BEHAVIORAL RESEARCH & STATISTICAL METHODS

“REINFORCEMENT LEARNING AND MEMORY SPECIFICTY OVER AGES”

TEAM: REWARD
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CONTENT

THE EXPERIMENT

Citation:

NUSSENBAUM, KATE, AND CATHERINE A HARTLEY. "REINFORCEMENT LEARNING INCREASINGLY SHAPES MEMORY SPECIFICITY FROM CHILDHOOD TO ADULTHOOD." OSF, 27 NOV. 2023. WEB.

THE EXPERIMENT

- Study the dynamic relationship between learning, decision-making, and memory across different life stages.

- Characterize how individuals of different age groups adapt the specificity of their representations during value-guided learning

- Two experiments conducted to explore how the specificity of these learned representations impacts subsequent memory by manipulating the reward structures.

OBJECTIVES

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- Conduct thorough data analysis on the dataset from the experiment. Use statistical tools to validate the results.

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- Address developmental questions about adaptive behavior and its significance for memory formation.

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- Conduct thorough data analysis on the dataset from the experiment. Use statistical tools to validate the results.
- Address developmental questions about adaptive behavior and its significance for memory formation.
- Gain insights into the complex relationship between experience, cognition, and memory throughout life.

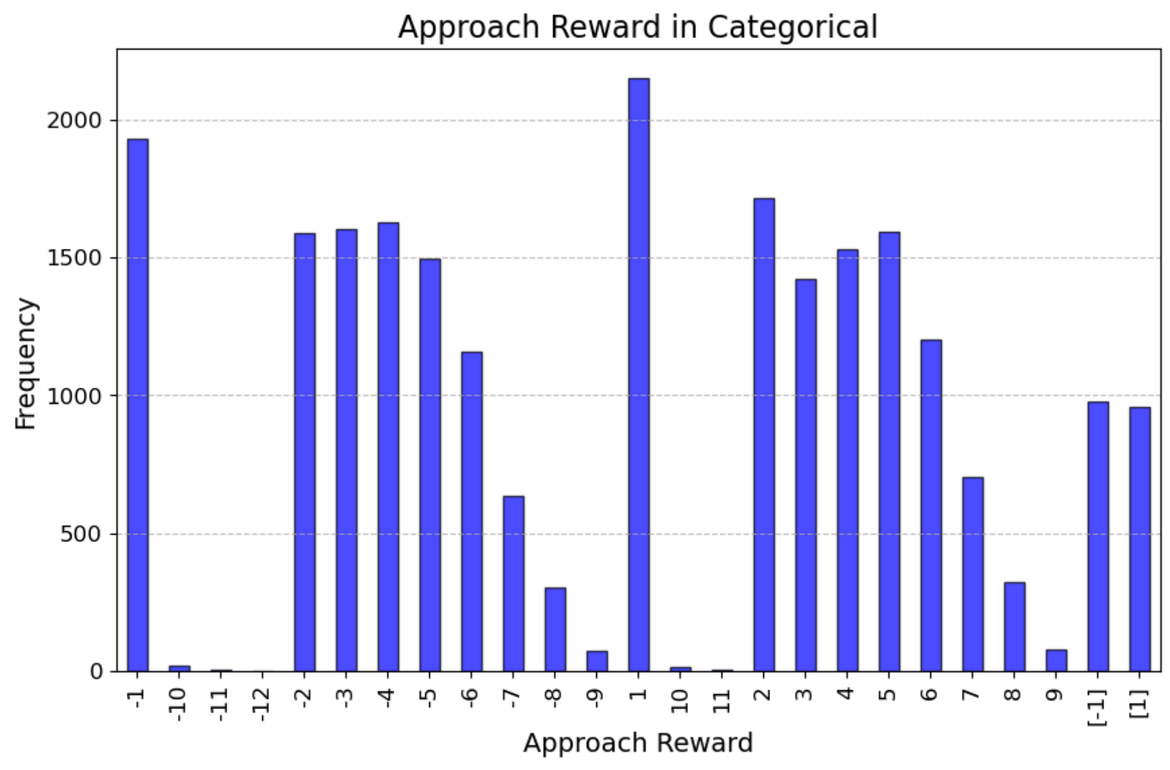
DATA DESCRIPTION

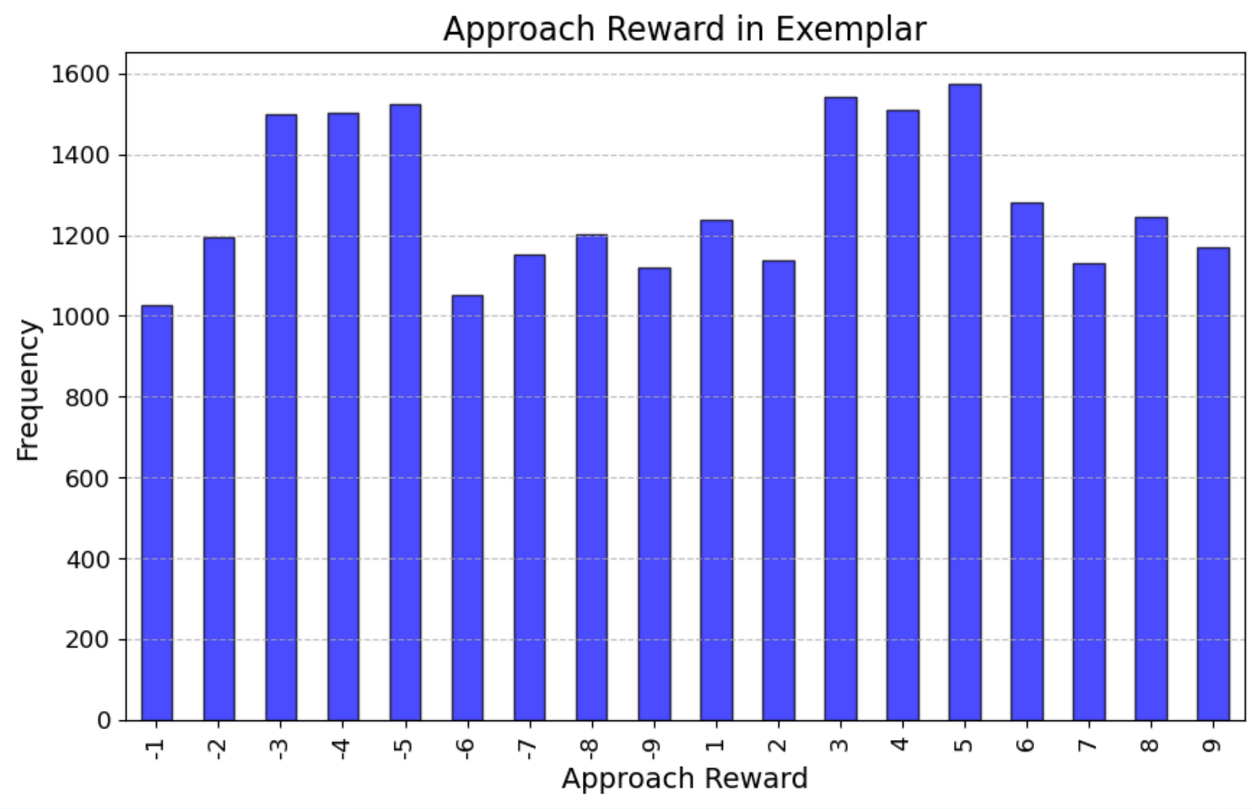
DATA

Comprises **behavioral data** collected from participants of different age groups through an experiments (N = 151)

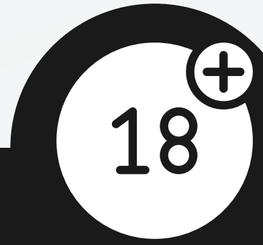
Provides insights into how reward and specficity shapes **learning strategies** and **memory formation** across developmental stages

EXPERIMENT DESIGN





TABLES



- subject IDs and ages

SUBJECT DATA

- Each row is a trial in RL task
- Has reaction times, points & decisions

LEARNING DATA

- Each row is a trial in RL task
- Has stimulus categories & block conditions

RL DATA

- Each row is a trial in Memory task
- Has accuracy, response time & confidence ratings

MEMORY DATA

EXPERIMENTAL DESIGN

Participants: People of different ages, including children, adolescents, and adults.

9 unique stimuli, each with 3 exemplars from broader categories. Each picture had a corresponding reward, either tied to that specific picture or to a broader category it belonged to.

RL TASK DESIGN

Participants encountered different pictures and had to make choices based on the association between pictures and rewards.

LEARNING TASK

1 week after completing the RL task, subjects completed a test of recognition memory to decide whether stimuli were old or new on a four-point confidence scale.

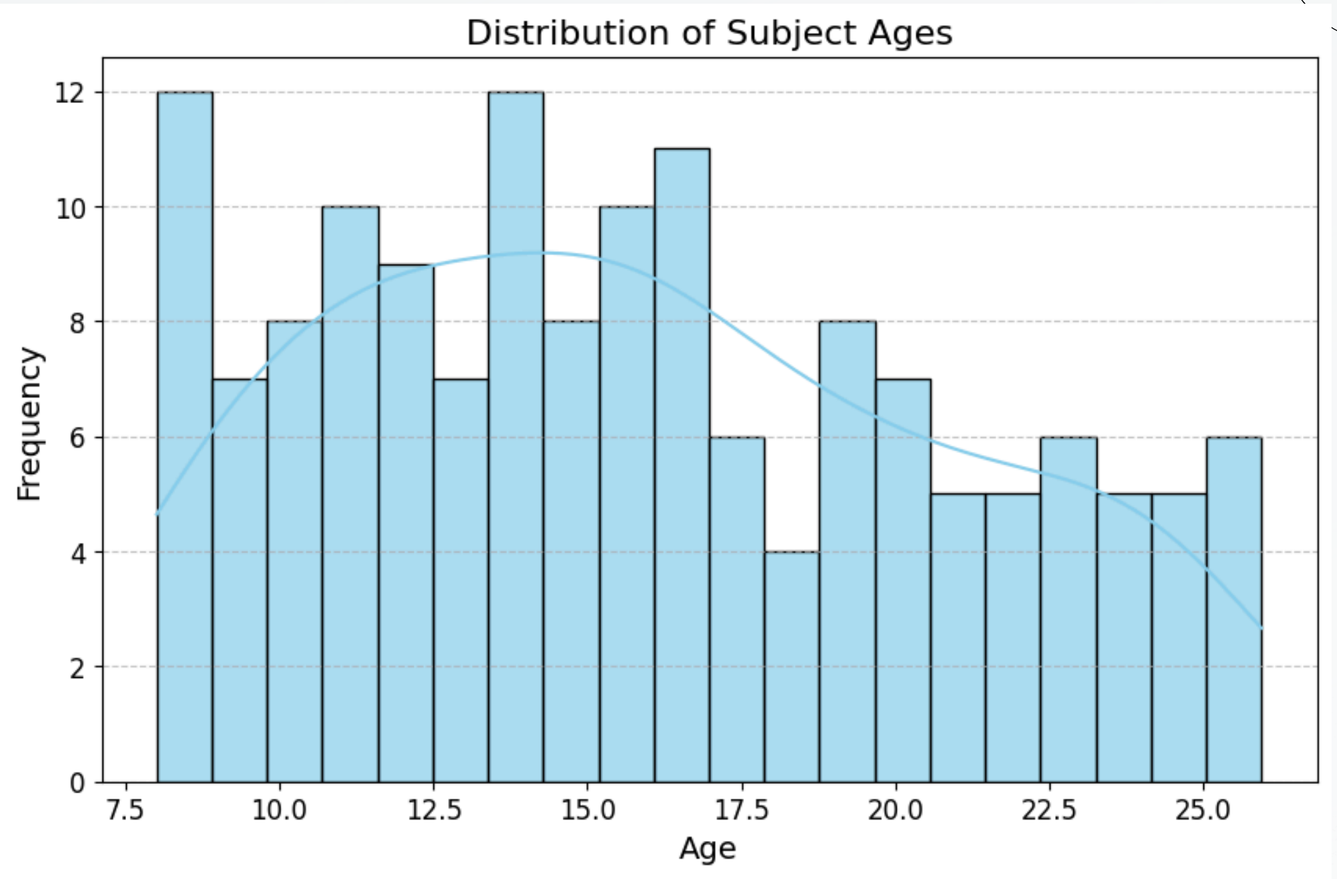
MEMORY TEST

Objective - To understand how individuals adjust the specificity of their mental representations during value-based learning and the subsequent impact of this adaptability on memory.

