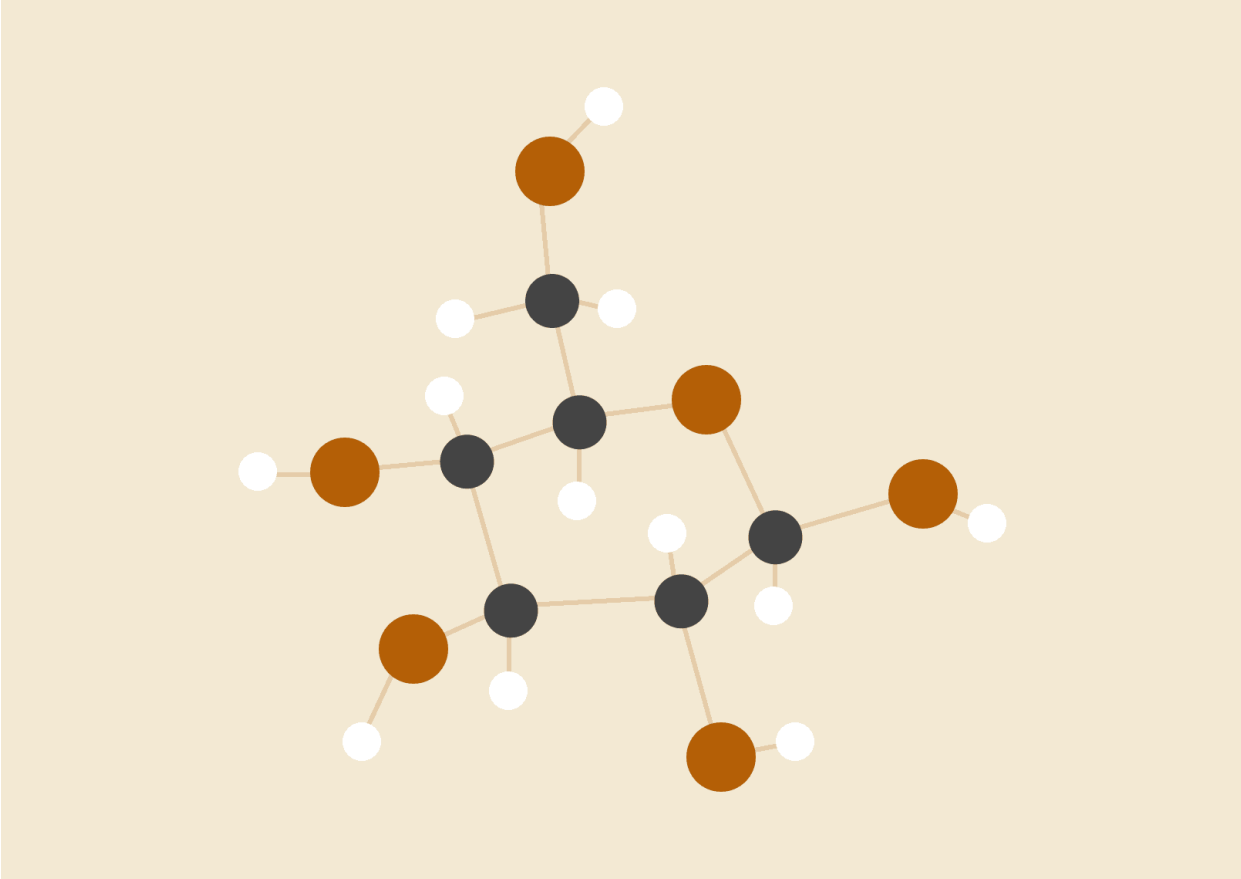
EFFECT OF TIME PRESSURE AND COGNITIVE LOAD ON DECISION-MAKING

BSE662A : Decision Making and the Brain



Team Psyched

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End-sem Report

INTRODUCTION

Making Decisions under limited time is nothing new to any of us. Every day, we encounter multiple such situations, be it deciding on the mode of travel when late to work or working on an important submission as the deadline looms large! The paper we reviewed chose to study that, as it investigated the effects of time pressure on decision-making and exploration. It explored the impact of cognitive constraints on decision-making strategies and uncertainty-based exploration.

Previous research in this domain has taken different views on this subject. While some state that emphasis on response speed increases the baseline firing rate of the involved neurons, leading to noisier results[2] .Others suggest that we can adapt according to the constraints on our computational capacity for the best results[3]

The chosen paper[1] elaborated on the *exploration-exploitation* dilemma. Experimental evidence states that *Random exploration* and *Directed exploration* are the two major strategies people use to make decisions. Diversity in choices increases with more randomness in exploration, which may or may not maximize the expected value. On the other hand, directed exploration might be computationally expensive, but is highly strategic in nature, and prioritizes choices with maximum uncertainty to gather more information. A very relevant example where we are faced with these options is choosing items from a menu.

While on one hand, it has been observed that time pressure leads to increased exploration, irrespective of expected value, which is visible in the less consistent results. On the other hand, it has also been known to decrease exploration by increasing the repetition of choices. This paper interpreted and finally displayed that people make decisions about exploration strategies based on the costs and benefits of those strategies relative to their limited cognitive resources.

