Project Report

Behavioral Research: Statistical Methods

REINFORCEMENT LEARNING SHAPES MEMORY SPECIFICITY ACROSS LIFESPAN

Source Code - GitHub Repo Link

TEAM REWARD

Srujana Vanka - 2020102005

Contents

1 Overview **3**
- 1.1 Introduction . . . 3
- 1.2 Objectives . . . 3
- 1.3 Understanding of the Experiment . . . 3
- 1.4 Experimental Design . . . 4

2 Dataset **5**
- 2.1 Data Description . . . 5
- 2.2 Exploratory Data Analysis - Experiment 2 . . . 5
  - 2.2.1 Subject Data . . . 6
  - 2.2.2 Learning Data . . . 6
  - 2.2.3 Memory Data . . . 7
  - 2.2.4 RL Data . . . 8

3 Hypotheses Tested by Me **9**
- 3.1 Age - Memory Specificity Hypothesis . . . 9
  - 3.1.1 Analysis Conducted . . . 9
- 3.2 Learning Specificity Hypothesis . . . 10
  - 3.2.1 Analysis Conducted . . . 10

4 Visualisation and Results for analysis done by me **11**
- 4.1 Age - Memory Specificity Hypothesis . . . 11
  - 4.1.1 Observations and Inferences . . . 12
  - 4.1.2 Key Results . . . 12
- 4.2 Learning Specificity Hypothesis . . . 13
  - 4.2.1 Observations and Inferences . . . 13
  - 4.2.2 Key Results . . . 13

5 Analysis done by my teammates **14**

6 Conclusion and Discussion **15**

7 References/Citations **15**

1 Overview

1.1 Introduction

Understanding how individuals learn, make decisions, and remember information is fundamental to cognitive psychology and crucial for understanding human behavior across different life stages. This study explores the intricate connections between learning, decision-making, and memory, exploring how individuals adapt their mental representations during value-based learning for effective decision-making.

1.2 Objectives

We aim to understand how individuals adjust mental representations during value-based learning for effective decision-making. The key objectives of our project are:

- 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.

1.3 Understanding of the Experiment

In this study, researchers aimed to explore how individuals across different age groups adjust the level of detail in their learning and memory representations based on reward experiences. Imagine you are playing a game where you win/lose points by making choices. Sometimes, you might need to remember small details to win, like remembering specific colors or shapes. Other times, you might just need to know the general idea of things.

Researchers designed such a game to see how children, adolescents, and adults learn in these situations. They designed a task where participants had to make choices guided by the rewards they received. The task involved learning from various stimuli, ranging from detailed to more general representations. By manipulating the reward structure of the task they wanted to understand how participants adapt their learning representations, and how this adaptation influences subsequent memory. In simpler words, they wanted to see if people change how they learn based on how much they're rewarded. They also wanted to know if the way they learn affects what they remember later.

1.4 Experimental Design

The experimental design comprised two reinforcement-learning tasks aimed at investigating the adaptation of mental representations during value-based learning across different age groups.

In each experiment, participants engaged in a specialized game where they were required to make decisions, sometimes relying on specific details and other times on broader categories to earn points. The reward structure of the game varied across blocks, with some segments emphasizing rewards for recalling details such as colors or shapes, while others focused on rewarding participants for grasping broader categories. Following the completion of each game, participants underwent memory tests to evaluate their retention of learned information. These assessments aimed to determine if participants retained detailed information better when incentivized accordingly.

Experiment 1:

1. **Total Subjects:** 151 participants
2. **Trials:** A total of 46,206 trials were conducted (151 participants x 306 trials/participant).
3. **Reinforcement Learning (RL) Task Design:** The RL task involved 9 unique stimuli, each with 3 exemplars from broader categories. Each stimulus had a corresponding reward, either tied to the specific picture or to the broader category it belonged to.
4. **Learning Task:** Participants encountered different pictures and had to make choices based on the association between pictures and rewards.
5. **Memory Test:** Conducted 1 week after completing the RL task, participants completed memory test to decide whether stimuli were old or new.