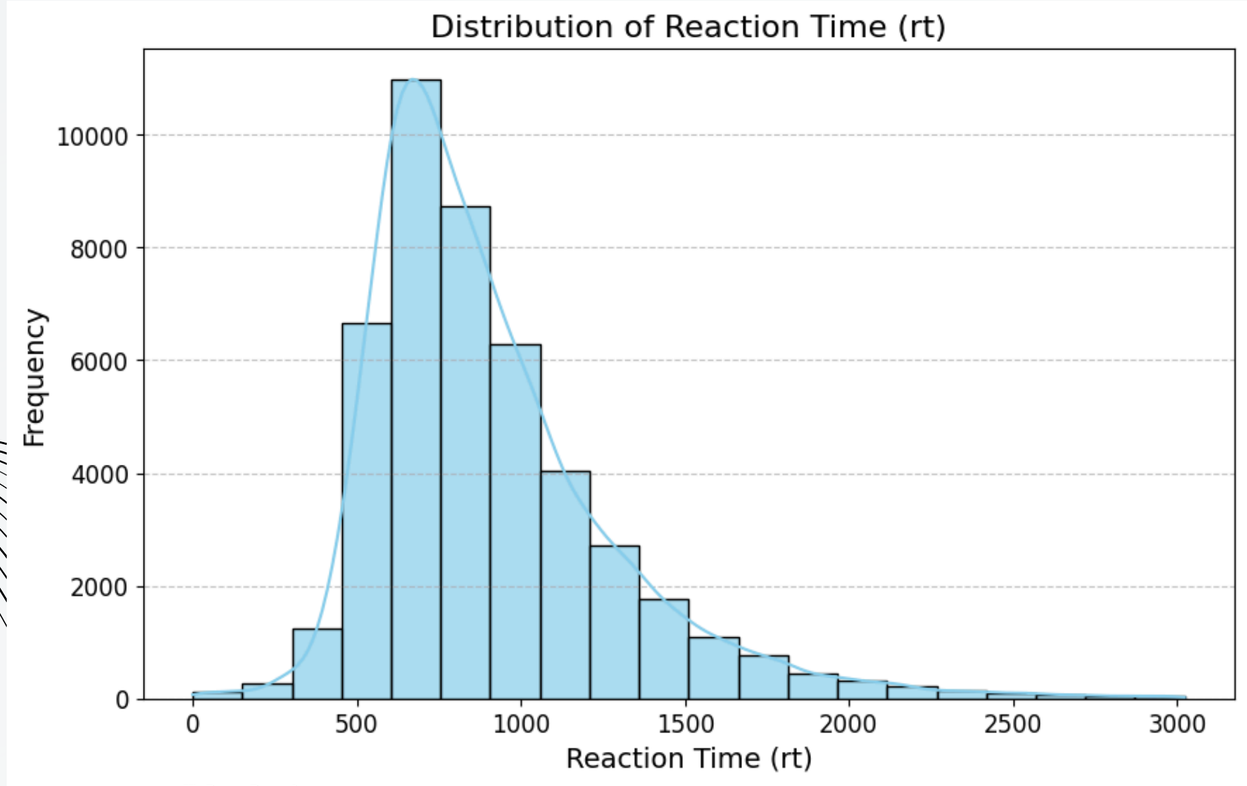
EXPLORATORY DATA ANALYSIS

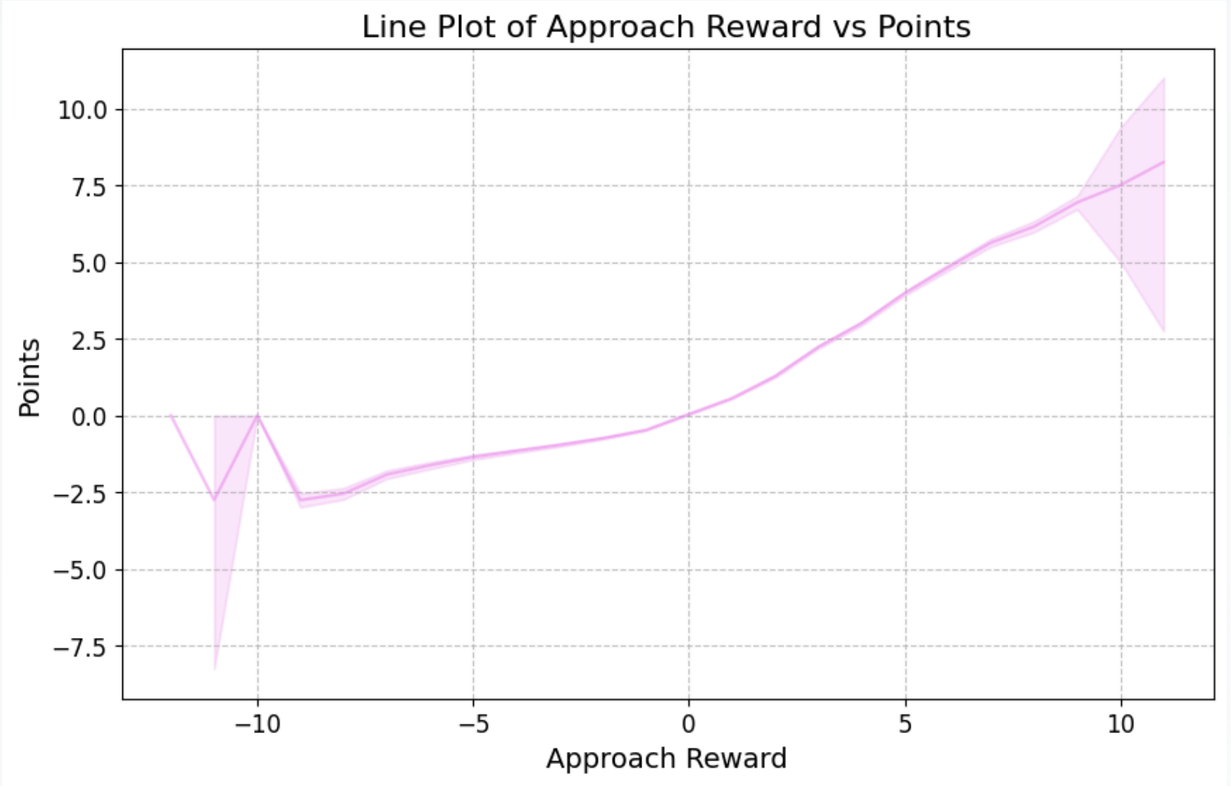
EXPERIMENT 1 : SUBJECT AGE

- There are 151 subjects.
- The age range is 8-25 years.
- The average age is 15.8 years .