Along with replicating the experiment carried out in the paper, we devised two extensions of the original experiment, based on what questions stood out to us the most while reviewing the paper. One version corresponded to a *loss domain* and the other introduced a different kind of load i.e *cognitive load*.

For the first extension – loss domain – the idea is that as we know from Prospect theory that people behave differently in the domain of losses and gains. People are generally loss averse and become more risk-seeking when it comes to losing. So, we wanted to explore how it affects their choices in terms of the exploration-exploitation dilemma, i.e., do they explore more options, increase uncertainty or stick to a more expected range of losses. If they are loss averse, what is their strategy to minimize their losses and how much loss do they incur compared to how much rewards they gain; and how time pressure is accounted for in this.

The other extension was increasing cognitive load by way of giving a working memory task whereby participants had to constantly keep in mind some digits while exploring which options were best for them. We explored that without time pressure to check how a different kind of load compares to a no- load condition. This was done only in the gain domain. Since time-pressure was limited to an externally imposed cognitive constraint, the idea was to design a task with an internal constraint. Since it is also known that working memory capacity limitations affect decision making, we test out the same in a reward context.

METHODS

There were three tasks in our experiment : the original replication task and two extension tasks. These tasks are explained in detail later in this section. For each task, we had fifteen participants. We collected the datasets based upon the participation of these individuals and analyzed the data obtained. The complete analysis is described in the following section.

REPLICATION

We replicated the study of the paper by creating a four-armed bandit challenge with four possibilities for each trial. There were twenty trials per round, and a total of twelve rounds. There are four rewards distributions namely IOWA, Equal Means, High and Low Variance. At the beginning of each round, a distribution is selected. The participant is shown four keys corresponding to different rewards (with reference to the allotted distribution). Based on the choice made, the participant is shown the reward received, and the goal is to maximize the final reward at the end. In the case of limited time, if the participant fails to make the choice before the timer runs out, no reward is given and a sad face flashes to indicate the same.

EXTENSION-1

For the extension-1 in the loss domain, we designed an experiment similar to the original four armed bandit task. However, instead of being rewarded for each trial, participants were given an initial amount of money every round, and for each trial, they incurred a penalty, which was deducted from the initial amount. The negative reward values were also generated in the same four distributions as above. Participants had to aim to maximize the final remaining amount by minimizing the penalties they received on each trial. In the case of a limited-time task, if all the time was consumed and no choice was made, a higher penalty was incurred..

EXTENSION-2

The experimental task was similar to the original four-armed bandit task, consisting of four options per trial, with twelve trials per round and twenty rounds in total. Each round chose from one of the four distributions as mentioned above. However, a memory task was added before each round, requiring participants to memorize a six-digit number. They were then asked to choose from the four keys and aim at maximizing the reward. At the end of the round, participants were also asked to recall the number they were given at the beginning of the round.The accuracy with which they recalled the string affected the reward proportionally.

RESULTS

REPLICATION

For the replication task, we first tried to analyze the trial-wise rewards gained. These plots will give us an idea of the impact of different distributions on the way rewards are accumulated. We took the average of the rewards gained by all the participants after every 2 trials. This analysis was performed for all the four payoff conditions separately (shown in Fig 1(a) below). There are two lines in the plot for untimed and timed versions of the task. After the trial-wise analysis, our aim was to analyze the overall data for the rewards gained. We took the mean of the overall rewards gained by all the participants and plotted the results (shown in Fig 1(b) below). As before, this analysis was also performed across all the four payoff conditions.

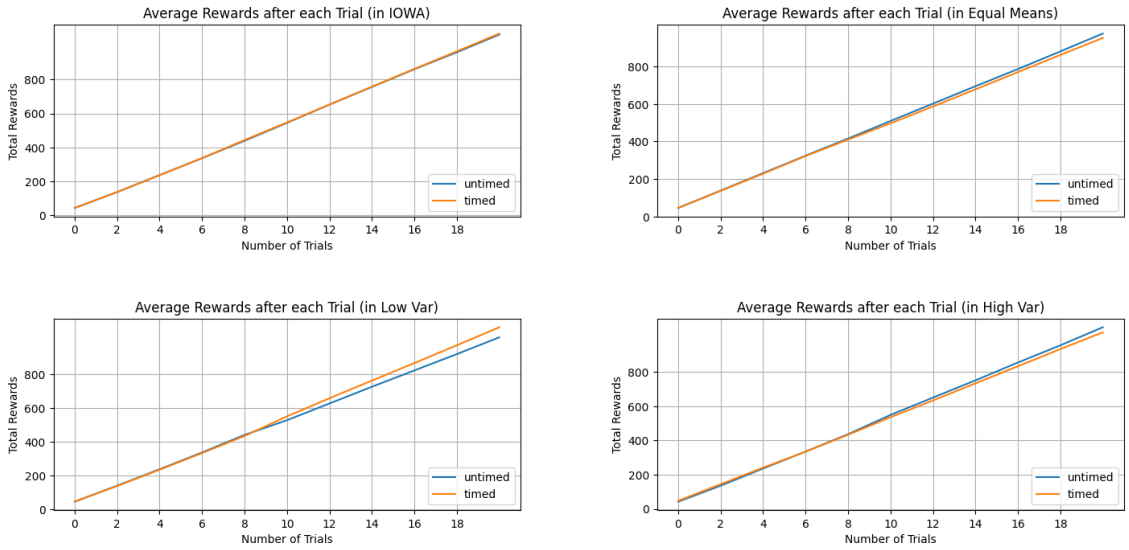

Figure 1 (a) : Trial-wise comparison of average rewards gained in untimed and timed versions of the Replication task

While we do not see very significant differences in average rewards across all Payoff Conditions in timed and untimed cases, Equal Means and High variance payoff conditions displayed better average rewards in untimed conditions when compared to the timed conditions (as expected). Further, the highest rewards were observed under the IOWA conditions (similar to the replication task).