Experiment 2:

1. **Total Subjects:** 73 participants
2. **Trials:** A total of 31,536 trials were conducted (73 participants x 432 trials per participant).
3. **Task Modifications:** Rewards made binary to introduce unpredictability and simulated a noisy environment for decision-making. Additional stimulus category with 5 novel stimuli and two novel exemplars per sampled category.
4. **Learning Task:** Participants encountered pictures with rewards tied to specific details or broader categories and had to choose from 3 options.
5. **Memory Task:** Participants were tested on their memory performance for stimuli encountered in different learning conditions.

2 Dataset

2.1 Data Description

The dataset comprises behavioral data collected from participants of various age groups across two experiments, totaling N = 224 individuals. It encompasses raw behavioral data, subject information, and metrics related to memory performance. The dataset can be accessed here.

The datasets consisted of four main tables:

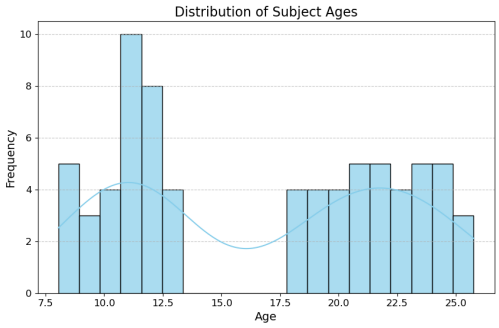
1. **Subject Ages**: This table contained information about the participants, including their subject IDs and ages. Each row represented a unique participant.
2. **Learning Data**: This table contained data from the reinforcement-learning task, including participants' approach/avoid decisions, reaction times, and points earned or lost. Each row represented a trial within the task.
3. **RL Data**: This table contained additional data from the reinforcement-learning task, such as stimulus categories, block conditions (e.g., category-predictive, exemplar-predictive), and trial information. Each row represented a trial within the task.
4. **Memory Data**: This table contained data from the memory task, including participants' memory accuracy, response times, and confidence ratings. Each row represented a trial within the task.

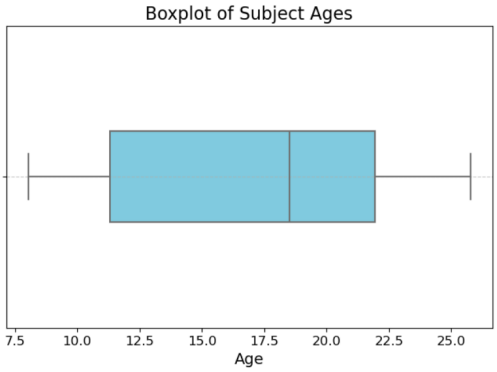
2.2 Exploratory Data Analysis - Experiment 2

By applying exploratory data analysis techniques, we were able to identify pat- terns and trends in the data, leading to the formulation of specific hypotheses about the relationship between reward structures and memory.

Exploratory data analysis for Experiment 1 was conducted by my teammates.

