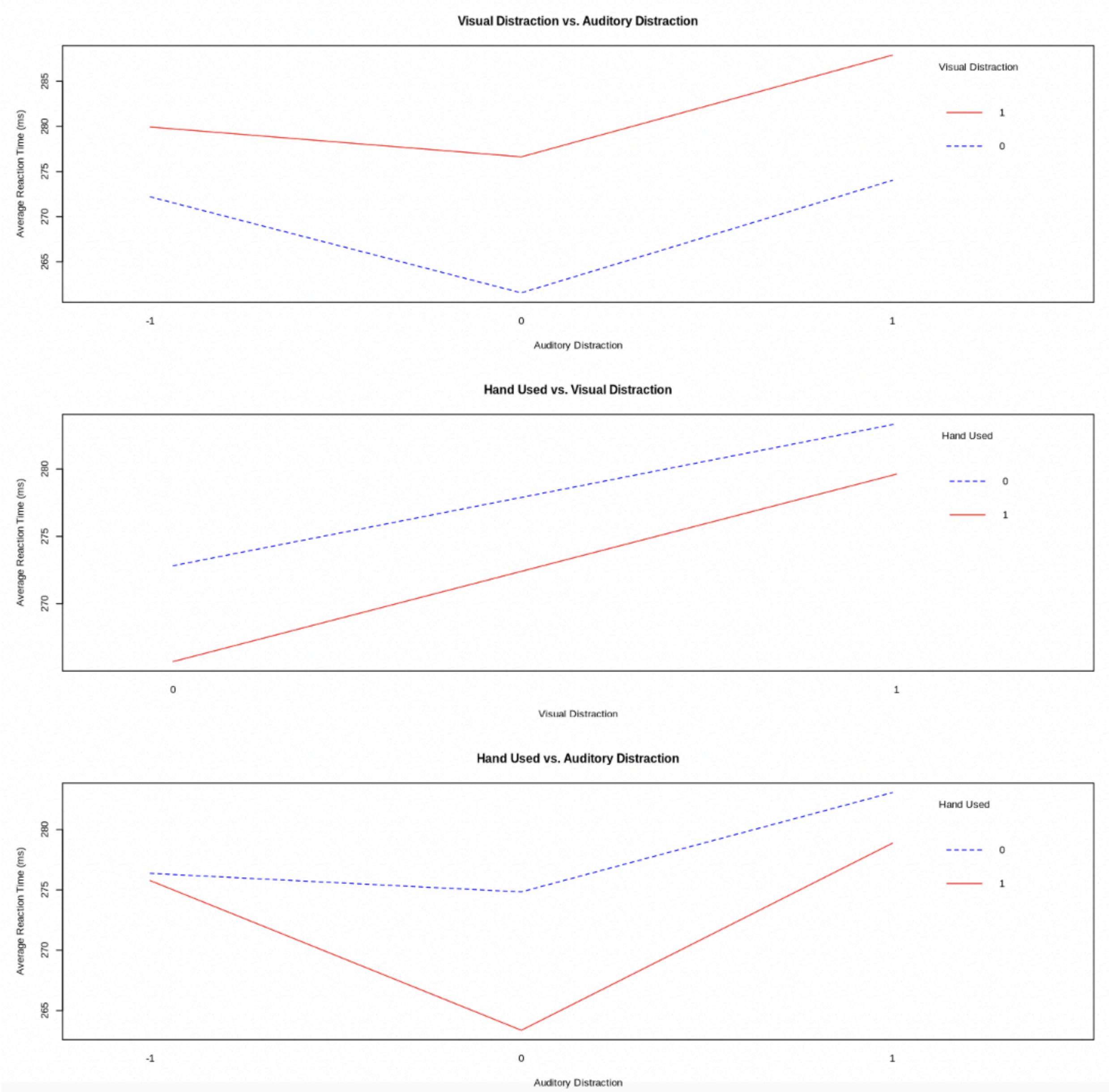

Figure 4: Interaction plots for the effects of treatment factors on reaction time.