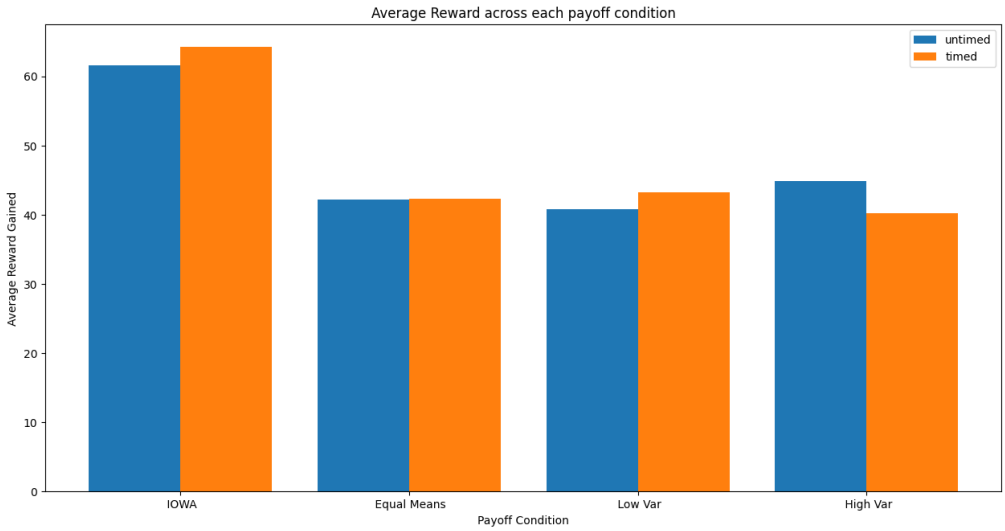

Figure 1 (b) : Overall comparison of average rewards across different payoff conditions in both timed and untimed versions of the replication task

After visualizing the average rewards, our aim was to observe the repeat choices made by the participants. We took the average values for the number of repeat choices made by the participants, in both the untimed and timed conditions. The result has been displayed in Fig 1(c) as a scatter plot. The next figure (Fig 1(d) below) shows the trial-wise number of repeat choices made by the participants. This analysis is similar to the one done in Fig 1(a) above.

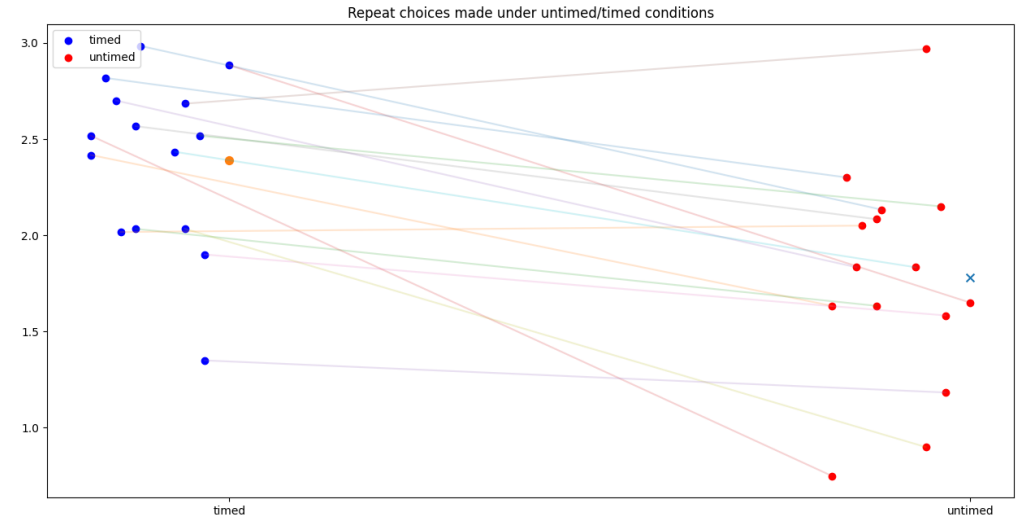

Figure 1 (c) : Comparison of repeat choices made (on an average) in timed and untimed conditions. Each line represents one participant. The yellow dot (in the left distribution) and the blue cross (in the right distribution) represent the mean of the respective distributions