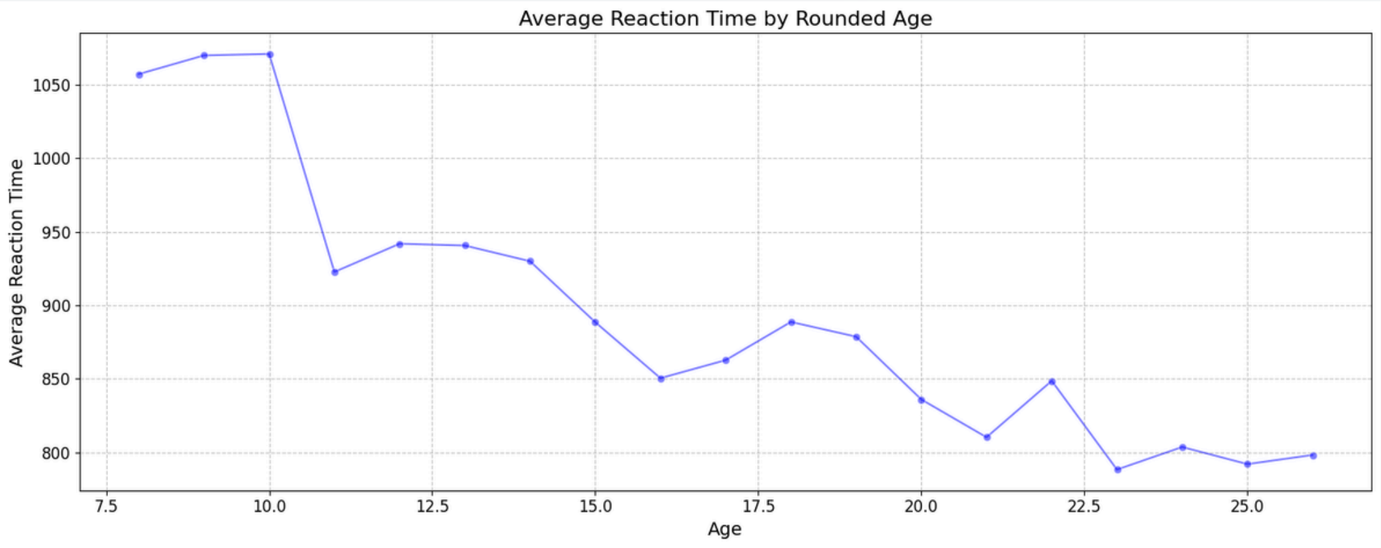


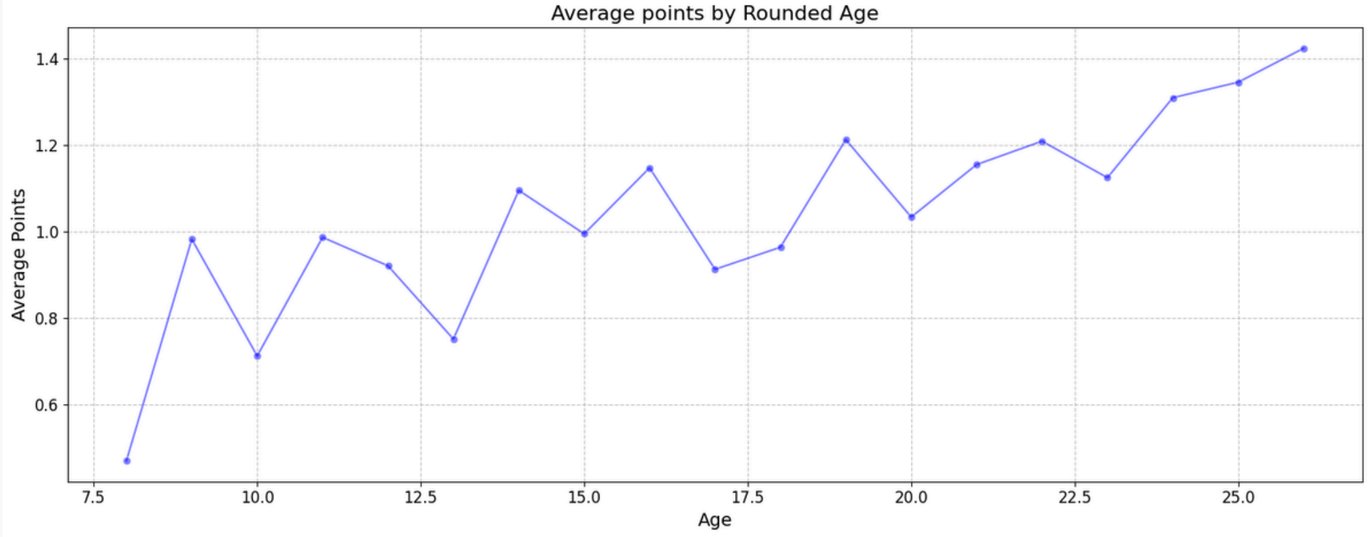
EXPERIMENT 1 : LEARNING DATA



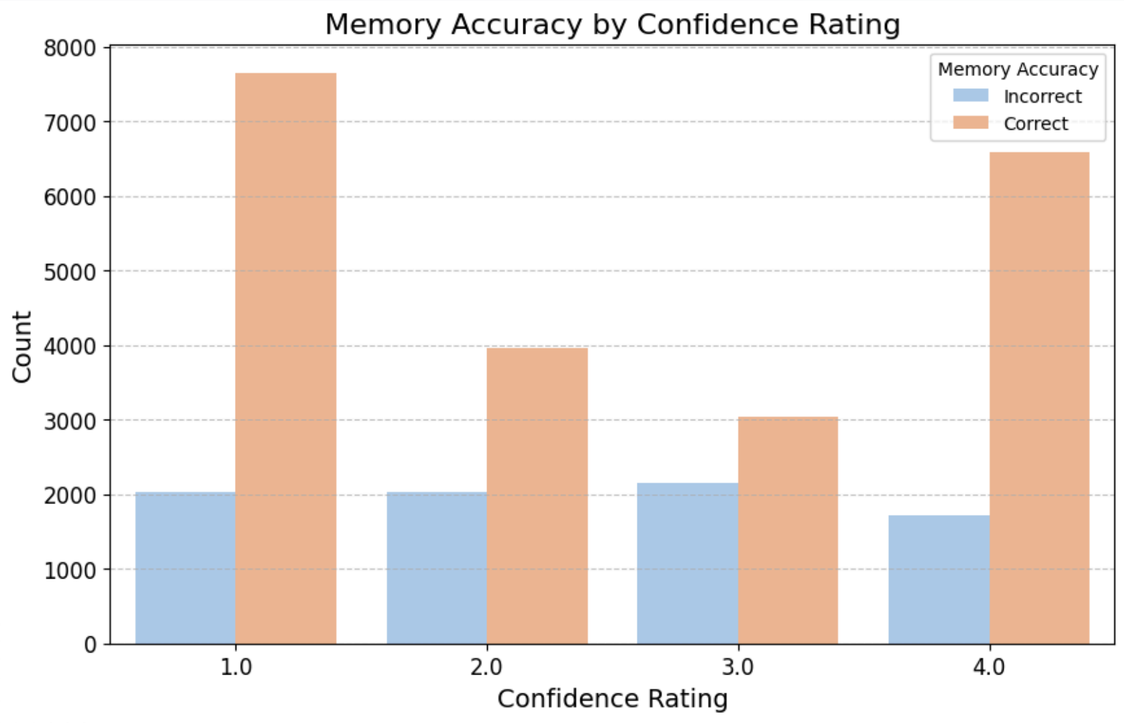


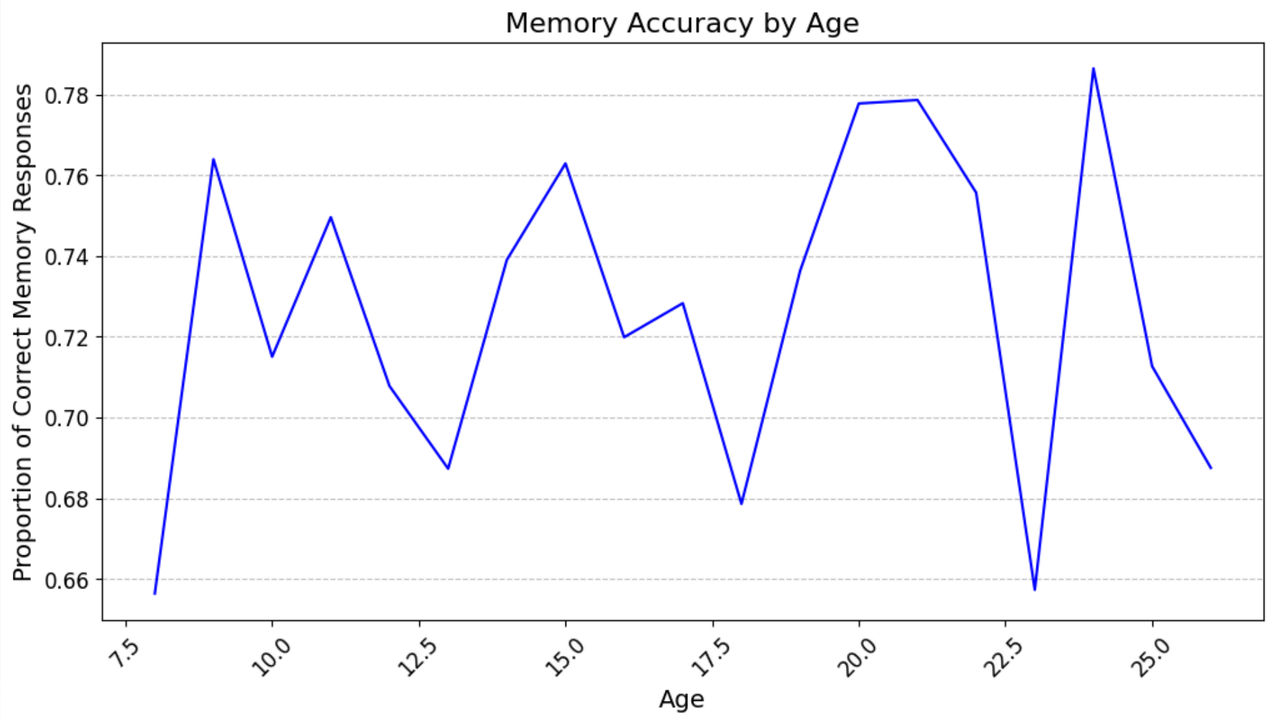
EXPERIMENT 1 : ANALYSIS ACROSS AGE



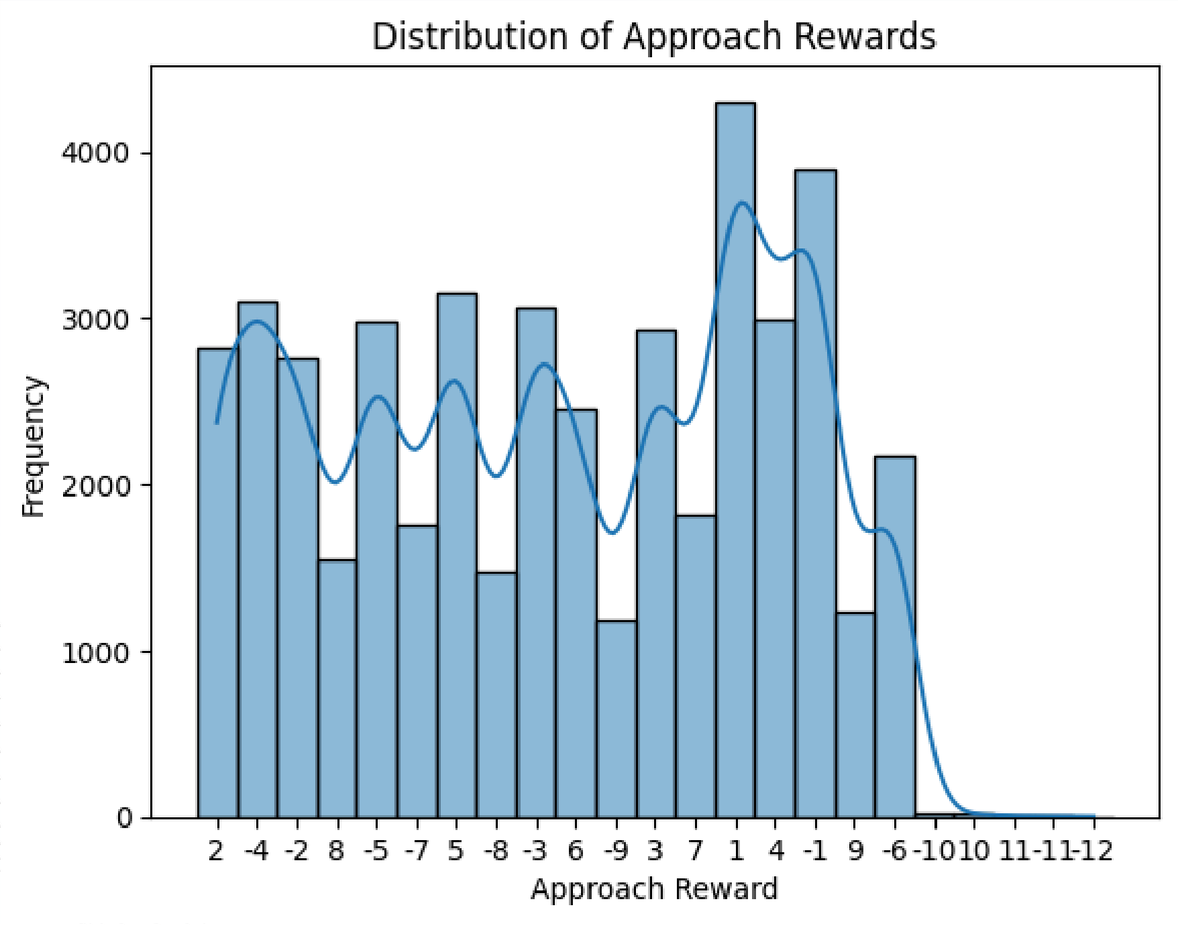


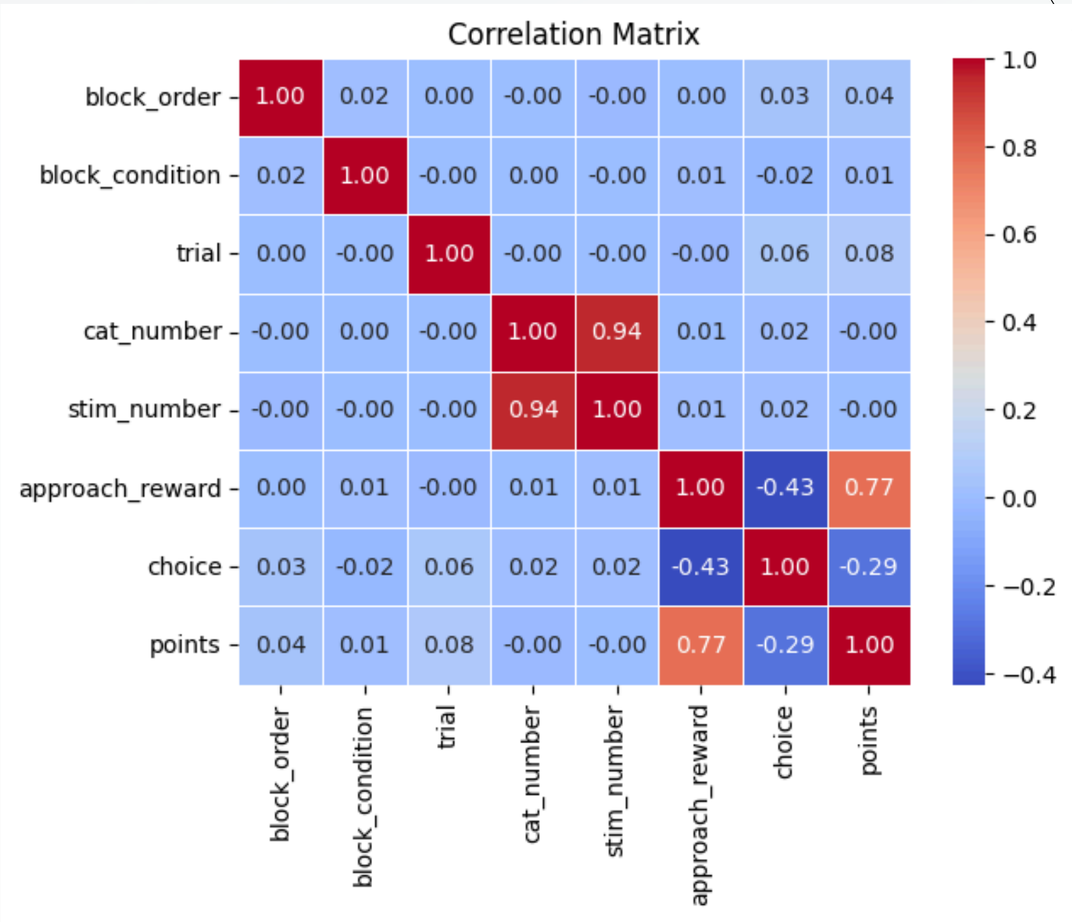
EXPERIMENT 1 : MEMORY DATA





EXPERIMENT 1 : RL DATA





HYPOTHESES


sample test
t-test
size
hochberg correct
bonferroni correct
pearson correlc
benjamini-hochb
cohen
whitney u test
moderation analysis

SPECIFICITY - MEMORY HYPOTHESIS

We aim to study the effect of Block Conditions on Memory Accuracy implying the influence of the level of specificity on how well we remember the stimuli (in the memory task).

