The Effect of Working Memory on Cognitive Flexibility of Humans and Primates

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1.0 Abstract

Humans and anthropoids are known for having nearly identical biological structures. Previous studies have shown that their behavioral psychology and processes of acquiring knowledge are surprisingly similar despite humanity's development since ancient times. Compared to anthropoids, humans tend to utilize learned rules that help humans to finish the work quickly. However, using learned rules often blinds humans from finding the more efficient alternatives. The research has considered only one variable: working memory. And, since humans have higher working memory than primates, the researchers have conducted non-verbal computer-based trials on humans and primates to see the effect of working memory on the humans' and primates' cognitive flexibility. During training phases, 60 humans, 7 rhesus macaques, and 22 capuchins learned to select three icons sequentially. They then went through 96 baseline trials which can only be completed using the learned strategy and the 96 probe trials in which the researchers have alleviated the working memory requirements and subjects can directly select the final icon ignoring the order. As a result, rhesus and capuchin monkeys have used shortcut methods more often than humans. Although humans used the shortcut as well, they used it significantly later than the monkeys. The researchers have suggested that the differences in cognitive flexibility have resulted from differences in rule encoding and their efficiency of utilizing learned strategy. Using data analysis, we test a hypothesis proposed by the researchers, "the two monkey species would behave more like humans and increasingly use the learned strategy (rather than the shortcut) when working memory requirements are alleviated."

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3.0 Introduction

The familiarity of learned rules often leads us to repeat the following strategies, preventing the usage of alternative shortcuts. Previous studies aimed to identify which of the primates were most susceptible to the bias of a cognitive set, which led to a conclusion that humans are most likely to rely on their predetermined way of construing a situation. The new study modifies this task from the past to find out whether or not the working memory – a cognitive system that temporarily holds information due to a limited capacity of the brain – contributes to utilizing more effective strategies. In other words, working memory lessens the cognitive flexibility of humans. However, can we certainly define that working memory is the sole reason for reduced cognitive flexibility? To figure out the effect of the working memory more clearly, the researchers have designed an experiment comparing humans to capuchins and rhesus monkeys to see the effect of working memory on other species as well. The experiment has aimed to remove the working memory and demonstrated that while capuchins and rhesus monkeys are more cognitively flexible, humans maintained a strict behavior with extremely low cognitive flexibility which resulted in a fall in productivity. From this paper, we want to look closely at the data of monkeys' and humans' behavior and analyze to what extent each species was affected by the working memory.

4.0 Methods

4.1 Participants

To see the effect of working memory availability on species with different working memory capacities, the research team has recruited a variety of participants. In addition to 60 humans, 22 capuchin monkeys, and 7 rhesus monkeys participated in the experiment. The research team has predicted that since capuchin and rhesus monkeys lack human language and culture, they are exempt from a possible cognitive bias applied to humans. Capuchin and rhesus monkeys were tested in individual test boxes, moving the on-screen cursor with a joystick. Humans were tested individually in a computer laboratory. They have given as minimal instructions as possible and worked with a standard keyboard and cursor to finish the test as accurately and fast as possible in less than 60 minutes. The experimenter provided the correct and incorrect feedback screens to them.

4.2 Training and Test Phases

The research team has designed the EZ LS-DS task, a simplified version of the LS-DS task that is less reliant on working memory. Participants completed three training phases before the trials. After selecting the start box, the participants would get negative (buzz and a green screen) or positive auditory and visual feedback based on their responses. Monkeys completed 24 trials and humans completed 8 trials during training phases. Participants could automatically advance to the next stage when they reached 80% accuracy.

Training Phase

During training 1, the participants were rewarded for selecting a striped square (square 1) and a dotted square (square 2) sequentially. During training 2, the researchers have added the number of response options in addition to square 1 and square 2 by adding two white squares. During training 3, instead of two white squares, the participants had to select an additional triangle after selecting square 1 and square 2. During training phases, 4 humans and 1 capuchin monkey have failed to pass training 1.

Test Phase

Participants who passed the training phases were moved to the test phase. The test phase consisted of 4 blocks of 48 trials which included 24 BASE trials and 24 PROBE trials in random order. BASE trials were similar to training 3 except for the fact that the triangle was hidden behind the blank square and if the participants clicked it, the response would still be recorded as a correct response (shortcut). In PROBE trials, the triangle was visible from the beginning and the participants could select it from the beginning. The visibility of the triangle helped to alleviate the working memory requirements as the participants no longer have to memorize the location of the triangle. Selecting the triangle directly produced a more immediate reward. Other than DS (direct strategy), the participants could use LS (learned strategy) by clicking Square 1 -> Square2 -> Triangle and SS (switch strategy) by clicking Square 1 -> Triangle.