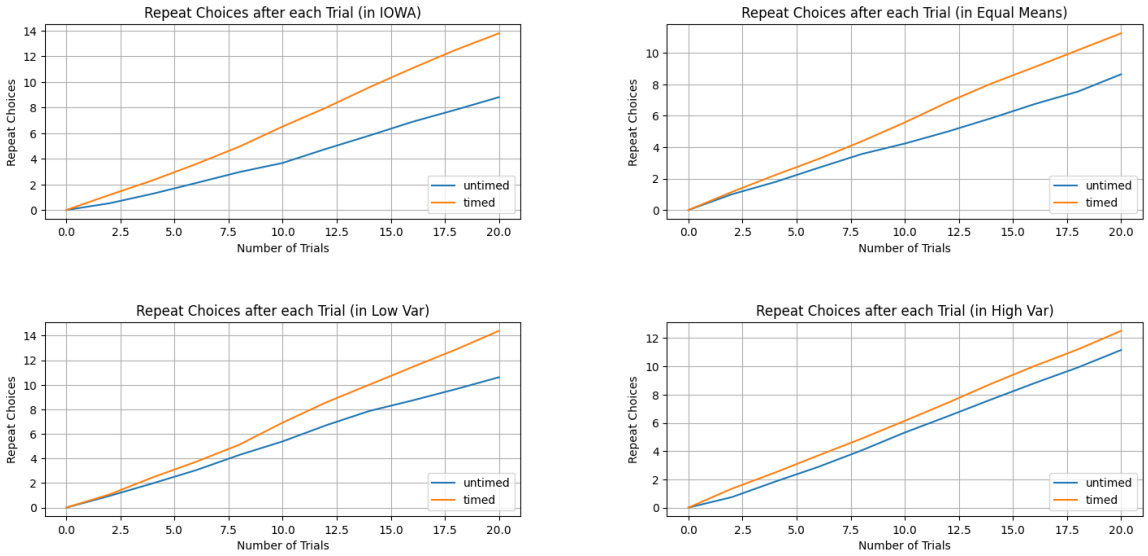

Figure 1 (d) : Trial-wise comparison of average repeat choices made in untimed and timed versions of the Replication task

We were able to replicate the results in this case since the mean of the number of repeat choices made was higher in the case of timed version as compared to the untimed version of the task. On an average, the timed conditions showed higher repeat clicks than the untimed conditions in all four Payoff conditions (as expected). Further, repeat choices were more frequent in low var conditions as compared to the high var conditions. This is also similar to the corresponding result obtained in the original experiment. The reason might be the relative ease in finding the highest rewarding arm under low var conditions.

EXTENSION-1

In the first extension task, we dealt with the loss domain instead of the gain domain. Hence, for the first analysis, we analyzed the amount remaining and its decrease pattern after every 2 trials. We took the average of the amount remaining for all the participants after every 2 trials and the result was plotted (Fig 2(a) below). Similar to the analyses in the replication task, we also measured and analyzed the overall data across all the four payoff conditions. In Fig 2(b) below, we observe the overall penalty incurred in each of the four payoff conditions (averaged out over all the participants).

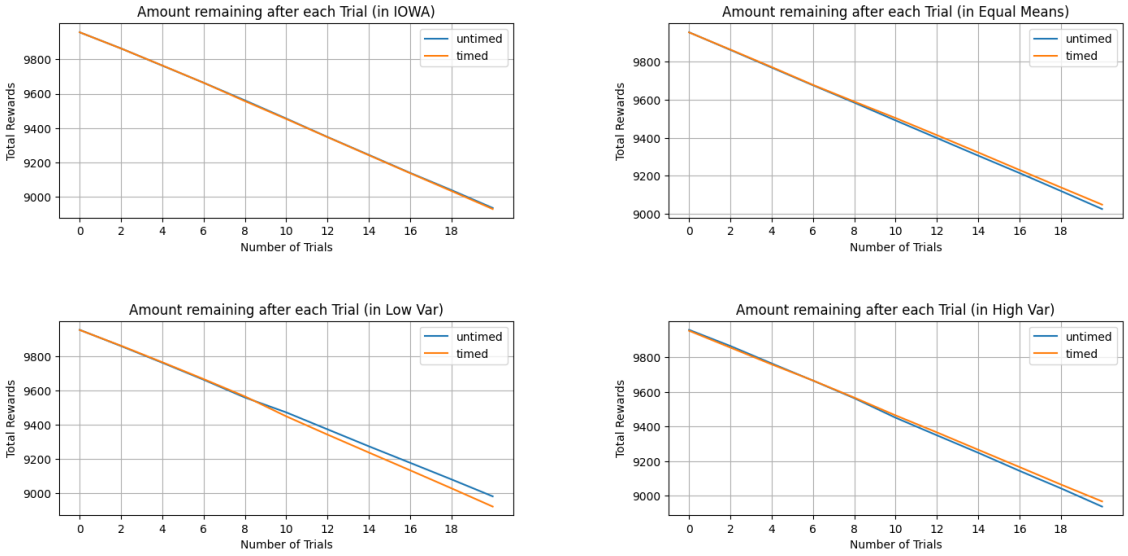

Figure 2(a) : Amount remaining (Trial-wise depletion) in untimed and timed versions of this extension task