2.2.1 Subject Data

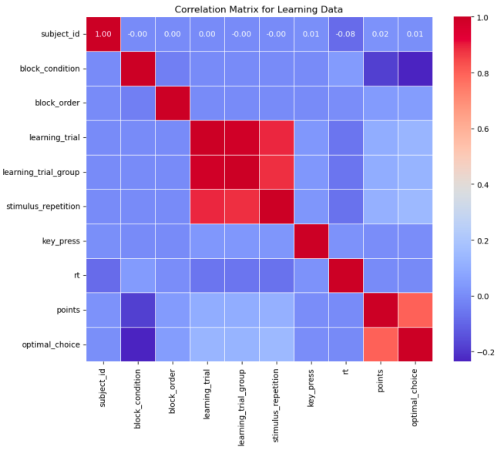


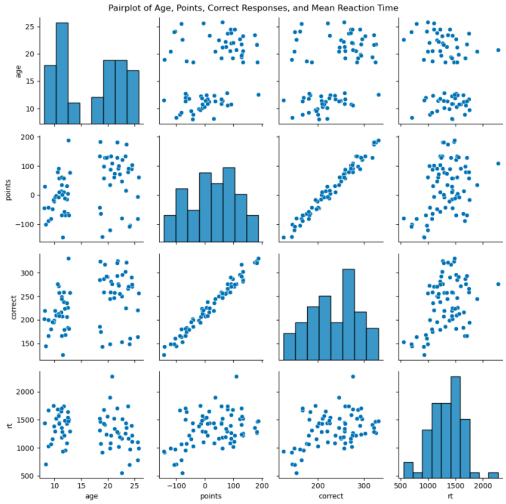


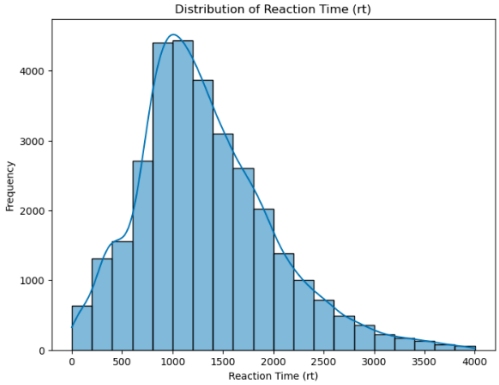
Key Observations and Inferences

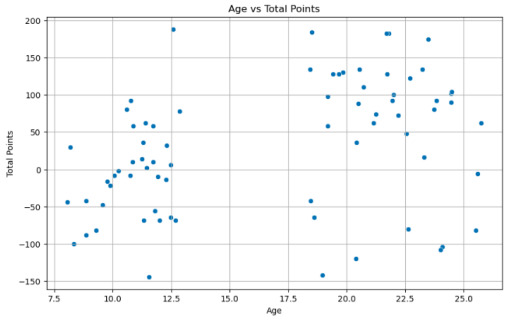
- The subjects' ages range from 8.05 to 25.76 years old.
- The standard deviation of age is approximately 5.79, indicating the spread or variability of ages around the mean.
- From the boxplot, we see that median age (50th percentile) is 18.51 years old, which is slightly higher than the mean, suggesting a slight right skewness in the age distribution.
- The interquartile range (IQR), which represents the middle 50% of the data, ranges from 11.33 to 21.95 years old.

2.2.2 Learning Data





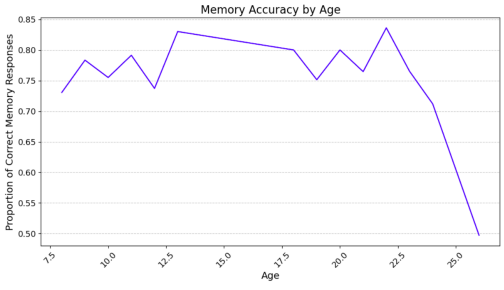


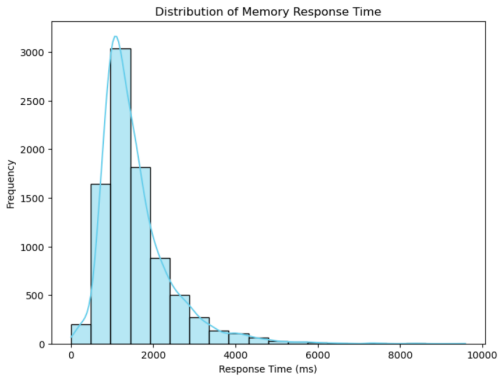


Key Observations and Inferences

- The distribution of reaction times is likely right-skewed. This means that there are more trials with faster reaction times than there are trials with slower reaction times.
- The spread of the reaction times appears to be large. There are trials with reaction times as fast as 200 ms and some as slow as 4000 ms.
- The rate of increase in reaction time diminishes with age, suggesting that older individuals experience a slower rate of change in reaction time compared to younger individuals.
- Points earned and whether the choice was correct (correct) appear to have a strong positive correlation. This means that earning more points is strongly associated with making correct choices.
- With the increase in stimulus repetition, the correctness increases.