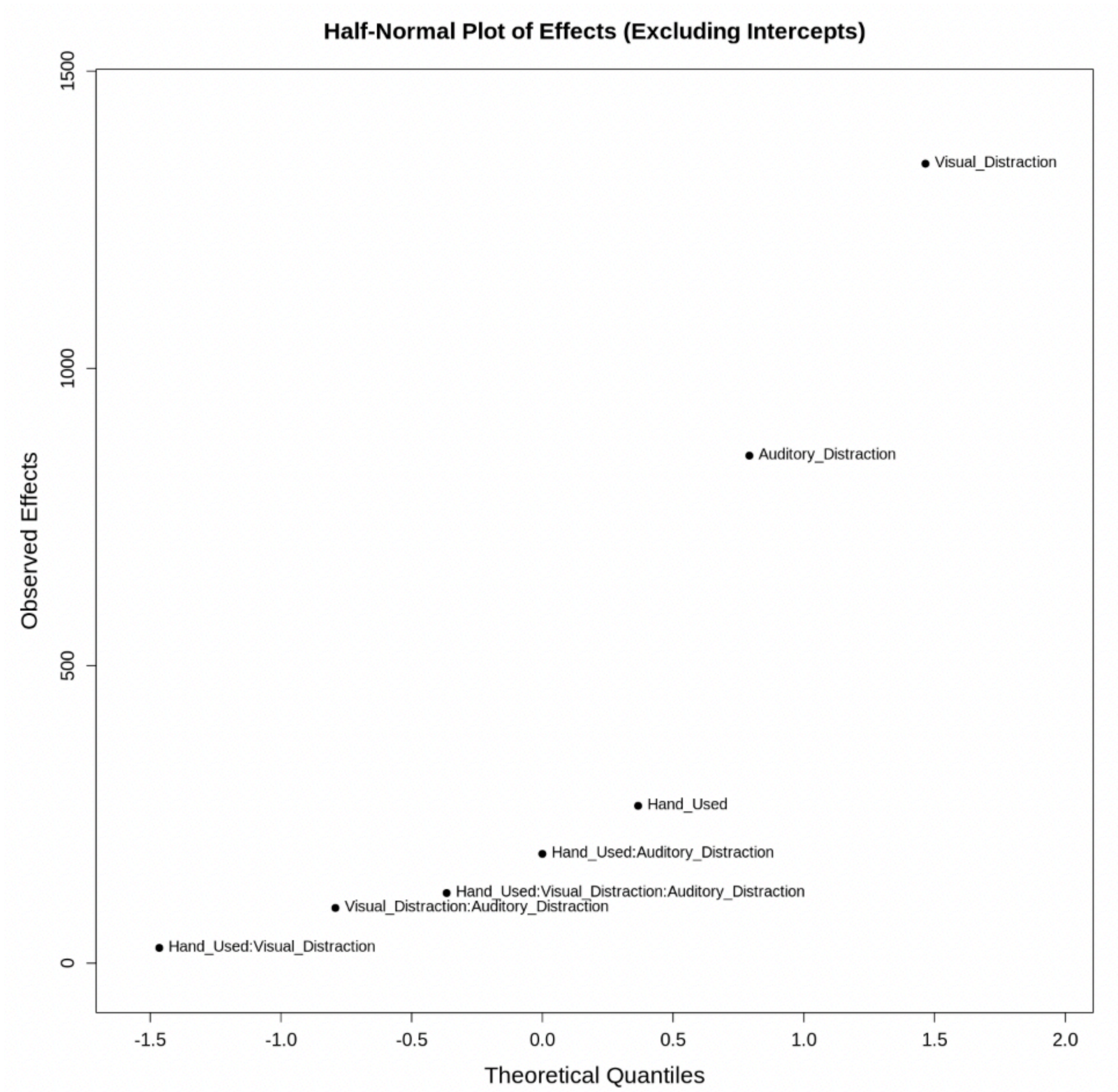

Figure 5: Half-Normal Plot of Effects (Excluding Intercepts)

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Appendix

Description of Variables in Experiment:

- ***Average Reaction Time:*** Mean reaction time (in milliseconds) from 5 observations of each unique treatment in a specified lighting condition. The reaction time for all trials are recorded by a single-color response website: https://humanbenchmark.com/.
- ***Hand Dominance:*** Whether participant is using dominant (1) or non-dominant hand (0) to perform each trial.
- ***Auditory Distraction:*** The level of auditory distraction imposed during a trial, whether none (0), moderate: low-decibel volume, half-step increment on Macbook (1) or high: maximum-decibel volume, full bar on Macbook (-1). The audio source used throughout the experiment can be found at https://www.youtube.com/watch?v=RlqUl-xdoiA. For no audio distraction, no video is played but noise-cancelling headphones are utilized still to minimize background noise.
- ***Visual Distraction:*** Whether the participant was subjected to a visual distraction while performing the tasks. The screen was split in half with the response website and either a black screen or the distractor video used: https://www.youtube.com/watch?v=i5_kLgSn_SE&ab_channel=ColorfulPlayButton.
- ***Lighting Condition:*** The 2 room light conditions which 12 unique treatments are conducted. The room being completely dark, dim-lit: half-bar in controlled light switch or bright: maximum bar in controlled light switch