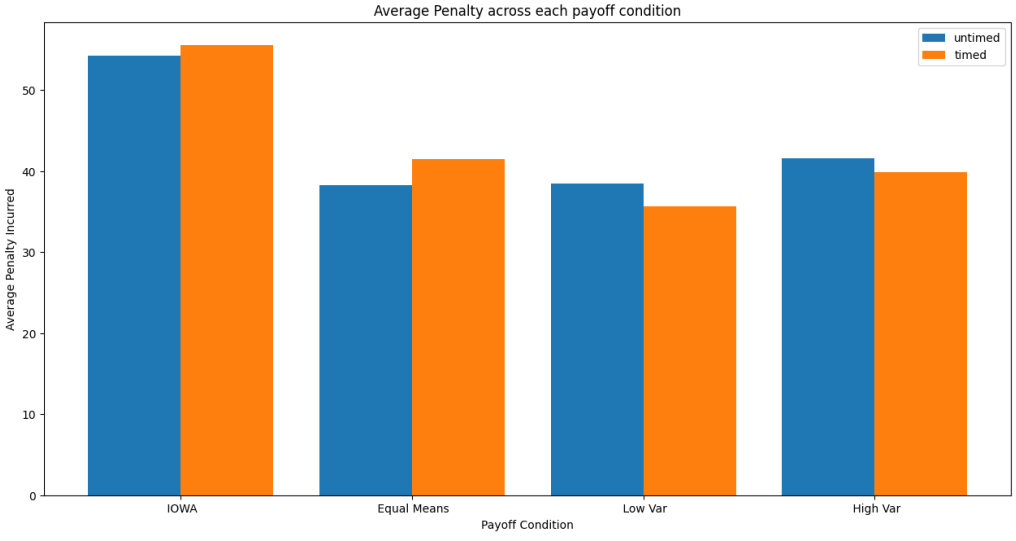

Figure 2 (b) : Comparison of the Average penalty incurred after completion of experiment (in untimed and timed versions)

From Fig 2(b), it is clear that similar to the gain domain, the largest negative change (i.e., penalty) was observed under the IOWA conditions. The similarity lies in the fact that in the replication task, the largest positive change (i.e., rewards) was observed under the IOWA conditions. While comparing the results of the gain domain (replication task) and the loss domain (this task), we observe that the magnitude of overall rewards gained was higher in the gain domain as compared to the magnitude of overall penalty incurred in each of the four payoff conditions. This is concluded by measuring the peak of each bar in Fig 1(b) and Fig 2(b). The overall distribution in the loss domain (this task) was almost similar to that in the gain domain (in the replication task).

Next, we analyzed the repeat choices made in this task. The corresponding scatter plot and the trial-wise plots have been shown in Fig 2(c) and Fig 2(d) respectively.

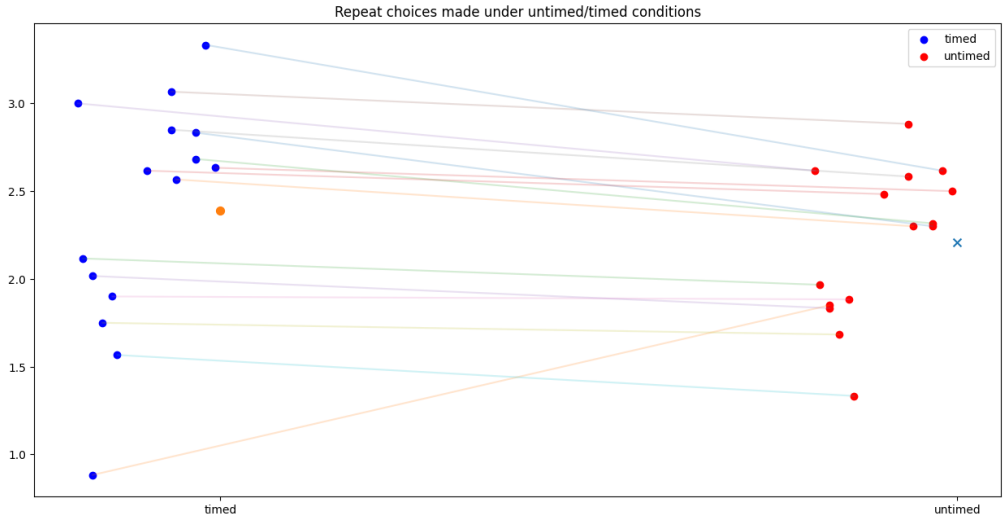

Figure 2 (c) : Comparison of repeat choices made (on an average) in timed and untimed conditions. Each line represents one participant. The yellow dot (in the left distribution) and the blue cross (in the right distribution) represent the mean of the respective distributions