- **H O**

There is no statistically significant difference in memory representations between individuals with different levels of specificity during learning.

- **H 1:**

There is a statistically significant difference in memory representations between individuals with different levels of specificity during learning.

KEY RESULTS

Block Condition vs. Memory Accuracy:

- **Chi-square test:** revealed a significant association between memory accuracy and block condition ($p < 0.001$), with a small effect size (Cramer's V = 0.029)

Chi-Square Statistic: 11.0919156

P-value: 0.000867

Block Condition vs. Confidence Weighted Memory Accuracy:

- Since the confidence-weighted memory accuracy is of **ordinal** type -> We use the Mann-Whitney U test
- **Mann-Whitney U test:** confirmed a significant difference in weighted memory accuracy across different block conditions ($p < 0.001$)

Mann-Whitney U Statistic: 21920093.5

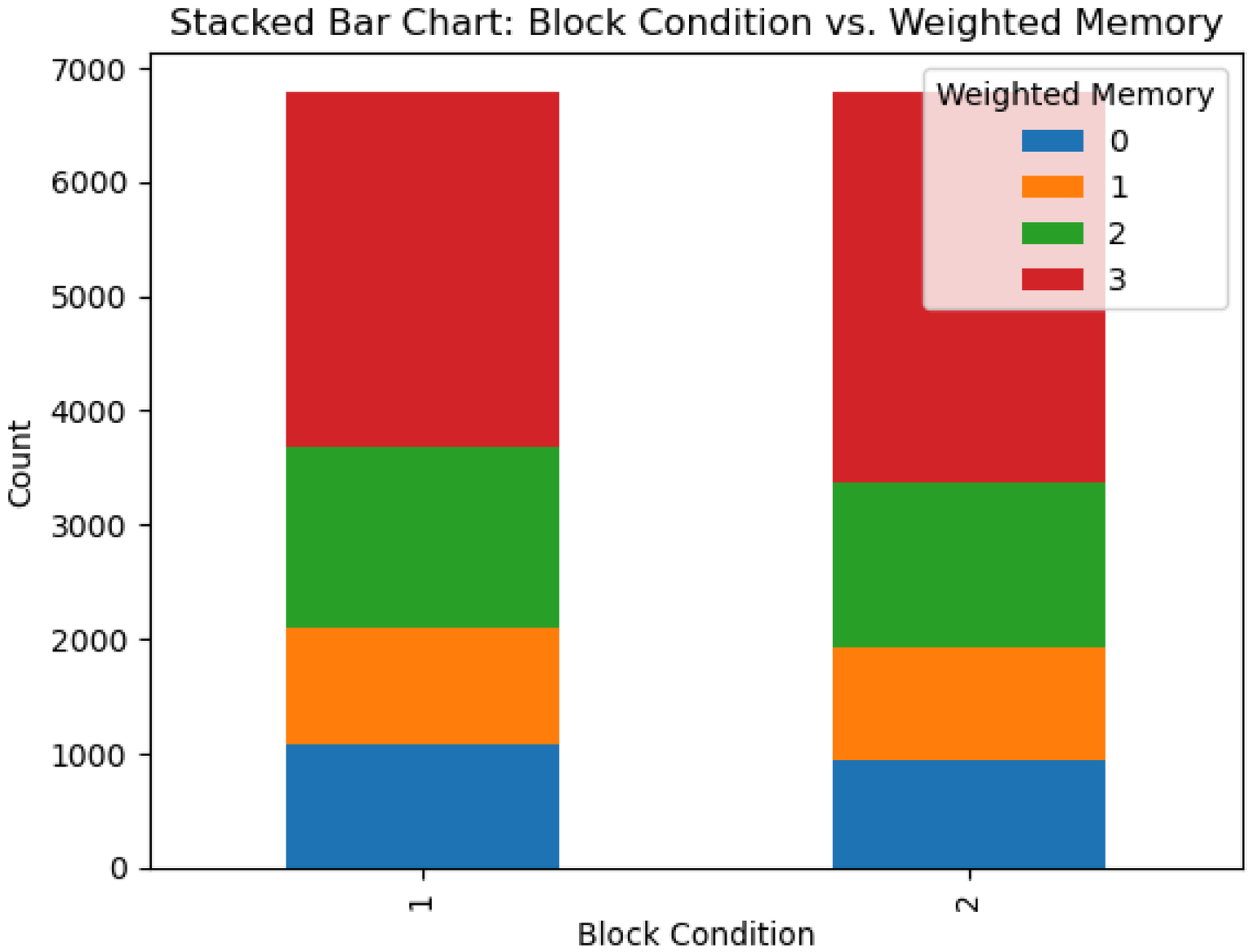
P-value: 1.2032235e-07

- **Regression Analysis:** indicated that both conf_number and block_condition significantly influence memory accuracy, with block_condition having a smaller but still significant effect.
- model's pseudo-R-squared value is 0.02449, indicating that about 2.45% of the variance in the outcome variable mem_acc is explained by the predictors in the model.

INFERENCES

- Varying levels of block conditions have a measurable impact on memory accuracy.
- The significant difference in weighted memory accuracy across different block conditions underscores the influence of block condition specificity on memory performance and our confidence levels associated.
- higher confidence levels and Exemplar block conditions being associated with higher memory accuracy

VISUALISATION



AGE - MEMORY SPECIFICITY HYPOTHESIS

We aim to study how age influences the adaptation towards specificity in memory representations, investigating whether this adaptation increases or decreases with age, ultimately influencing performance in memory tasks.

Null Hypothesis (HO): There is no significant relationship between age and the adaptation towards specificity in memory representations.

Alternate Hypothesis (H2): Adaptation towards specificity in memory representations increases/decreases with age.

KEY RESULTS

Age vs. Memory Accuracy:

- **Chi-square test:** $p < 0.05$, indicated significant age-memory accuracy relationship.
- **Small effect size** (Cramer's V = 0.036), indicating a weak association.
- Memory accuracy tends to increase with age, with more correct responses in adults.

Age vs. Memory Accuracy within Specificity Conditions:

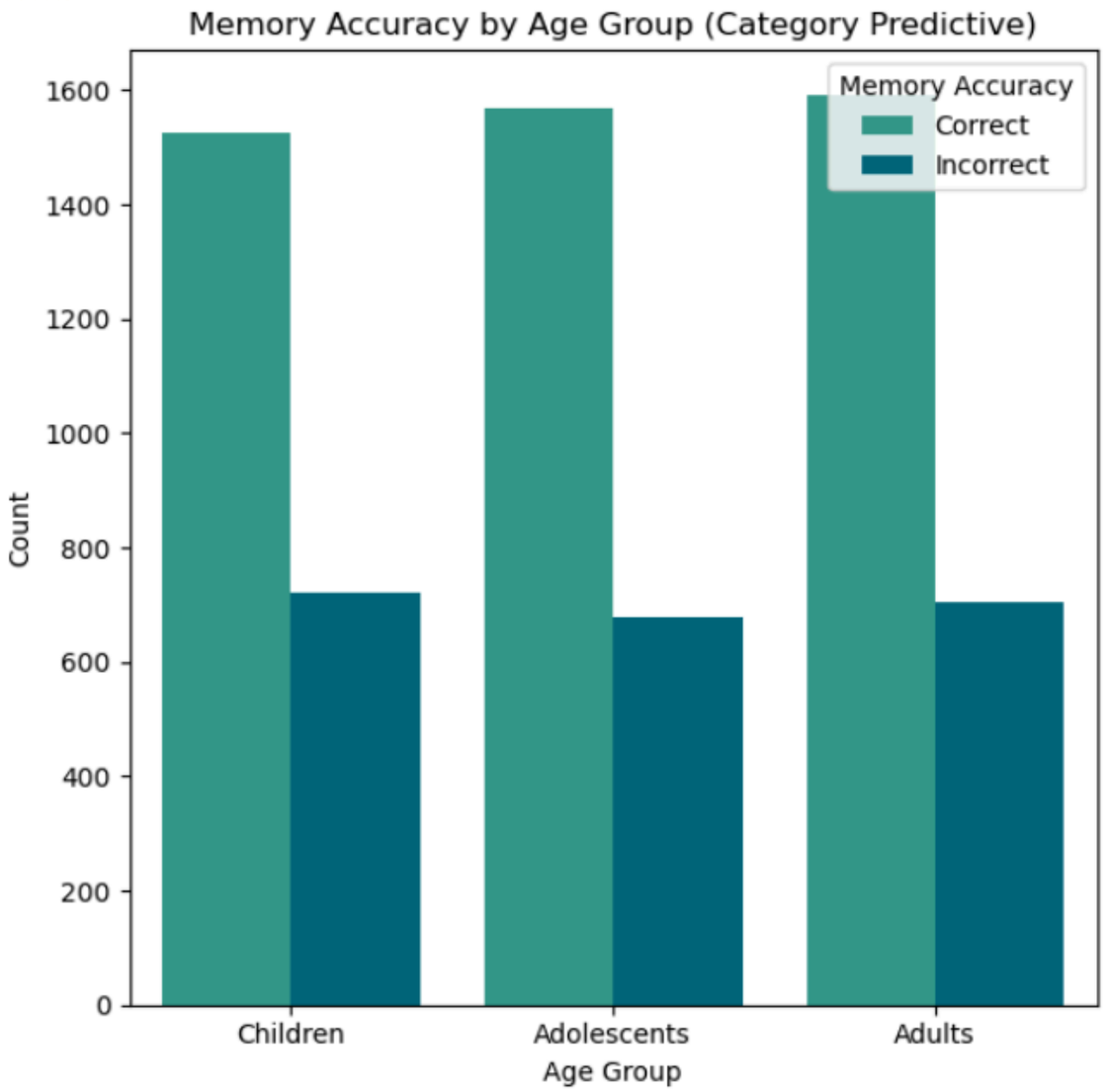
- **For Category Predictive:**
  - **Chi-square test:** $p > 0.05$, no significant relationship between age and memory accuracy
  - **Very small effect size** (Cramer's V = 0.018), weak association.
  - **Post hoc tests** (pairwise chi-square tests with Bonferroni correction): No significant differences between age groups ($p > 0.05$).

