Cognitive Load and Discounting*

Xueer (Michelle) Chen†

Advisors: Alessandra Casella, Mark Dean

April 6, 2021

Abstract

Discounting has long been seen as due to time preference. Gabaix & Laibson (2017) proposed an *As-if* discounting model, which suggests that discounting is, in fact, due to the simulation noise associated with forecasting future utils. This paper presents the results of an experiment designed to test such model. Specifically, we introduce cognitive load and test its differential effect in the gain compared to the loss domain. As predicted by theory, the results show that people are more impatient in the gain domain than the loss domain, and such difference is exacerbated by higher cognitive load.

Keywords: Cognitive load, Delay discounting, Inter-temporal choice

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* I sincerely thank my advisors Professor Alessandra Casella and Professor Mark Dean for their valuable support and guidance. I also thank Professor Michael Best for the comments and advice, and my peers at the honors thesis seminar. The experiment was approved under Columbia IRB Protocol AAAT5263.

†Columbia University: xc2413@columbia.edu

1 Introduction

Understanding how individuals make intertemporal trade-offs has important economic implications, such as understanding behaviors like saving and borrowing. Time discounting refers to individuals' preference for earlier over later rewards. It has long been seen as due to fundamental time preferences, i.e. people who exhibit heavier discounting of later rewards are more impatient. However, a new line of research has suggested that discounting is due to noisy signals of future events. Gabaix-Laibson (2017) propose that **perfectly patient** agents act **as if** they are discounters because of noisy simulations when predicting future events. The as-if discounting model studies Bayesian decision-makers with a perfectly patient time preference. They don't know the true utility of future events, but can mentally generate simulations, and combine these noisy signals with their priors to form posteriors. Thus, average expectations are shaded toward the mean of the prior distribution, generating behavior that partially mimics the properties of classical time preferences.

This paper presents the results of an experiment that tests the *"As-if"* discounting model in Gabaix-Laibson (2017) by investigating the **main hypothesis**, which is implied by the model, that cognitive load has a *differential* effect on discounting in the gain and loss domains. We then break down the main hypothesis into each of the two domains, and further hypothesize that higher cognitive load leads to more discounting in the gain domain but less in the loss domain. In addition to the main research question above, we also report results to auxiliary hypotheses including the baseline difference in discounting in gain and loss domains and the monotonicity violations in each cognitive load conditions.

We are aware of the literature which shows that people discount more steeply for gains than losses (Abdellaoui et al., 2009; Loewenstein, 1987; Scholten &Read, 2013; Thaler, 1981), and existing experiments on whether higher cognitive load leads to greater discounting of delayed rewards, where the results are mixed (Hinson et al., 2003; Deck & Jahedi, 2015). However, little is known about how cognitive load affects discounting differently in the gain and loss domains.

Gabaix-Laibson (2017) are part of a larger literature that investigates the problem of deducing preferences in the presence of possible perceptual biases. An important recent contribution is Woodford (2019), who also talks about modeling imprecision and the applications on discounting of future payments, where valuation biases that are commonly interpreted as indicating subjects' preferences may instead be due to a perceptual bias.

In a more applied perspective, such questions can help us better understand the relationship between poverty and saving. Mani et al. (2013) find that poverty reduces cognitive capacity, because the poor must manage sporadic income, juggle expenses, and make difficult trade-offs, which increase cognitive load. If there is a correlation between poverty and cognitive load, the results of this paper may add to our understanding of "poverty traps". The different reactions in the gain and loss domains are important insights if we want to induce certain discounting behaviors by framing the payoffs differently to be above or below the prior.

2 The Model

2.1 The binary case in Gabaix-Laibson (2017)

Consider an agent at time zero, who must choose between two rewards: *Early* at date, $t \geq 0$ and *Late* at date, $t + \tau > t$. The agent doesn't know the true value of *Early* reward u_t and *Late* reward $u_{t+\tau}$, but can mentally generate unbiased simulation s_t for the value of the early reward and $s_{t+\tau}$ for the late reward:

$$\begin{aligned} s_t &= u_t + \epsilon_t \\ s_{t+\tau} &= u_{t+\tau} + \epsilon_{t+\tau}. \end{aligned} \tag{1}$$

Here ϵ_t is the simulation noise associated with the *Early* reward and $\epsilon_{t+\tau}$ is that of the *Late* reward.