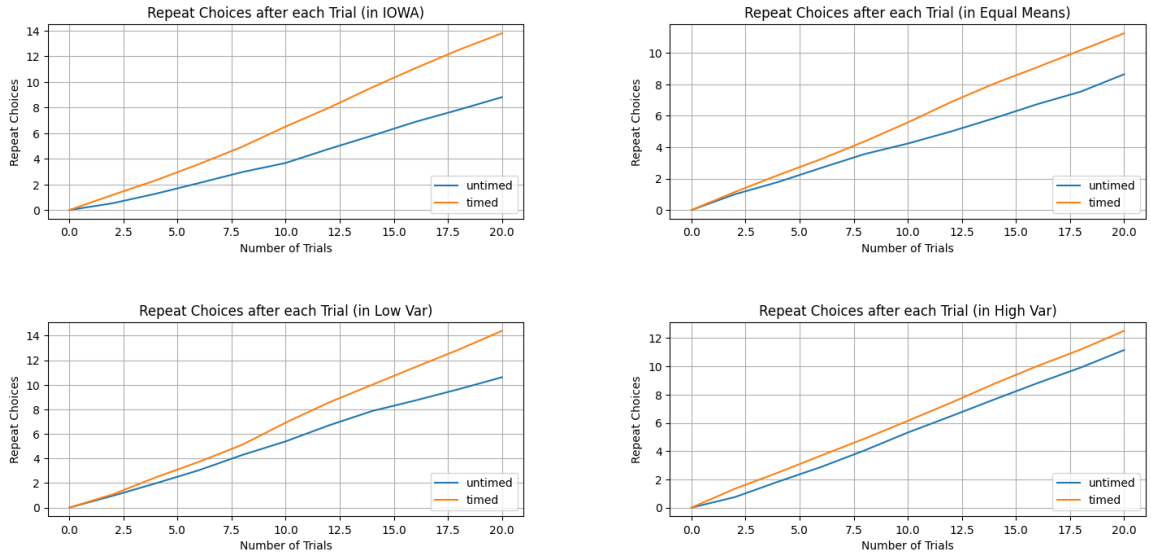

Figure 2 (d) : Trial-wise comparison of average repeat choices made in untimed and timed versions of this Extension task

Similar to the replication task, the timed conditions showed higher repeat clicks than the untimed conditions in all four Payoff conditions as expected. This is concluded from the fact that the orange curve (timed version) lies above the blue curve (untimed version) in Fig 2(d). This pattern is repeated across all the four payoff conditions. Fig 2(c) is similar to the one obtained in Fig 1(c) since the mean of the overall data for number of repeat clicks was higher in the case of timed version. When compared with the gain domain, there were more repeat choices in the loss domain (the height of the blue cross was lesser in the case of Figure 1(c)). Hence, the results were again as expected.

EXTENSION-2

Finally, the analysis done in the replication and the first extension task is repeated in the second extension task as well. The only difference being that there is no timed version in this case. Hence, the comparison in each plot has been done among the four payoff conditions.

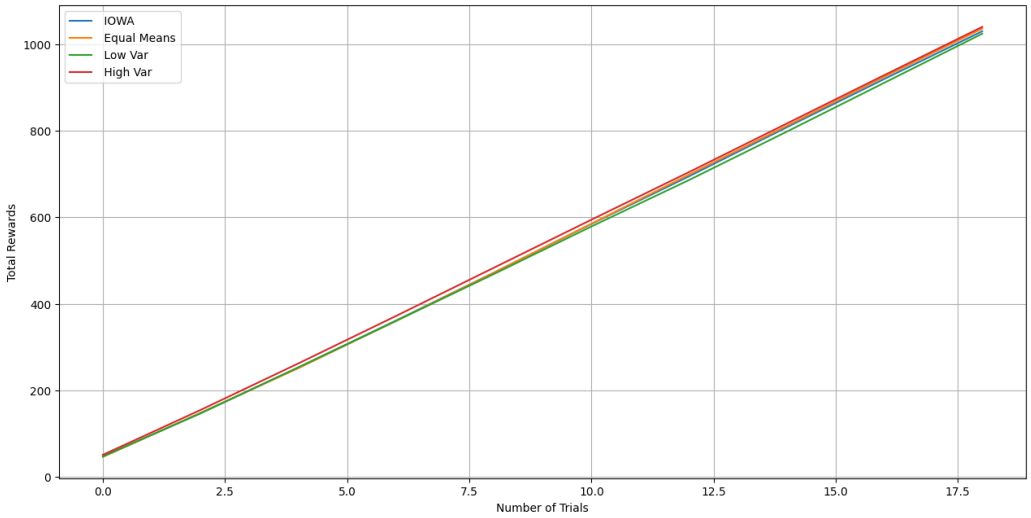

Figure 3 (a) : Trial wise average rewards in this Extension task (compared across the four different payoff conditions)