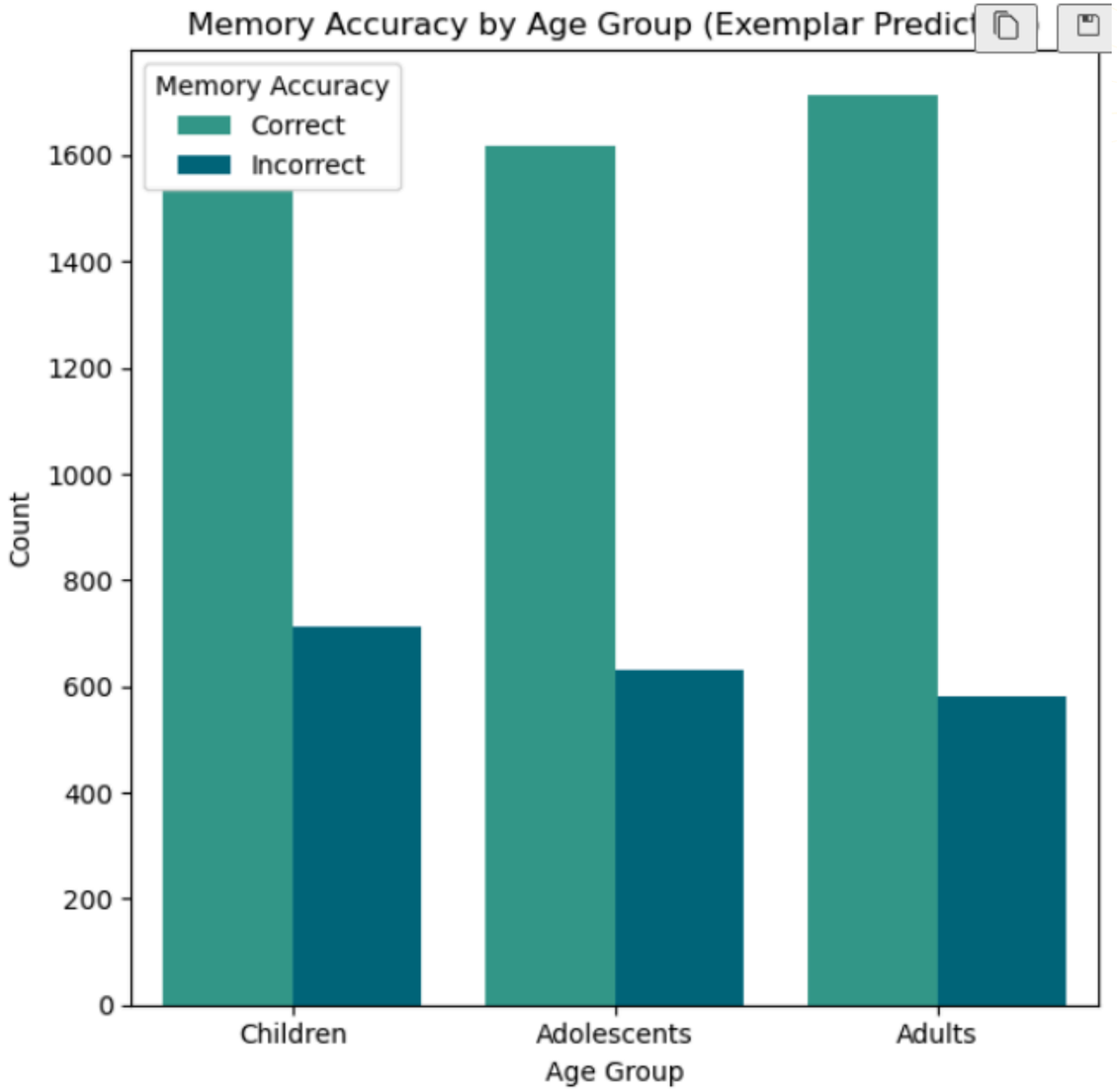
- **For Exemplar Predictive:**
  - **Chi-square test:** $p < 0.05$, the p-value is very low (close to zero), indicating strong relationship.
  - **Larger effect size** (Cramer's V = 0.058), weak to moderate association.
  - **Post hoc tests** (pairwise chi-square tests with Bonferroni correction): Significant differences between children and adolescents ($p < 0.001$), children and adults ($p < 0.001$), and adolescents and adults ($p < 0.001$)

INFERENCES

- Age significantly influences memory accuracy, particularly in Exemplar Predictive specificity.
- No significant age-memory accuracy relationship observed in Category Predictive specificity.
- Significant differences exist between age groups in memory accuracy within Exemplar Predictive specificity.

VISUALISATION





SPECIFICITY IN LEARNING HYPOTHESIS

We aim to study how age influences the adaptation towards the specificity of learning computations, potentially leading to enhanced learning performance.

Null Hypothesis (HO): There is no significant relationship between age and the adaptation towards the specificity of learning computations.

Alternate Hypothesis (H3): Adaptation towards the specificity of learning computations increases/decreases with age.

KEY RESULTS

- **Distribution of Correct Responses by Age Group:**
  - **Chi-square test:** $p < 0.05$, indicate a significant relationship between age and correct response made.
  - **Small effect size** (Cramer's V =0.06), weak to moderate association.

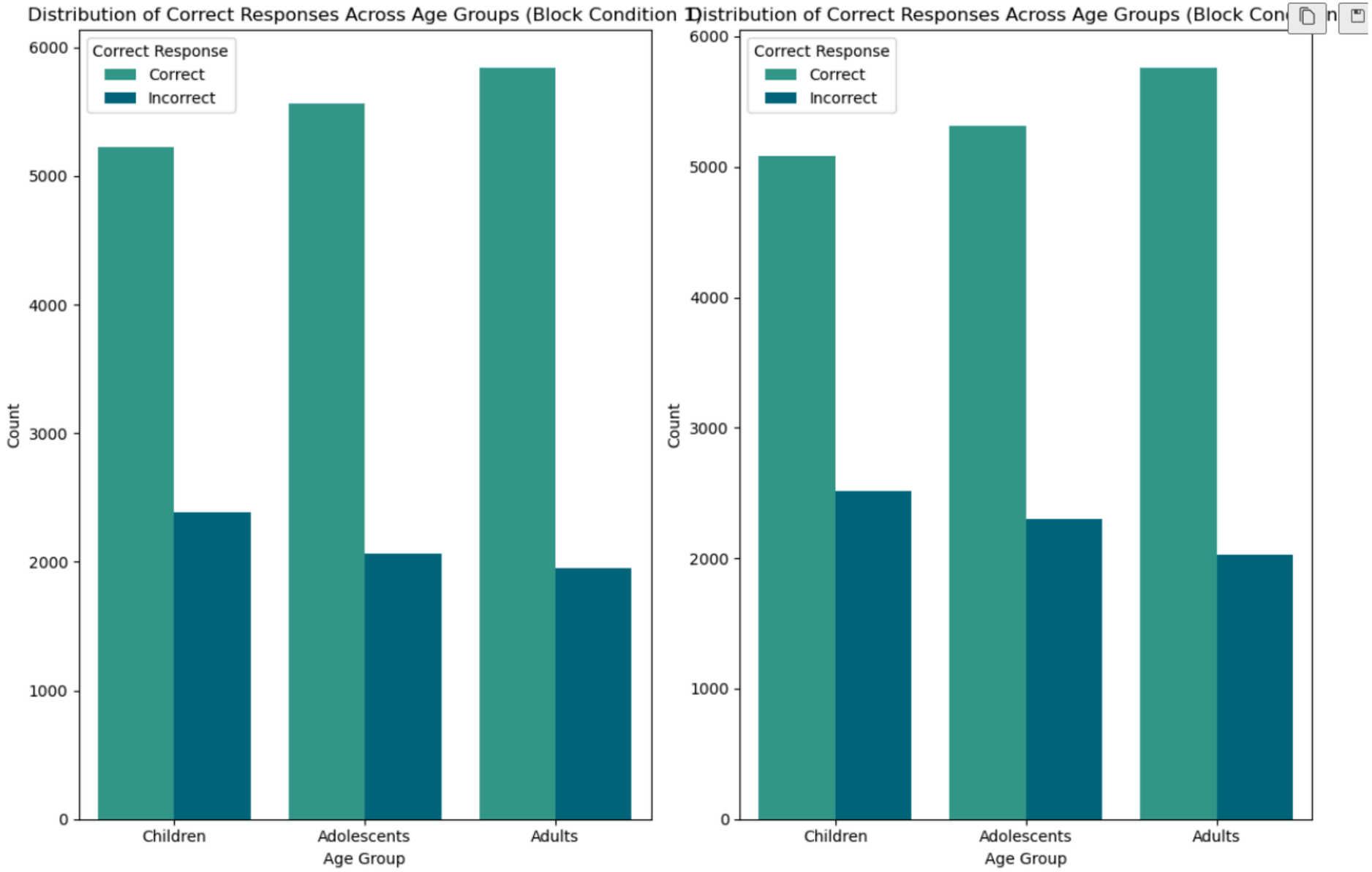
- **Association between Block Condition and Correct Response Made:**
  - **Chi-square test:** $p < 0.05$, indicates an association between block condition and response
  - **Small effect size** (Cramer's V = 0.021), indicating a weak association.
  - Slight difference in response distributions between block conditions.

- **Relationship between Age Group and Correct Response Made within Each Block Condition:**
  - **Chi-square tests:** $p < 0.05$, reveal significant relationships between age group and correct response made within both block conditions.
  - **Post hoc tests** (pairwise chi-square tests with Bonferroni correction) demonstrate specific differences between age groups within each block condition.
  - **Independent Samples T-test** for Block Condition 2: Significant differences in mean responses between age groups.

INFERENCES

- Age significantly influences the adaptation towards the specificity of learning computations.
- Adults tend to exhibit better learning performance compared to adolescents and children.
- There are specific differences in learning performance between age groups within each block condition.

VISUALISATION



EFFECT OF STIMULUS REPETITION-REACTION TIMES

Here, we try to find out if there exists any effect of stimulus repetition on reaction times.

Null Hypothesis (HO)

- There is no significant relationship between stimulus repetition and reaction times.

Alternate Hypothesis (H4a):

- Stimulus repetition influences the reaction times, leading to either faster or slower responses.

KEY RESULTS

Normality Tests:

- Kolmogorov-Smirnov tests indicate non-normality in reaction time data for all stimulus repetition groups ($p < 0.001$).

- **Homogeneity of Variances:**
  - Levene's test does not reject the assumption of homogeneity of variances ($p > 0.05$).

- **Kruskal-Wallis Test:**
  - Kruskal-Wallis test showed a significant difference in reaction times across stimulus repetition groups ($p < 0.001$).

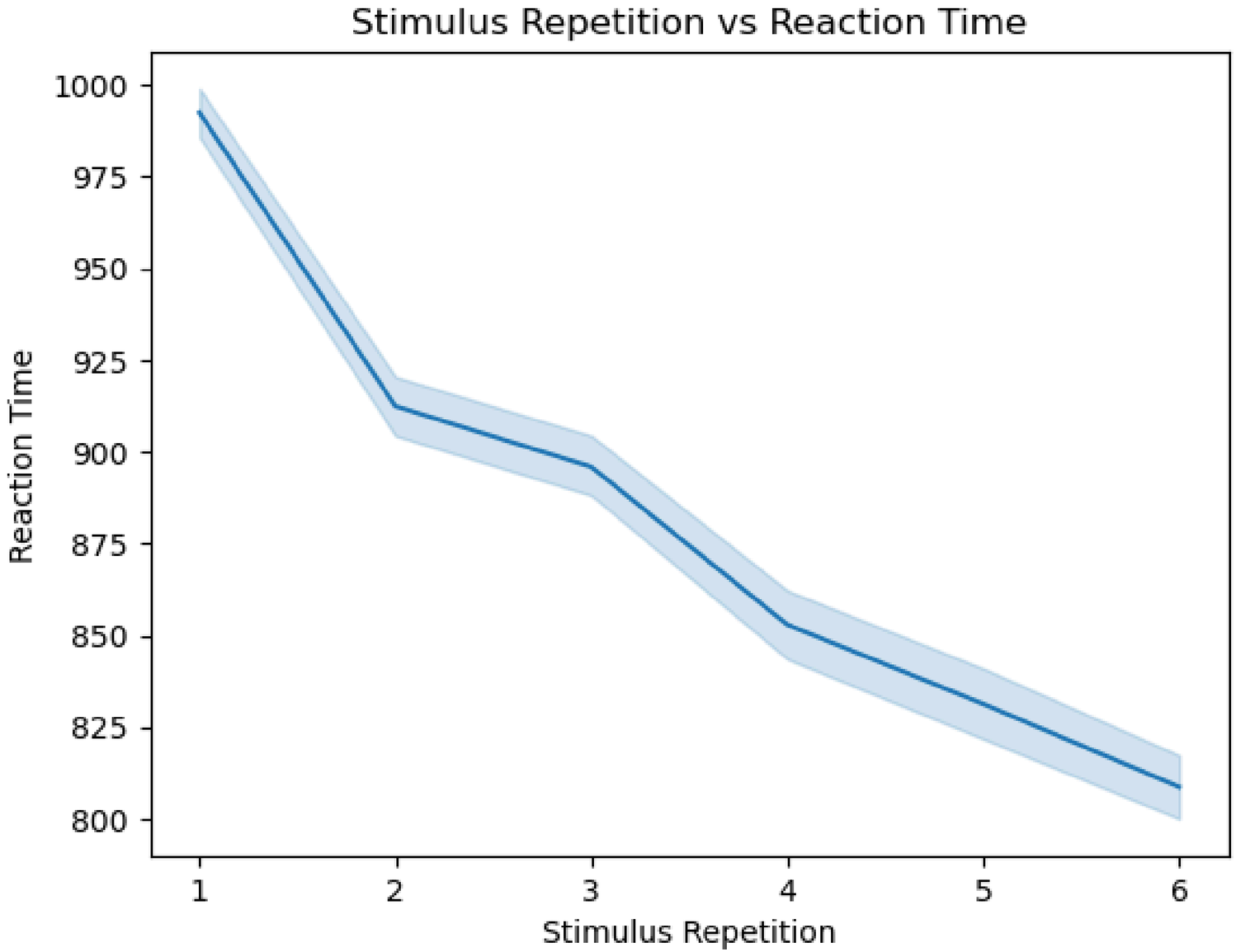
- **Post Hoc Analysis:**
  - Dunn's post hoc test revealed significant differences in reaction times between all pairs of stimulus repetition groups ($p < 0.05$), suggesting that certain stimulus repetitions influence reaction times differently.