Intuitively, when an event is further in time, the harder the simulation, so we assume that the variance of the simulation noise increases in time, i.e.,

$$var(\epsilon_t) < var(\epsilon_{t+\tau})$$

The agents in the model combine Bayesian priors (a Gaussian density with mean μ and variance σ_u^2) with the signals s_t and $s_{t+\tau}$ to generate a Bayesian posterior.

$$u \sim N(\mu, \sigma_u^2) \tag{2}$$

The resulting Bayesian posterior distribution by combining the prior (4) and signal s_t is:

$$u_t \sim N\Big(\mu + D(t)(s_t - \mu), (1 - D(t))\sigma_u^2\Big), \tag{3}$$

where

$$D(t) = \frac{1}{1 + \frac{\sigma_{\epsilon_t}^2}{\sigma_u^2}} \tag{4}$$

is the as-if discount function, and the variance of her simulation noise is $\sigma_{\epsilon_t}^2$.

We see from (4) that as-if discount rate $D(t)$ is decreasing in the variance of the simulation noise $\sigma_{\epsilon_t}^2$. Comparing (2) and (3), we also see that a decrease $D(t)$ leads to a posterior distribution (3) that is closer to the prior distribution (2). Thus, the model predicts that an increase in the variance of simulation noise causes agents to form posteriors that are closer to their priors. In other words, if all future rewards are above priors, i.e., in the gain domain, these rewards will appear closer to prior and thus not as good; on the other hand, if all future rewards are below priors, i.e., in the loss domain, these rewards will appear not as bad. Therefore, we deduct from the model that agents should be more impatient gain domain than in the loss domain.

2.2 Cognitive Load

Gabaix & Laibson (2017) predict that cognitive load reduces an agent's ability to forecast accurately, leading to more discounting. In this paper, we formally introduce cognitive load to the original model and investigate its differential effect in the gain and loss domains.

Consider an agent under high cognitive load and the same agent under low cognitive load. We denote the variance of the simulation noise of an event at time t of the high load condition to be $\sigma_{\epsilon_{th}}^2$, and that of the low load condition to be $\sigma_{\epsilon_{tl}}^2$.

We assume an increase in cognitive load leads to an increase in the variance of simulation noise. This is built on the theory that cognitive capacity is a limited resource (Mani et al., 2013; Mullainathan et al., 2013). Cognitive load manipulation takes up such limited bandwidth, leading to decreased capacity for other tasks.

$$\sigma_{\epsilon_{th}}^2 > \sigma_{\epsilon_{tl}}^2 \tag{5}$$

We calculate the as-if discount rate for the high and low conditions using (4), and denote the as-if discount rate for an event at time t under high cognitive load as $D(t)_h$, and that under low cognitive load as $D(t)_l$. We have,

$$D(t)_h = \frac{1}{1 + \frac{\sigma_{\epsilon_{th}}^2}{\sigma_u^2}} < D(t)_l = \frac{1}{1 + \frac{\sigma_{\epsilon_{tl}}^2}{\sigma_u^2}} \tag{6}$$

Thus, the model predicts that an increased cognitive load leads to a lower as-if discount rate

(6) , and thus a posterior distribution that is closer to the priors ((2) & (3)). Recalling from the last section the predicted *difference* in the gain and loss domains due to the mechanism that subjects form posteriors that are closer to their priors, we hypothesize that, with the same mechanism, increased cognitive load exacerbates such *difference* and has a differential effect in the gain and loss domains, specifically, it should leads to even higher discounting in the gain domain, and lower discounting in the loss domain.

3 The Experiment

3.1 Hypotheses

This paper will report the results of an experiment designed to test the above predictions. More precisely, the hypotheses driving the experiment are:

Hypothesis 0 (H0): An agent is more impatient in the gain domain than in the loss domain. Due to simulation noise, she views future gain outcomes to appear not as good and loss outcomes to appear not as bad.

Hypothesis 1 (H1): Cognitive load has a positive differential effect on discounting in the gain compared to that in the loss domain, specifically:

- H1.1: If all expected outcomes are above prior, i.e., the gain domain, increased cognitive load makes an agent more impatient. She adopts higher discounting rate and views future outcomes to appear not as good.