4.3 Data Analysis

Using the data collected from the experiment by the research team, we have conducted data analysis to test for the hypothesis and further withdraw useful trends about cognitive flexibility and psyche of the humans and monkeys. We used programs and codes including panda, NumPy, and seaborn to organize the dataset of 15963 rows x 23 columns and visualize it into different scatter plots that represent the general trends of rhesus, capuchins, and humans. (See Figure 1 and 2 below)

```
species_id_list = list(set(list(probe_df['Subject'])))

species_score_ss = {}
for s_id in species_id_list:
    species_score_ss[s_id] = 0

for i in range(len(probe_df)):
    subject_id = probe_df.loc[i,'Subject']
    if probe_df.loc[i,'Score2']==1:
        species_score_ss[subject_id]+=1

for key in species_score_d:
    species_score_ss[key] = (species_score_ss[key]/96)*100

human1_df = probe_df.loc[probe_df['Species']=='Human']
human1_subjects = list(set(list(human1_df['Subject'])))

rhesus1_df = probe_df.loc[probe_df['Species']=='Rhesus']
rhesus1_subjects = list(set(list(rhesus1_df['Subject'])))

capuchin1_df = probe_df.loc[probe_df['Species']=='Capuchin']
capuchin1_subjects = list(set(list(capuchin1_df['Subject'])))

human1_ds, capuchin1_ds, rhesus1_ds = [], [], []

for key in species_score_ss:
    if key in human1_subjects:
        human1_ds.append(species_score_ss[key])
    elif key in capuchin1_subjects:
        capuchin1_ds.append(species_score_ss[key])
    else:
        rhesus1_ds.append(species_score_ss[key])

sns.catplot(x='species', y='ss', data=switch_df)
```

Figure 1: Data Visualization of Switch Strategy

In [13]:
```
df = pd.read_csv('cogset_exp.csv')
df.head()
```

Out [13]:

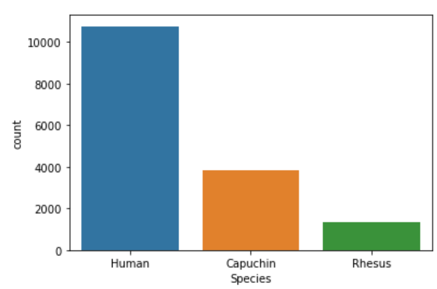
	Species	Subject	Date	Time	Phase	Block	Trial	ConfigID	Correct1	Correct2	...	Response3	RT1	RT2	RT3	ACC1	ACC2	ACC3	Score
0	Human	EZ_06	2017-09-26	13:25:22	Exp	1	1	7	TopRight	TopLeft	...	BottomRight	1093	886.0	1530.0	1	1.0	1.0	1
1	Human	EZ_06	2017-09-26	13:25:28	Exp	1	2	16	BottomLeft	BottomRight	...	TopLeft	1107	778.0	963.0	1	1.0	1.0	1
2	Human	EZ_06	2017-09-26	13:25:35	Exp	1	3	5	TopLeft	BottomRight	...	BottomLeft	1260	951.0	1253.0	1	1.0	1.0	1
3	Human	EZ_06	2017-09-26	13:25:42	Exp	1	4	0	TopLeft	TopRight	...	BottomLeft	1069	954.0	1364.0	1	1.0	1.0	1
4	Human	EZ_06	2017-09-26	13:25:47	Exp	1	5	2	TopLeft	BottomLeft	...	TopRight	901	864.0	813.0	1	1.0	1.0	1

5 rows × 23 columns

Count each species

In [14]:
```
sns.countplot(x='Species', data=df)
```

Out [14]: <AxesSubplot:xlabel='Species', ylabel='count'>



How many percentage of each species used direct strategy in PROBE stage?

In [17]:
```
### Select PROBE stage only
probe_df =df.loc[df['Condition'] == 'PROBE']
probe_df = probe_df.reset_index(drop=True)
```