INFERENCES

- Different stimulus repetitions indeed lead to varied reaction times, with some repetitions significantly affecting reaction speed compared to others.

- Stimulus repetition plays a significant role in modulating reaction times

VISUALISATION



EFFECT OF STIMULUS REPETITION-REACTION TIMES ON AGE

In this part of the analysis, we try to find out the interaction effect between stimulus repetition and age on reaction times.

Null Hypothesis (HO): There is no significant relationship between the decreasing effect of reaction times with stimulus repetition on age.

Alternate Hypothesis (H4b): The decreasing effect of reaction times with stimulus repetition increases/decreases with age.

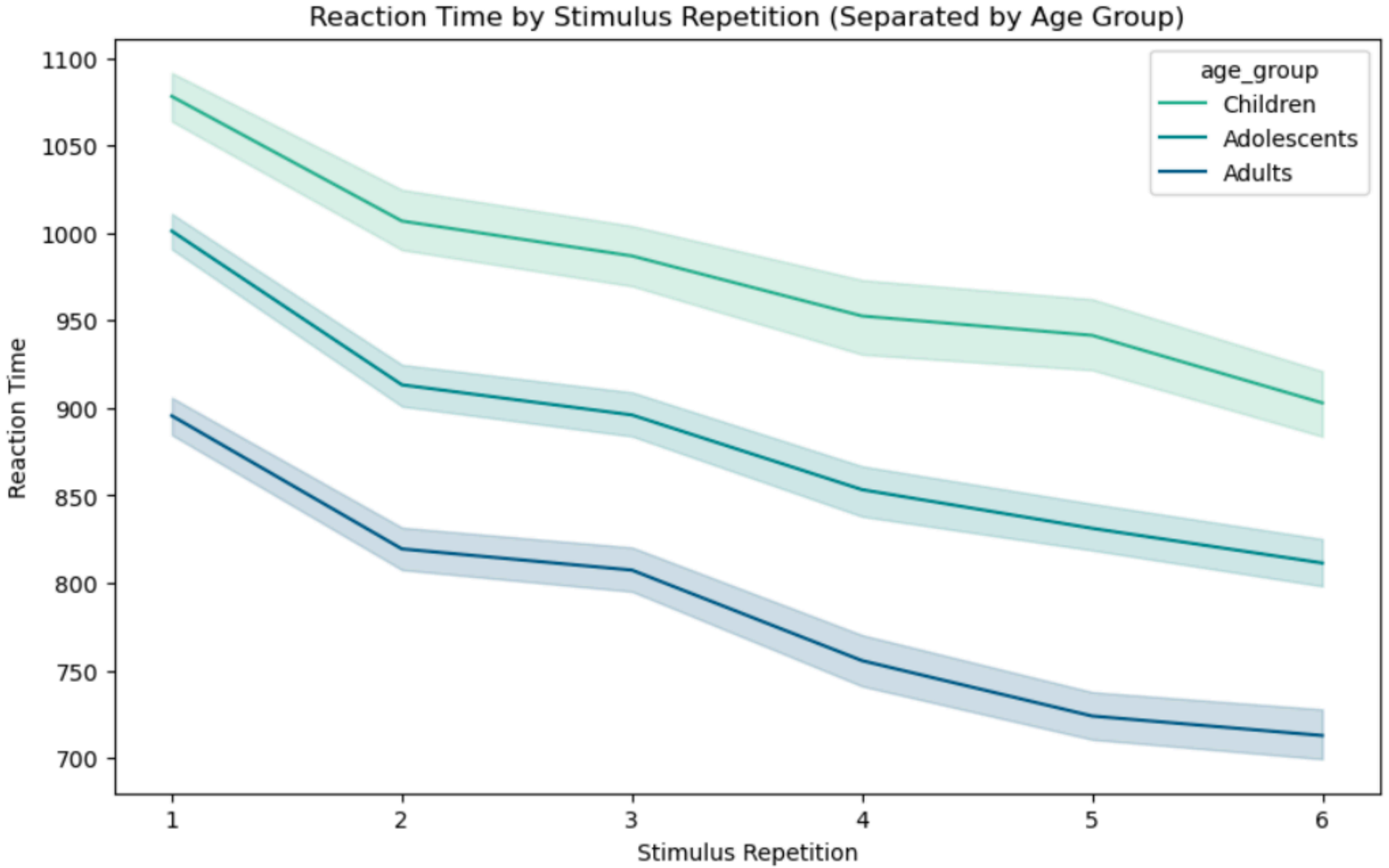
KEY RESULTS

- **Relationship between Age Group and Reaction Time for each stimulus repeated:**
  - **One way ANOVA:** Highly significant relationships between age group and reaction time for each stimulus repetition (PR(>F) < 0.05).
  - **Substantial effect sizes with high F-values,** suggest considerable differences between group means relative to variability within groups.
  - **Post Hoc Tests (Tukey's HSD)**: Significant differences in mean reaction time between age groups within each level of stimulus repetition.
  - **Regression Analysis:**
    - Coefficient for age: is -14.0029, Negative coefficient indicates that as age increases by 1 unit, reaction time decreases by approximately 14.0029 units.
    - p-value < 0.001, indicating a significant effect of age on reaction time.

INFERENCES

- The slope of reaction time decrease with stimulus repetition is steeper for adults than for children, indicating age-related differences in response to repeated stimuli.
- All age groups responded faster as they became more familiar with the stimulus.

VISUALISATION



EFFECT OF THE MAGNITUDE OF REWARD

In this part of the analysis, we try to find out of the magnitude of reward or threat had any effect on how well the participants learnt/remembered the stimuli.

Null Hypothesis (HO): There is no relation between the magnitute of reward associated with a particular stimulus and the learning about the stimulus.

Alternate Hypothesis (H5a): Higher the magnitude of the reward associated with a stimulus, better the subject learns to avoid/approach the stimulus.

KEY RESULTS

Test for Normality:

- **Shapiro-Wilk test:** For the distribution of the reward variable, the statistic came out to be **0.95** and p value was **0.79**, and for the points obtained, the statistic came out to be **0.97** with p-value as **0.91**. Hence, these do not significantly differ from a normal distribution.

Test for Homogeneity of Variances:

- **Levene's test:** The Levene's statistic came out to be **0.023** with p-value: **0.88**. Hence, we can conclude that the variances of the two groups are more or less equal.

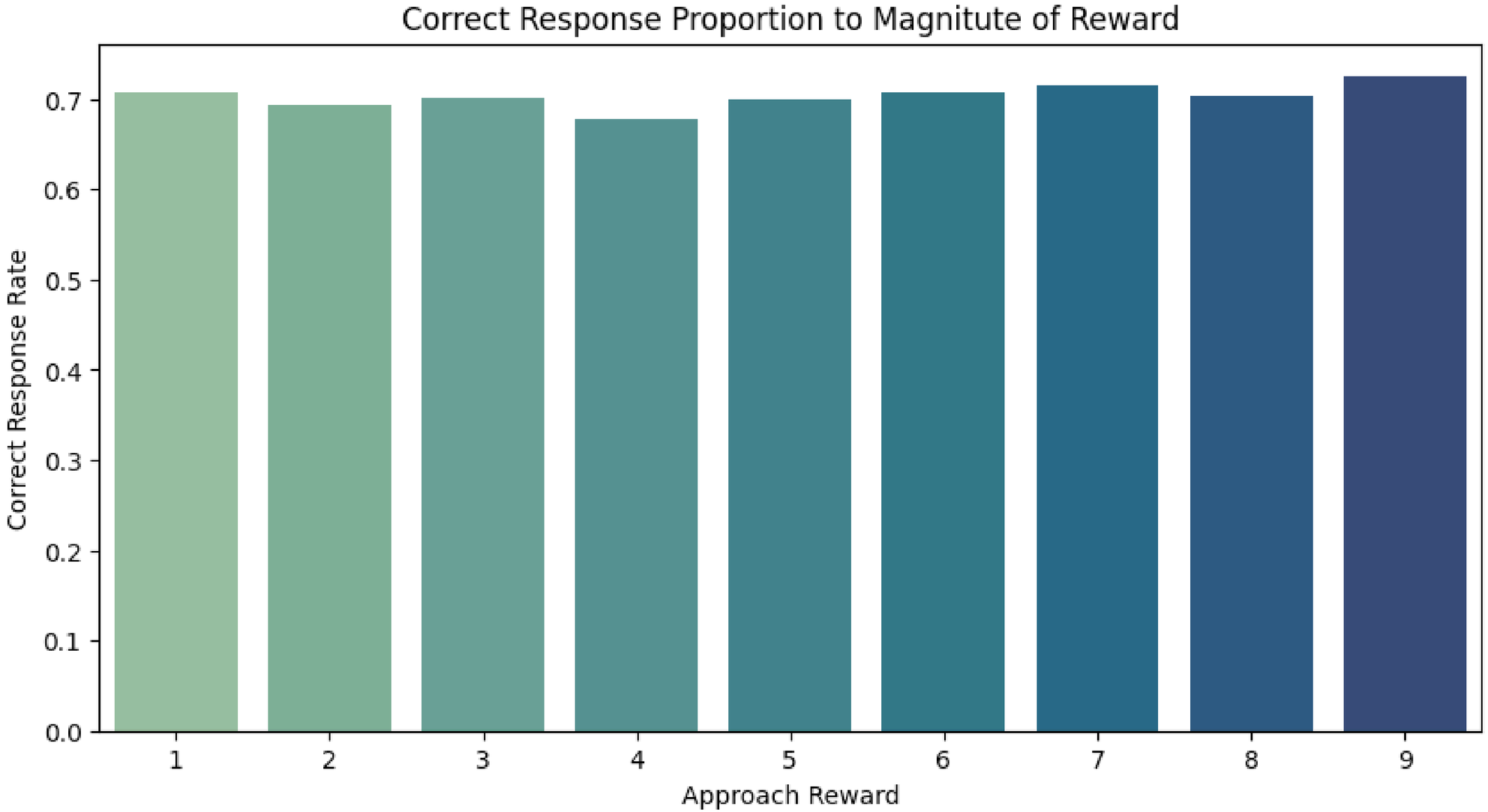
Effect of Magnitude of Reward on Learning:

- Since the distribution of variables is normal and they are homogeneous. We can use parametric tests for this hypothesis testing.

- **Pearson's Correlation:** The value of the correlation statistic came out to be **0.24**, with pvalue=**0.23**.

- Hence, There is not enough evidence to conclude that there is a significant correlation between the variables in the population. We **fail to reject the null hypothesis**.