- H1.2: If all expected outcomes are below prior, i.e., the loss domain, increased cognitive load makes an agent more patient. She adopts lower discounting rate and views future outcomes to appear not as bad.

Hypothesis 2 (H2): Higher cognitive load causes higher variance in the posterior distribution, which induces more monotonicity violations, i.e., multiple-switching behavior indicating a reverse of preference when the late payment is strictly increasing/decreasing.

3.2 Experimental Design

The main focus of the experiment is to test the difference between discounting in the gain and loss domain, and the differential effects of cognitive load on discounting in each domain. Table 2 shows the 2 x 2 design of the experiment: two types of time preference question (gains and losses) and two levels of cognitive load (low and high). The former will be manipulated within subject, the latter between subject.

Table 1: 2x2 Experimental Design

	High Cognitive Load (97 Subjects)	Low Cognitive Load (103 Subjects)
Loss (8 questions)	**Condition 1** (N=776)	**Condition 2** (N=824)
Gain (8 questions)	**Condition 3** (N=776)	**Condition 4** (N=824)

Across subjects

Within subjects

The experiment was designed in *Qualtrics* software and Javascript. We conducted the experiment in March 2021, with participants recruited using the *Amazon Mechanical Turk (Mturk)* platform. Subjects were naïve to the main purpose of the study. All subjects provided informed consent. The experiment takes on average about 15 minutes, including instructions and payment.

200 subjects were recruited according to the following power calculation. Within the gain and loss domains, respectively, we have a one-sided hypothesis. Assuming a pooled standard deviation of 0.289[1], an 80% power, a 95% confidence interval, and an MDES of 10%, we have

$$N = \frac{4\sigma^2(t_{0.95} + t_{0.8})^2}{D^2} \approx 208$$

The experiment consists of two tasks, one of which measures time preference, and the other one manipulates cognitive load.

[1]In Deck & Jahedi's (2015) experiment on cognitive load's effects on inter-temporal choice, the standard error for OLS was 0.032 and 0.026 for the 348 observations for high and low cognitive load. The pooled standard deviation for choosing the Early option was 0.289. The standard deviation of the choosing the early option across subjects is expected to be similar in this experiment.

3.2.1 Decision Task

In each round, participants are presented a binary choice, where they must choose irreversibly between two rewards: *Early* and *Late*. Participants see 1 decision task per round, either a gain domain question, or a loss domain question.

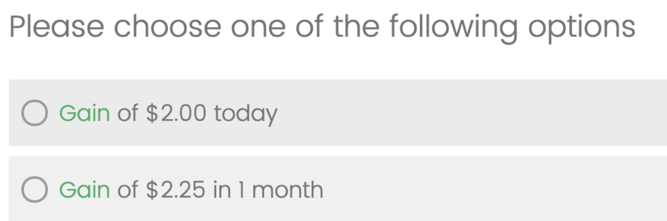

Figure 1. Example of a decision task in the gain domain

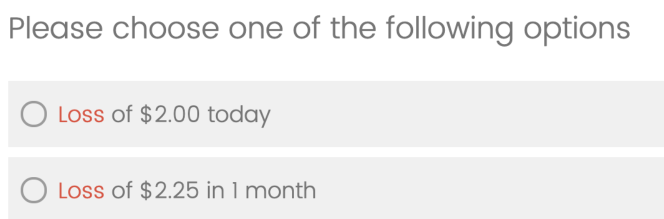

Figure 2. Example of a decision task in the gain domain

Participants will always get **two** default bonuses today **and** in 1 month, which controls for transfer costs. The gains and losses presented in the decision tasks are amounts that will be added or subtracted to the default base bonuses.

Each *Early* option includes an amount X_e which, if selected, will be added/subtracted from the \$3 default bonus today, and the \$3 default bonus in 1 month will remain unchanged, i.e., the participant will receive $\$3 + X_e$ today and \$3 in 1 month. Each Late option includes an amount X_l, which, if selected, will be added/subtracted from the \$3 default reward in 1 month, while the \$3 default bonus today will remain unchanged, i.e., the participant will receive \$3 today and $\$3 + X_l$ in 1 month.