2.2.3 Memory Data

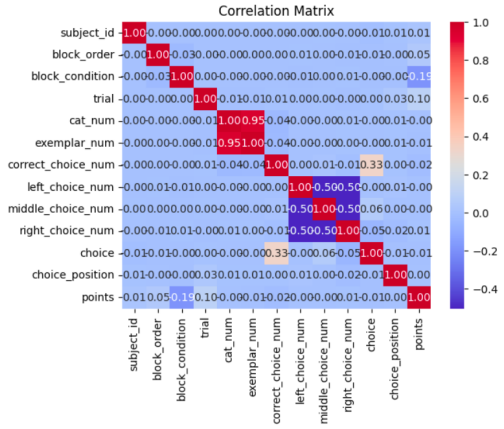




Key Observations and Inferences

- There is a decline in memory accuracy as age increases. This suggests memory weakens as we age.
- Memory response times vary widely, spanning from approximately 0 milliseconds to around 10,000 milliseconds. This indicates that some memory accesses occur very quickly, while others take considerably longer.
- There's a higher correct memory response for the "old" category type compared to the "new" category type, indicating better memory for previously seen items.
- The majority of memory response times fall within the range of 1000 to 3000 milliseconds. This suggests that the typical time taken to retrieve data from memory is between 1 and 3 seconds.

2.2.4 RL Data



Key Observations and Inferences

- The correlation matrix reveals how different variables in the dataset relate to each other. High correlations along the diagonal suggest strong relationships between variables and themselves.
- The distribution of trial plot provides insights into the frequency of different trial numbers throughout the experiment.

3 Hypotheses Tested by Me

Based on the insights from the data analysis we came up with different hypotheses we can test to analyze the study better.

3.1 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 (H_0): There is no significant relationship between age and the adaptation towards specificity in memory representations.

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

3.1.1 Analysis Conducted

From hypothesis 1, we see that there's a significant relationship between `memory_accuracy` and `block_condition` or `confidence level` and `block_condition`. We now check if there is a significant relationship between age group and memory accuracy.

Age vs. Memory Accuracy:

To test the relationship between age and memory accuracy, we use the Chi-Square Test of Independence. This test is appropriate because both age group and memory accuracy can be made categorical variables to test their association.

- **Chi-square test:** $p < 0.05$, indicated significant age-memory accuracy relationship.
- **Small effect size** (Cramer's $V = 0.036$), indicating a weak association.

Age vs. Memory Accuracy within Specificity Conditions:

Now we want to determine if there is a significant relationship between age and memory accuracy within each specificity condition.

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 a 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 ($p < 0.001$).

3.2 Learning Specificity Hypothesis

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

Null Hypothesis (H0): 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 increase/decrease with age.

3.2.1 Analysis Conducted

Distribution of Correct Responses by Age Group:

To test the relationship between `age` and `correct response made`, we'll use the Chi-Square Test of Independence. This test is appropriate because both age group and correct response made can be made categorical variables, and we want to assess if there is an association between them.

- **Chi-square test:** $p < 0.05$, indicates a significant relationship between age and correct response made.
- **Small effect size** (Cramer's V = 0.06), indicating a 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 ($p < 0.001$).

Association between Block Condition and Correct Response Made:

We need to assesses the association between two categorical variables, which are `correct_response_made` (categorical) and `block_condition` (categorical).

- **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.