VISUALISATION



EFFECT OF THE MAGNITUDE OF REWARD

Having seen the effect of magnitude on learning, we now check and see how it impacts memory performance.

Null Hypothesis (HO): There is no relation between the magnitute of reward associated with a particular stimulus and the memory associated with the stimulus.

Alternate Hypothesis (H5b): Higher the magnitude of the reward associated with a stimulus, better the subject remembers the stimulus.

KEY RESULTS

Test for Normality:

- **Shapiro-Wilk test:** For the distribution of the reward variable, the statistic came out to be **0.95** and p value was **0.72**, and for the points obtained, the statistic came out to be **0.97** with p-value as **0.91**. Hence, these do not significantly differ from a normal distribution.

Test for Homogeneity of Variances:

- **Levene's test:** The Levene's statistic came out to be **0.023** with p-value: **0.88**. Hence, we can conclude that the variances of the two groups are more or less equal.

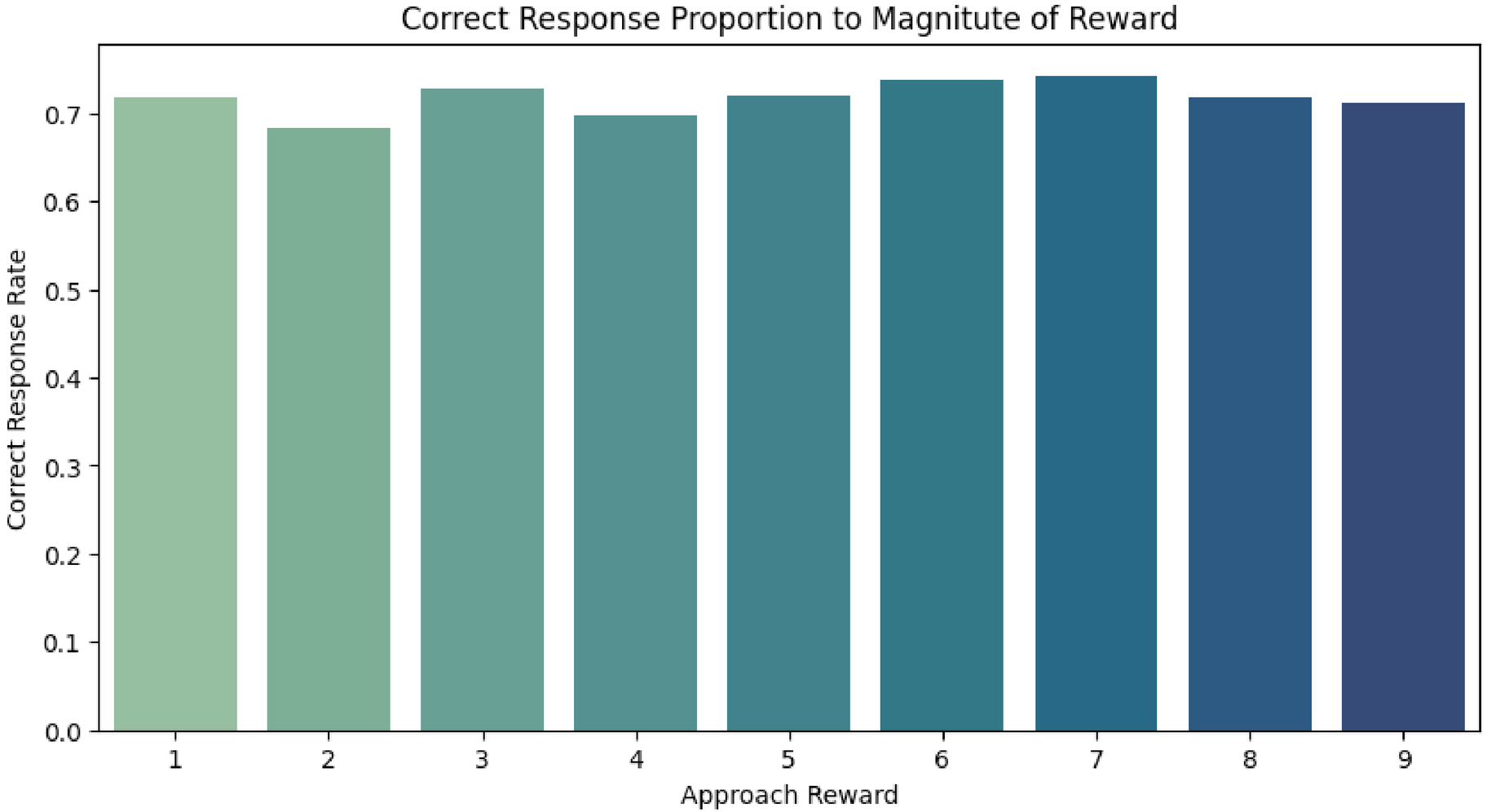
Effect of Magnitude of Reward on Memory:

- Since the distribution of variables is normal and they are homogeneous. We can use parametric tests for this hypothesis testing.

- **Pearson's Correlation:** The value of the correlation statistic came out to be **0.25**, with pvalue=**0.35**.

- Hence, There is not enough evidence to conclude that there is a significant correlation between the variables in the population. We **fail to reject the null hypothesis**.

VISUALISATION



INFERENCES

- We observe the pearson’s statistic for correlation as 0.24 and 0.25 for the learning and memory tasks with respect to the reward associated with each stimuli.
- However, in both cases the p-value is much above the significance level.
- Hence, we fail to reject the null hypothesis.

LEARNING, MEMORY AND SPECIFICITY

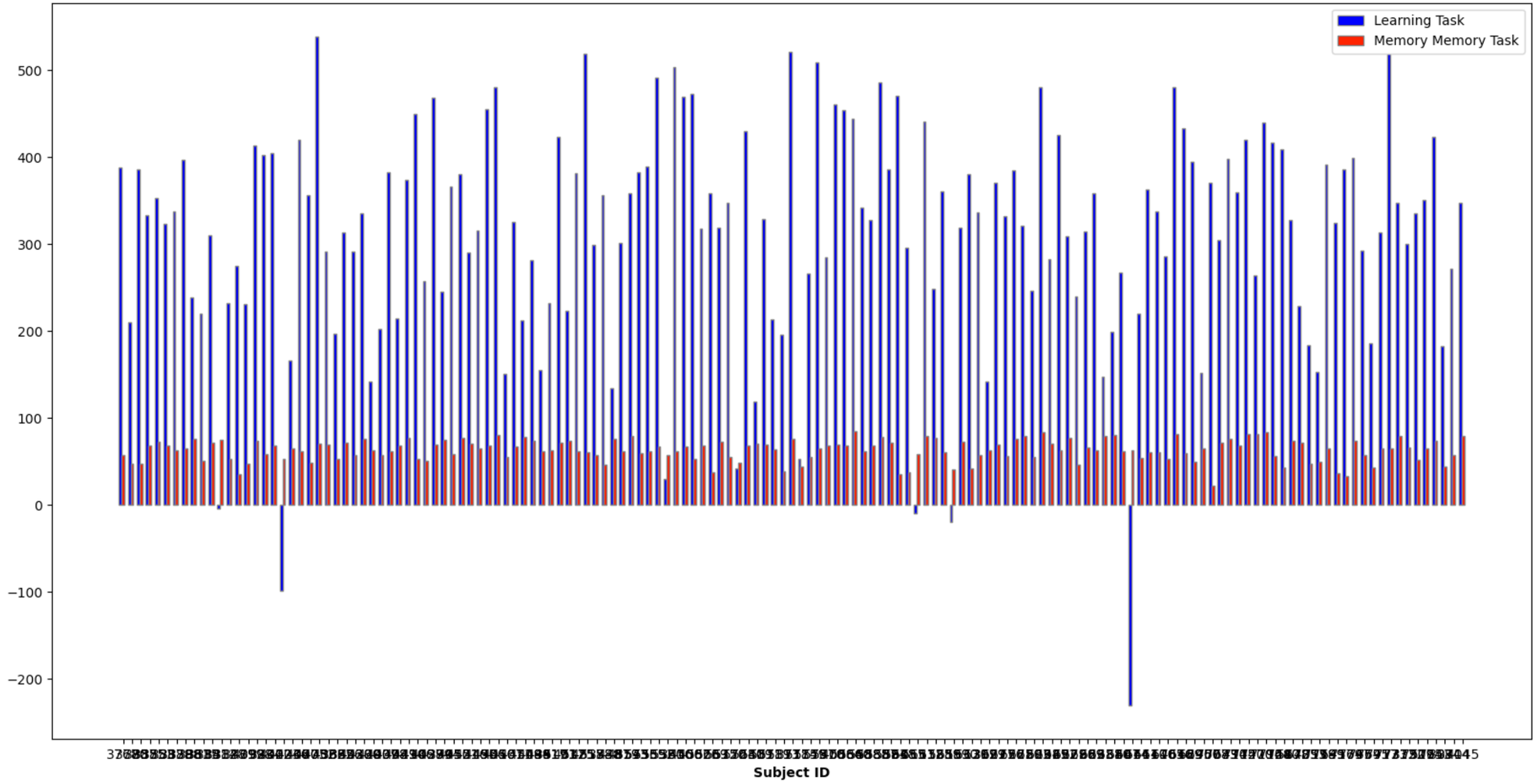
In this part, we statistically try to prove a hypothesis that seems to be quite obvious at first glance. The research question we first pose is simply: "Does Better Learning Lead to Better Retention?

H0: Points obtained by a subject in the learning task is unrelated to their performance in the memory task.

H6: There is no relation between the magnitute of reward associated with a particular stimulus and the memory associated with the stimulus.

VISUALISATION

Participant Scores in Learning Task and Memory Task across block conditions



KEY RESULTS

Test for Normality:

- **Shapiro-Wilk test:** For the distribution of the score for learning task, the statistic came out to be **0.94** and p value was **6.40 x 10e-6**, and for the points obtained in memory task, the statistic came out to be **0.97** with p-value as **0.002**. Hence, these variables significantly differ from normal distribution.

Test for Homogeneity of Variances:

- **Levene's test:** The Levene's statistic came out to be **141.29** with p-value: **5.99x10e-27**. Hence, we can conclude that there are significant differences in variances between the groups or samples being compared.