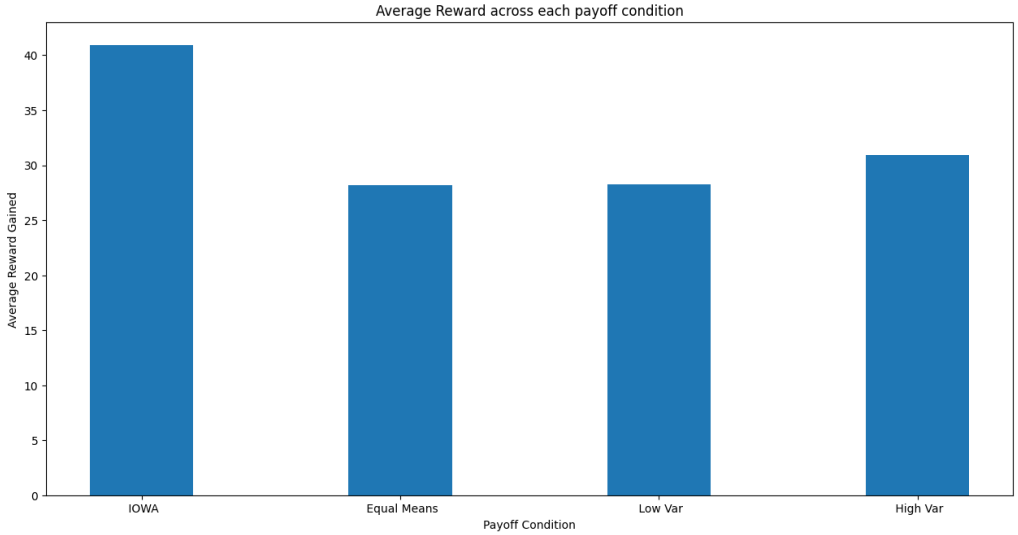

Figure 3 (b) : Overall comparison of the average rewards (after completion of the experiment)

The distribution from figure 3(b) is quite similar to the original replication task. The relative values of the average rewards gained across the payoff conditions remains almost same (IOWA the highest, and so on)

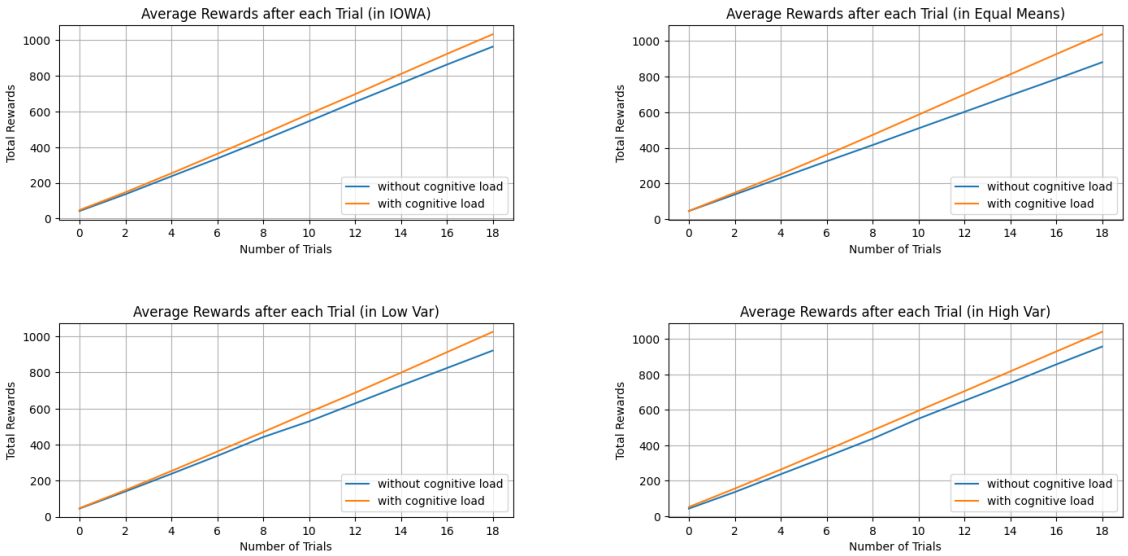

Figure 3 (c) : Comparison of trial wise rewards gained in the replication task (without any cognitive load) with this extension task (with some cognitive load)

On an average, slightly higher average rewards were observed in cognitive load conditions as compared to no load conditions across all payoff conditions. There might be two possible reasons:

i. The numbers used to increase the cognitive load were not too complex, and hence, easy to remember by the participants.

ii. The replication task was performed in the beginning, and hence, the extension task (performed in the last) gave an unintentional advantage of task experience to the individuals. Combined with the first point above, this resulted in higher average rewards in the extension task.

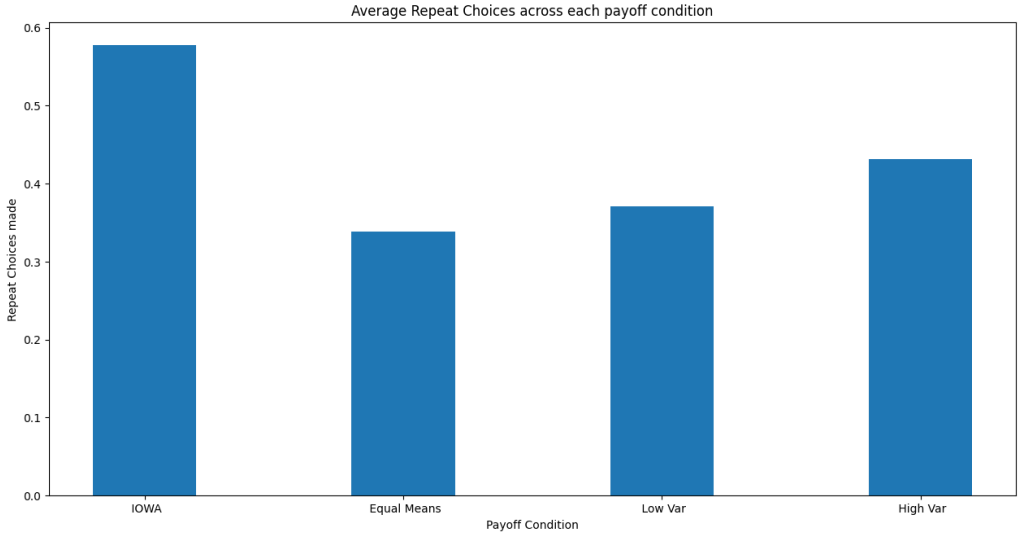

Figure 3 (d) : Average repeat conditions observed after completion of the overall experiment