Relationship between Age Group and Correct Response Made within Each Block Condition:

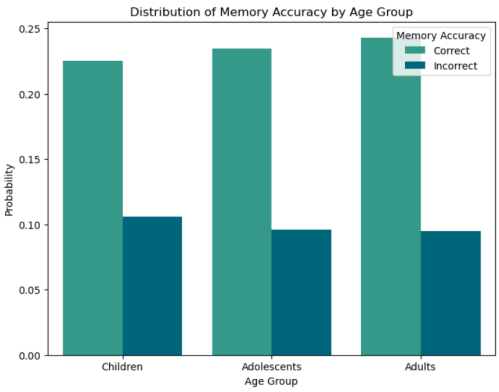
We want to assess the relationship between age group (categorical) and correct response made (categorical) within each block condition.

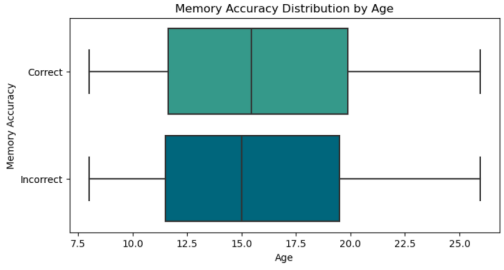
- **Chi-square tests:** $p < 0.05$, reveal significant relationships between age group and correct response made within both block conditions.
- **Post hoc tests** (pairwise chi-square tests with Bonferroni correction) demonstrate specific differences between age groups within each block condition.
-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

4 Visualisation and Results for analysis done by me

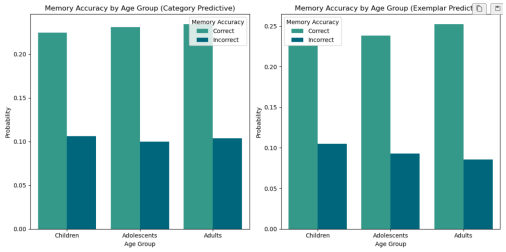
4.1 Age - Memory Specificity Hypothesis

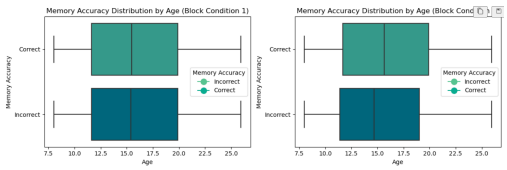
Age vs. Memory Accuracy:





Age vs. Memory Accuracy within Specificity Conditions:





4.1.1 Observations and Inferences

- The chi-square test reveals a significant relationship between age and memory accuracy, suggesting that age influences memory performance.
- Within the category predictive condition, there is no significant relationship between age and memory accuracy.
- However, within the exemplar predictive condition, there is a significant relationship between age and memory accuracy, indicating that memory performance varies with age in this condition.

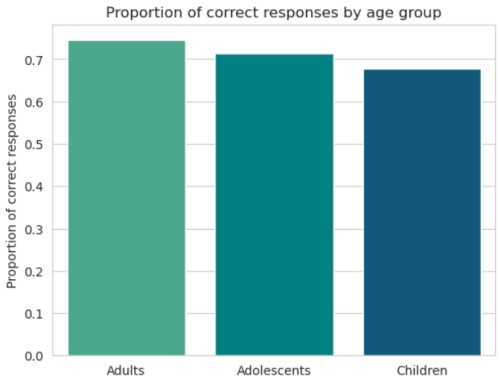
4.1.2 Key Results

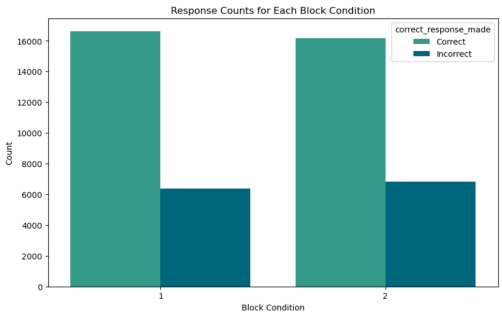
- Adaptation towards memory specificity increases with age, especially evident in the Exemplar Predictive condition.
- While age does not significantly impact memory accuracy in the Category Predictive condition, it significantly influences memory accuracy within Exemplar Predictive specificity.