Figure 2: Visualization Codes

5.0 Results

BASE Accuracy & PROBE Accuracy

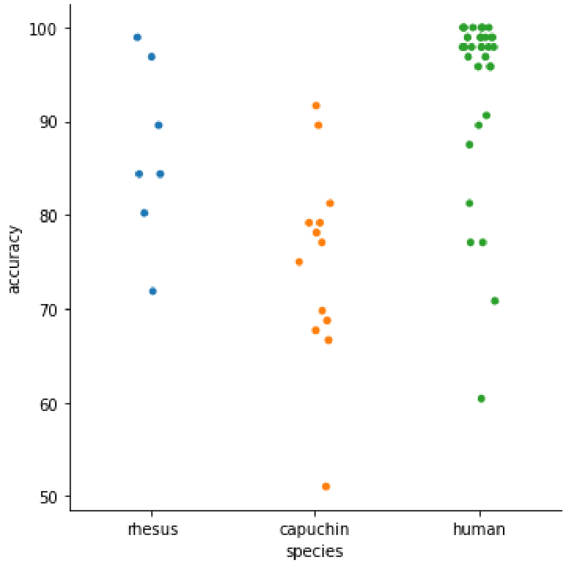


Figure 3

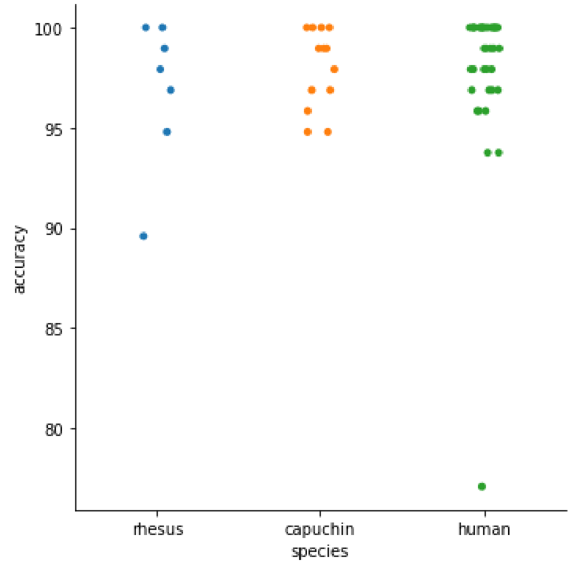


Figure 4

Figures 3 and 4 are the scattered plots representing the accuracy (%) of rhesus, capuchins, and humans during BASE and PROBE trials. In Figure 3, the majority of green dots are gathered over 90% accuracy rate meaning humans have high accuracy. Rhesus dots are scattered widely from 70% to 100%. Although there is not much data to support the idea, 4 out of 7 data points are located between 80% to 90% indicating its high accuracy level. On the other hand, the majority of capuchins' data are located between 60% and 80%. The difference in accuracy rates indicates the inter-species variation on cognitive sets.

During PROBE trials, overall accuracy rates increased as most of the data are located above 95%. All humans' data are above 90% except one (maybe an outlier). Capuchins show a similar trend as well. Since all the data are located above 90%, rhesus monkeys also show a high accuracy level with most data located over 90%. In Figure 4, data are more gathered and less scattered. The highest range it has is from rhesus monkeys, which is about 10%. Based on the data, it is interpreted that since the species no longer need to memorize the location of the figures, the experiment requires less intellect. Therefore, all species can reach a high accuracy level regardless of their ability.

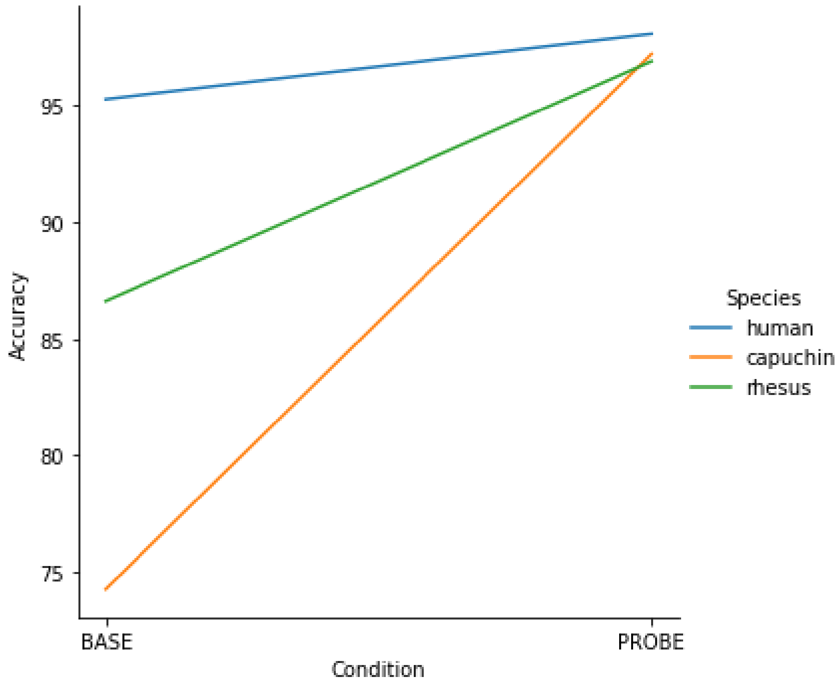


Figure 5: Accuracy Trend

Overall, the accuracy levels of the species (See Figure 5 above) increased from BASE trials to PROBE trials, which can be presumed that lessened working memory load has enhanced the participants' performance. One other difference shown in PROBE trials is the higher accuracy level of capuchin monkeys than the rhesus monkeys.