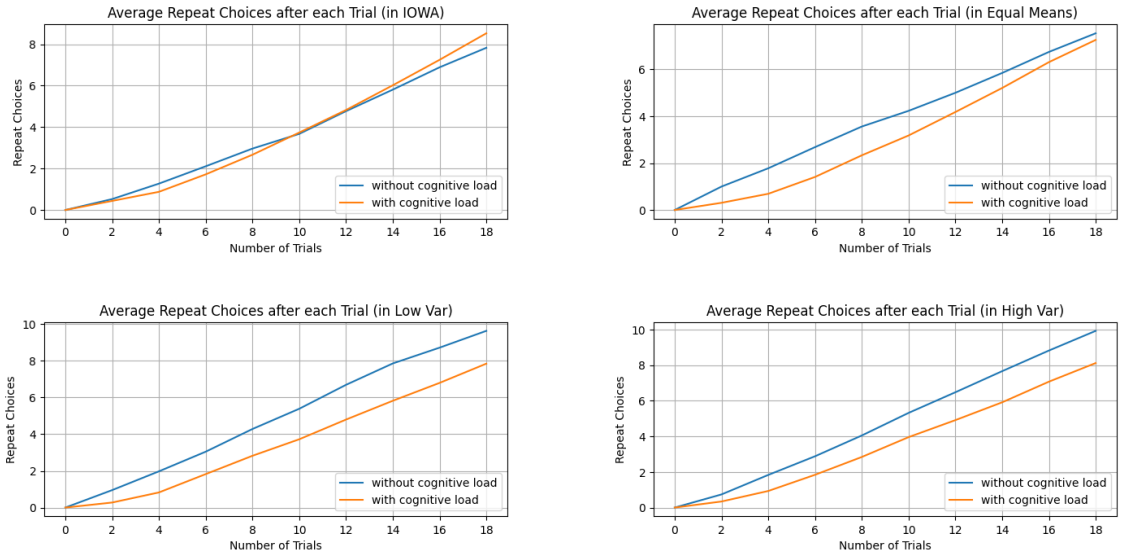

Figure 3 (e) : Comparison of the trial wise repeat choices made in the replication task (without any cognitive load) and this extension task (with some amount of cognitive load)

Lesser number of repeat choices were observed in the cognitive load case as compared to the no load case. But, the repeat choices were nearly equally distributed across all four payoff conditions which demonstrated that exploration is higher in load conditions.

CONCLUSION

In this section, we aim to conclude the results and analyses performed in the previous section. There were two major aspects which had to be observed in all the three tasks : rewards (or penalty in Extension-1), and the number of repeat choices made. All the analysis done on the latter shows quite promising results. The repeat choices plots suggest that individuals tend to make more repeat choices under time pressure as compared to situations having no time pressure.

The average results across all the four payoff conditions were found to follow an almost similar distribution in the replication task in terms of comparison of rewards gained across all the payoff conditions. In our comparison between the loss domain (Extension-1) and the gain domain (Extension-2), we observed that the magnitude of rewards (gain domain) was higher than the magnitude of penalty incurred (loss domain). This situation can be interpreted in terms of some of the postulates of the Prospect Theory. Although this statement cannot be directly applied in our case since we had multiple trials and we analyzed the cumulative results at the end, we can probably agree with a slight modification of the above statement. To be more precise, under conditions similar to our experimental setup, individuals make decisions in such a way that on an average, the magnitude of rewards (in the gain domain) tend to be higher than the magnitude of penalty incurred (in the loss domain).

Finally, the second extension task showed some counterintuitive results in terms of average rewards gained with/without cognitive load. Intuition suggests that since there is an additional load on our cognitive resources, average rewards gained might reduce in the case of cognitive load. However, the results indicate the opposite. As mentioned in the previous section as well, we analyzed the plots carefully and concluded that there might be two possible reasons for these results: (a) Numbers to be remembered were not much complex, (b) The replication task was performed prior to the extension task. Also, the number of repeat choices made were lesser in the case of cognitive loads, and we can make an attempt to explain this in terms of the increased degree of cognitive load in this case. In addition to the choices made earlier, participants now have to remember the string as well and hence, this might lead to reduced degree of exploitation (reduced repetition of choices). Hence, these were some of the key conclusions and learnings that we had throughout the course of conduction of this experiment.

REFERENCES

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[2] Bogacz, R., Wagenmakers, E.-J., Forstmann, B. U. & Nieuwenhuis, S. The neural basis of the speed-accuracy tradeoff. Trends Neurosci. 33, 10–16 (2010).

[3] Bhui, R., Lai, L. & Gershman, S. J. Resource-rational decision making. Curr. Opin. Behav. Sci. 41, 15–21 (2021).