Overall, based on the results of the conducted analyses, we can reject the null hypothesis (H_0) and conclude that there is a significant relationship between age and memory accuracy, particularly within the exemplar predictive condition.

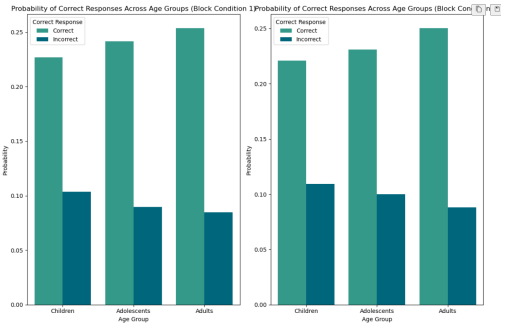
4.2 Learning Specificity Hypothesis

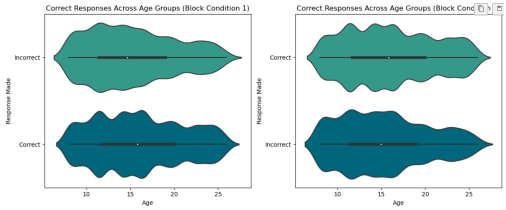
Association between Block Condition and Correct Response Made





Relationship between Age Group and Correct Response Made within Each Block Condition





4.2.1 Observations and Inferences

- Age significantly influences the adaptation towards the specificity of learning computations
- Adults tend to have a higher proportion of correct responses than adolescents and children.
- There is a significant association between block condition and correct response made. Block conditions 1 and 2 show slightly different distributions of correct and incorrect responses.

4.2.2 Key Results

- 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

- There is a significant association between block condition and correct response made. Block conditions 1 and 2 show slightly different distributions of correct and incorrect responses.

Overall, we reject the null hypothesis (H_0) and conclude that age group influences the adaptation towards the specificity of learning computations.

5 Analysis done by my teammates

1. 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).
   - **Results**:
     - 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.

2. To study the interaction effect between stimulus repetition and age on reaction times.
   - **Results**:
     - Different stimulus repetitions indeed lead to varied reaction times, with some repetitions significantly affecting reaction speed compared to others.

     - Adults tend to exhibit faster reaction times as stimulus repetition increases, compared to children and adolescents.

3. To analyse if magnitude of reward or threat had any effect on how well the participants learnt/remembered the stimuli.
   - **Results**:
     - A greater reward/punishment does not significantly affect learning/memory performance.

4. To study if better learning leads to better retention?
   - **Results**:
     - Subjects who learn better, retain better.

     - The effect is seen to be increased with an increase in the specificity of learning.

6 Conclusion and Discussion

Our findings indicate that memory accuracy improves with more specific representations, and this adaptation increases with age. Moreover, learning specificity also shows an upward trend with age, leading to better learning performance in adults. Additionally, we observed varying reaction times with different stimulus repetitions, particularly with adults showing faster responses. Notably, the magnitude of reward/punishment did not significantly affect learning/memory performance. Overall, our research contributes to a deeper understanding of how experience, cognition, and memory interact throughout life, offering valuable insights into human behavior and cognitive development.

7 References/Citations

[1] Nussenbaum, Kate, and Catherine A. Hartley. "Reinforcement Learning Increasingly Shapes Memory Specificity from Childhood to Adulthood." OSF, 27 Nov. 2023. Web.

[2] Cohen, A. O., Phaneuf, C. V., Rosenbaum, G. M., Glover, M. M., Avallone, K. N., Shen, X., & Hartley, C. A. (2022). "Reward-motivated memories influence new learning across development." doi: 10.1101/lm.053595.122