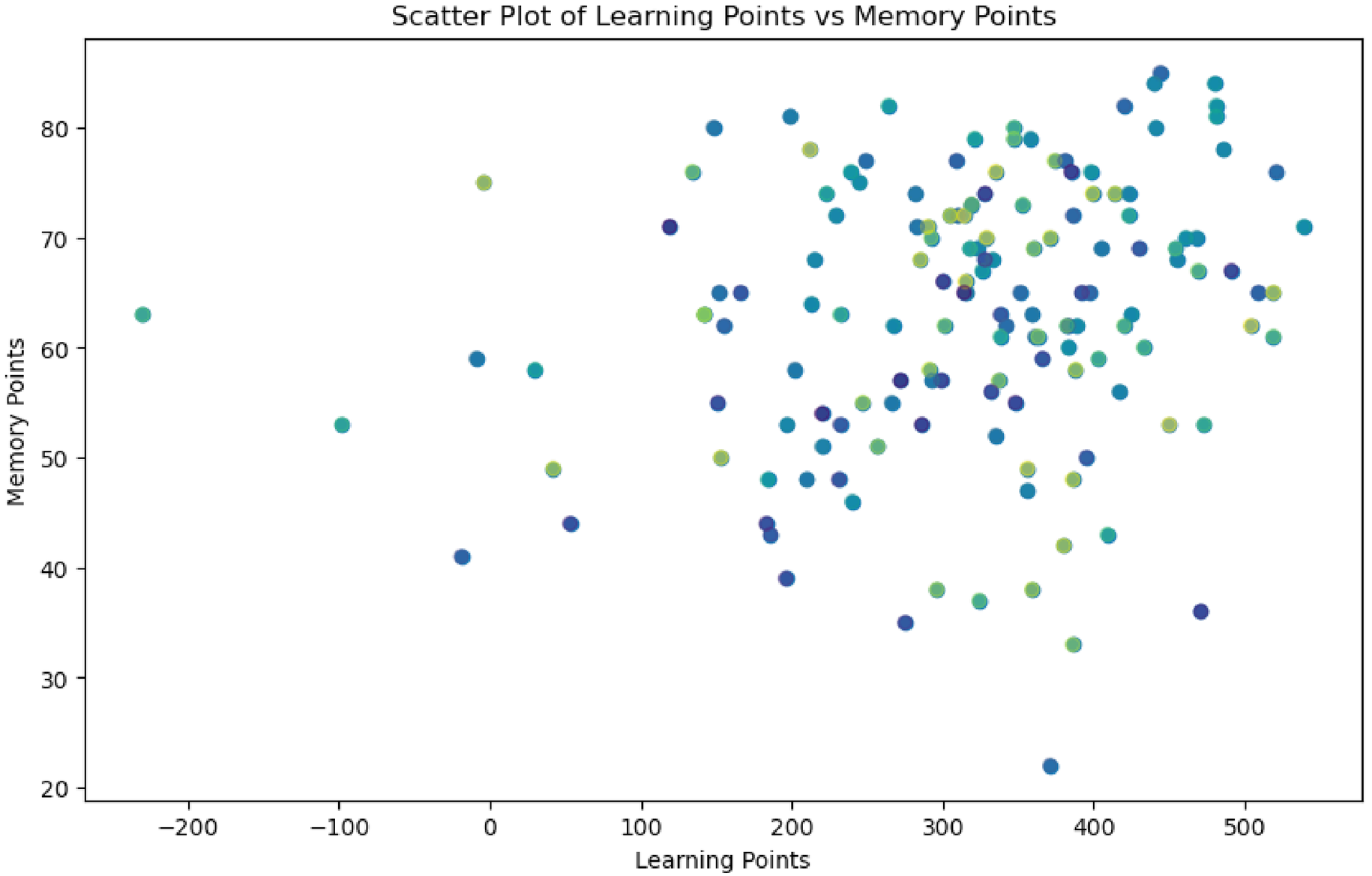
Correlation between Learning and Memory:

- Since the distribution of variables is not normal and they are not homogeneous. We need to make use parametric tests for this hypothesis testing.

- **Spearman’s Rank Correlation:** The value of the correlation coefficient came out to be **0.217**, with pvalue=**0.007**.

- Hence, There is a **statistically significant weak positive correlation** between learning and memory.

VISUALISATION



INFERENCES

- The Spearman correlation coefficient(ρ), which came out to be 0.218 suggests a relatively weak positive monotonic relationship between learning points and memory points.

- However, the p-value which is approximately 0.0073, suggests that there is a statistically significant correlation between learning points and memory points.

- In summary, while the correlation between learning points and memory points is not extremely strong, it is statistically significant, suggesting that there is indeed a relationship between performance on the learning task and performance on the memory task.

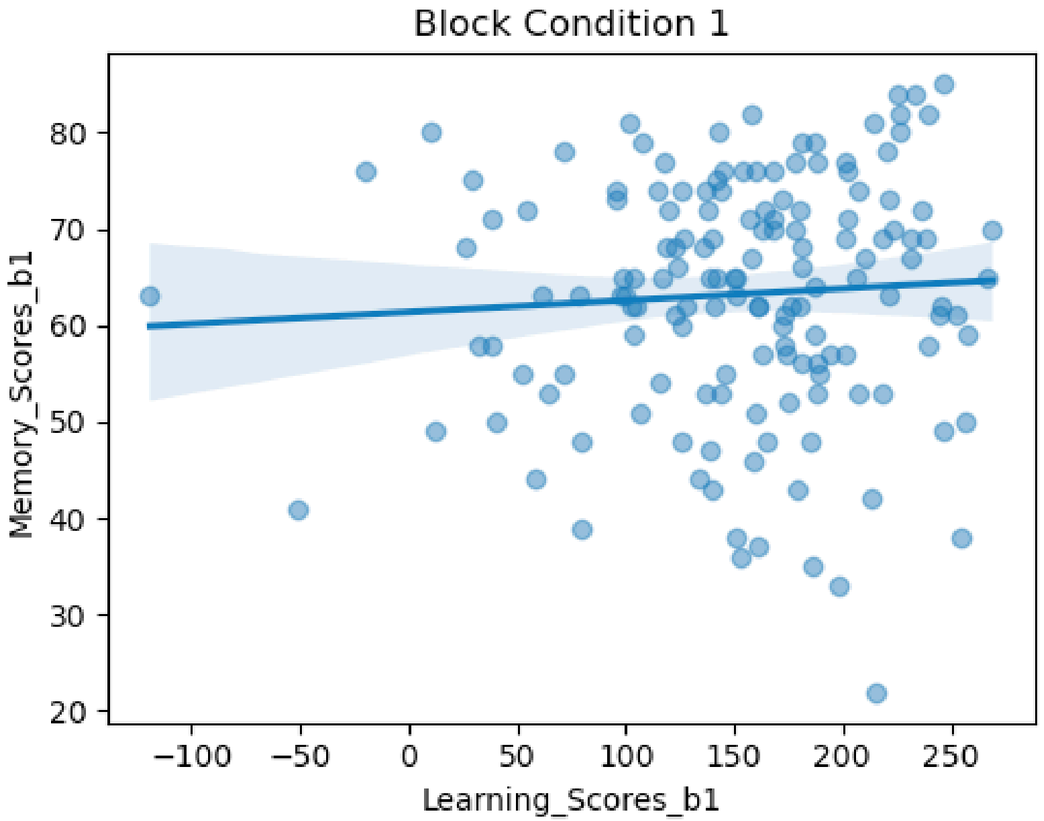
Now, we can also conduct a multiple regression analysis to study the effects of two independent variables on one dependent variable. We wish to see how Performance on the memory task is affected by two variables: block condition, and the performance on the learning task.

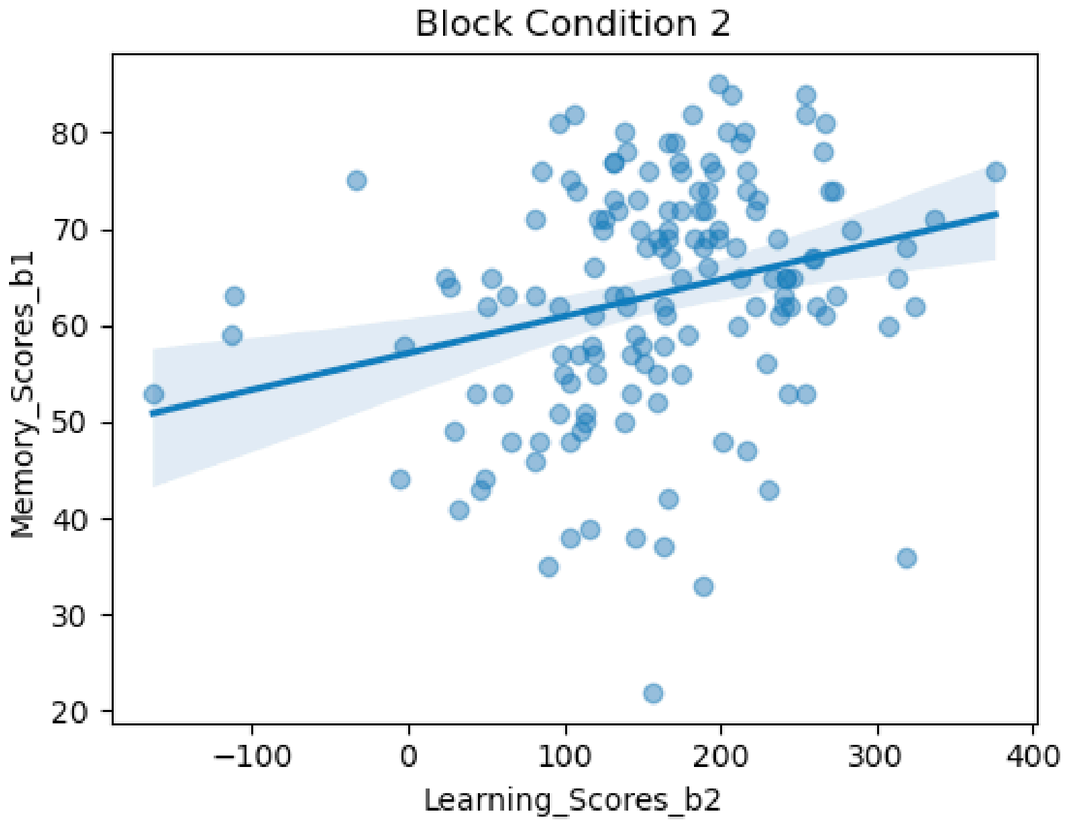
```
                            OLS Regression Results
==============================================================================
Dep. Variable:       Memory_Scores_b1   R-squared:                       0.072
Model:                            OLS   Adj. R-squared:                  0.059
Method:                 Least Squares   F-statistic:                     5.735
Date:                Sat, 04 May 2024   Prob (F-statistic):            0.00399
Time:                        08:56:53   Log-Likelihood:                -587.14
No. Observations:                 151   AIC:                             1180.
Df Residuals:                     148   BIC:                             1189.
Df Model:                           2
Covariance Type:            nonrobust
================================================================================
                     coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------
const             58.0842      2.664     21.804      0.000      52.820      63.349
Learning_Scores_b1  -0.0096      0.016     -0.588      0.558      -0.042       0.023
Learning_Scores_b2   0.0412      0.013      3.285      0.001       0.016       0.066
==============================================================================
Omnibus:                       10.766   Durbin-Watson:                   1.883
Prob(Omnibus):                  0.005   Jarque-Bera (JB):               10.967
Skew:                          -0.633   Prob(JB):                      0.00416
Kurtosis:                       3.376   Cond. No.                         656.
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Based on the Regression Analysis, we see that:

- **Learning Scores Influence on Memory:**
  - Learning scores in block condition 2 significantly influenced memory scores, with a coefficient of 0.0412 ($p = 0.001$).
  - In contrast, learning scores in block condition 1 did not show a significant effect on memory scores (coefficient = -0.0096, $p = 0.558$).
- **Impact of Block Condition:**
  - The results suggest that the effect of learning performance on subsequent memory tasks may vary depending on the block condition in which the learning task was conducted.
  - Specifically, Exemplar Stimuli leads to greater scores in the memory task compared to categorical stimuli.
- **Overall Model Significance:**
  - The overall regression model was statistically significant (F-statistic = 5.735, $p = 0.00399$), indicating that the independent variables collectively explained a significant portion of the variance in memory scores.
  - However, the model's adjusted R-squared value was low (0.059), suggesting that only a small proportion of the variance in memory scores was accounted for by the predictors included in the model.

VISUALISATION





RESULTS

- **Specificity-Memory Hypothesis:** The block condition significantly affects memory accuracy. More specific representations used during learning help the subjects remember the stimuli better and with higher confidence.

- **Age - Memory Specificity hypothesis:** Memory specificity adaptation increases with age, particularly in the Exemplar Predictive condition. While age has no significant impact on memory accuracy in Condition 1, it notably influences accuracy within Exemplar Predictive specificity.

- **Specificity in learning hypothesis:** Adaptation towards learning specificity increases with age, impacting learning performance. Adults demonstrate higher correct response rates compared to younger age groups within each block condition.

- **Stimulus Repetition with Reaction Times**
  - **Stimulus Repetition-Reaction Times effect:** Different stimulus repetitions indeed lead to varied reaction times, with some repetitions significantly affecting reaction speed compared to others.
  - **Stimulus Repetition-Reaction Times effect on age:** Adults tend to exhibit faster reaction times as stimulus repetition increases, compared to children and adolescents.

- **Effect of the magnitude of reward:** A greater reward/punishment does not significantly affect learning/memory performance.

- **Relation between learning, memory and specificity:** Subjects who learn better, retain better. The effect is seen to be increased with increase in specificity of learning.

THANK YOU

TEAM REWARD

Shreeya Singh

Srujana Vanka

Hariharan Kalimutuu