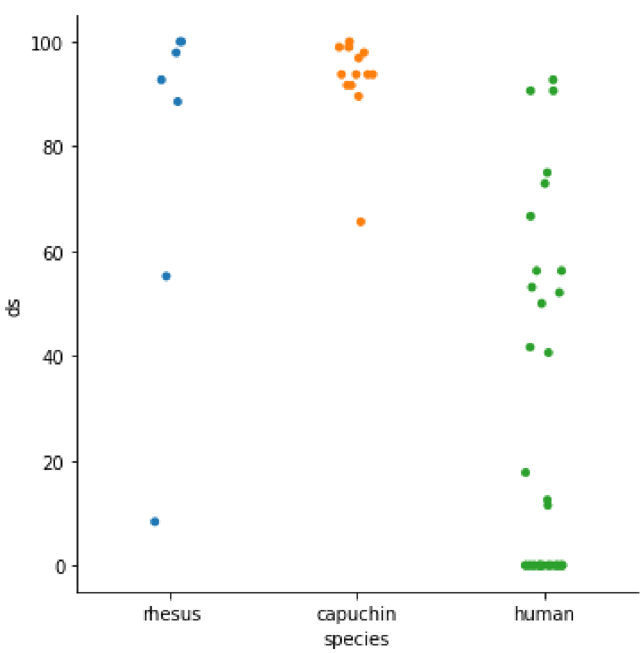


Figure 6: Direct Strategy - PROBE Stage

During the PROBE stage, humans used the direct strategy (shortcut) significantly less than the capuchin and rhesus monkeys. (See Figure 6 above) Differences in working memory capacity may explain this. Humans have a high working memory capacity compared to the primates, therefore, when the working memory load is alleviated in the PROBE stage, humans tend to use the safer learned strategy rather than the direct strategy. On the other hand, since rhesus and capuchin monkeys have smaller working memory capacity, they still prefer to use direct strategy regardless of the load.

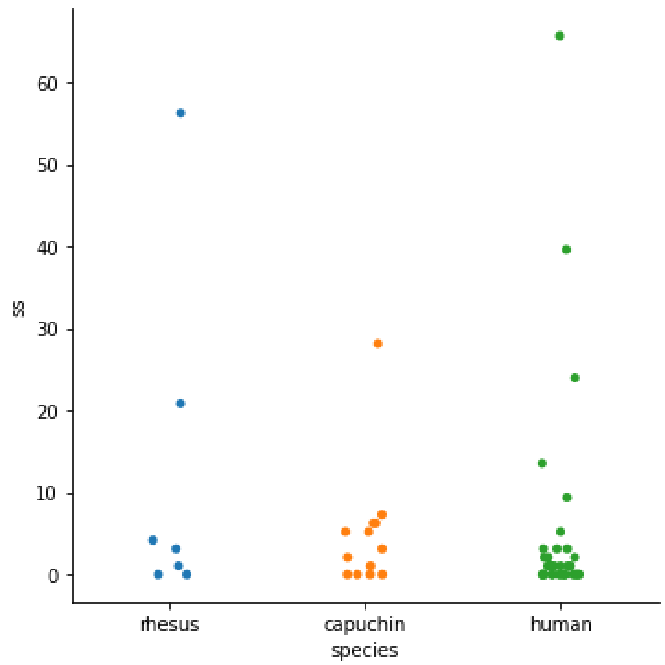


Figure 7: Switch Strategy - PROBE Stage

The data here demonstrate a slight shift in the rhesus and capuchin monkeys' behavior. (See Figure 7 above) Compared to the BASE stage, rhesus and capuchin species have used the intermediate/switch strategy more often, shifting towards a more habitual learned strategy. Although the difference in the working memory capacity varies the results, the graph implies that the decreased working memory load has affected the participants to shift towards the learned strategy to some extent.

6.0 Conclusion

Based on the findings that the previous team experimented with, they "suggest[ed] that differences in working memory capacity might influence strategy use on the LS-DS task. Specifically, limited working memory capacity or increased load might promote the use of the shortcut, which requires no working memory, over the use of the learned strategy." (Julia Watzek, Sarah M & Sarah f. Brosnan) Furthermore, following the previous study, another research team conducted a new experiment to prove the new hypothesis saying whether working memory influences the advantages of taking a shortcut or not. They found out that if the working memory capacity is high, it is highly possible for the species to use the learned strategy rather than shortcuts even though the working memory requirements are alleviated. Alternatively, the lower working memory capacity and lower working memory load would make the species use the shortcuts. Based on the result and gathered data, our team utilized data analyzing tools, including Python, Numpy, and Panda, to visualize them and came up with four different graphs showing how each species reacted to each trial that they had to complete. By arranging and organizing the data, we were able to observe that working memory load makes an impact on the usage of learned strategy as suggested.

7.0 References

Capuchin and rhesus monkeys but not humans show cognitive flexibility in an optional-switch task

(Julia Watzek 1, Sarah M. pope2,3 & Sarah f. Brosnan1,2,4)