Participants see one decision question (either a gain question or a loss question) for each round i. There are 8 gain domain rounds in which all X_e and X_l are positive amounts, where we denote the early and late rewards X_{eg} and X_{lg}. For each gain domain question, X_{egi} is \$2 and X_{lgi} is randomly selected, without repetition, from a list of dollar amounts with minimum of \$1.25 and maximum of \$3 with constant steps in quarters, capturing implied discount rates that are lower and higher than 1.

$$X_{egi} = 2,$$

$$X_{lgi} \in \{1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00\}.$$

Similarly, there are 8 loss domain rounds where we denote the early and late rewards X_{el} and X_{ll}. For each loss domain round,X_{eli} is -\$2 and X_{lli} is randomly selected, without repetition, from a list of dollar amounts with minimum of -\$3 and maximum of -\$1.25 with constant steps in quarters, capturing implied discount rates that are lower and higher than 1.

$$X_{eli} = -2,$$

$$X_{lli} \in \{-1.25, -1.50, -1.75, -2.00, -2.25, -2.50, -2.75, -3.00\}.$$

The questions are symmetrical in gain and loss domains, and the average payoff is zero, which is intended to maintain an average prior distribution with the mean of zero. In addition, the sequence of the questions is randomized with gain and loss questions appearing in alternate for the same purpose. The delay between *Early* and *Late* is chosen to be 1 month based on existing experimental literature on discounting (Loewenstein & Prelec, 1992; Weber et al., 2007) and the average payment amount in this experiment. In addition, we take into consideration that the payment on MTurk doesn't transfer directly to Worker's bank account but rather to their MTurk account, from where the workers can transfer to their Amazon account, workers might be more indifferent to shorter delays than 1 month because they likely already have a delay in transferring money to their accounts.

3.2.2 Cognitive Load Task

In each round, in addition to one decision task, the participants see one cognitive load task. Each cognitive task will be one of the following 3 types: numerical Stroop questions, color Stroop questions, and Flanker test questions.

The **Numerical Stroop Test** consists of numbers that are written in big or small font sizes. Subjects are asked to choose which number has a higher value regardless of the font sizes. The high cognitive group sees numbers in different font sizes (Figure 3), whereas the low cognitive group only sees 3-digit numbers in the same font sizes (Figure 4).

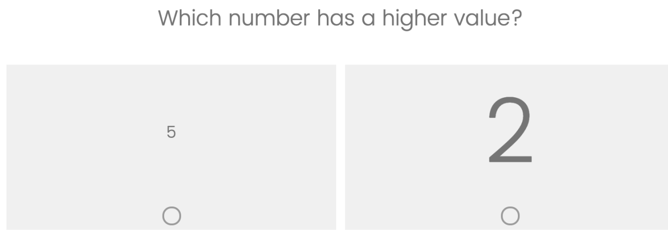

Figure 3. Example of a numerical Stroop task for the high cognitive load treatment

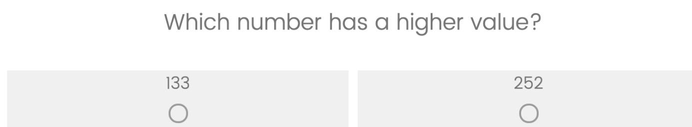

Figure 4. Example of a numerical Stroop task for the low cognitive load treatment

The **Color Stroop Test** consists of words written in either red, blue, yellow, or green. Subjects are screened for normal color vision before the experiment begins. They asked to choose what color is the word written in regardless of what the word means. The high cognitive load group sees words that are written in colors that are different from what the words mean (Figure 5), and the low cognitive load group only sees words that are written in colors that are same as what the words mean (Figure 6).

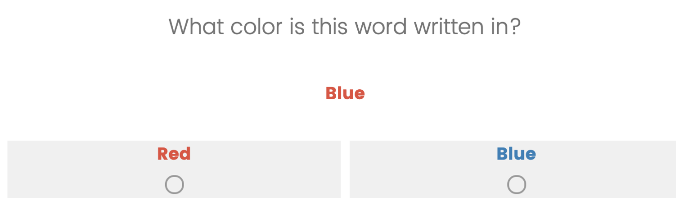

Figure 5. Example of a color Stroop task for the high cognitive load treatment

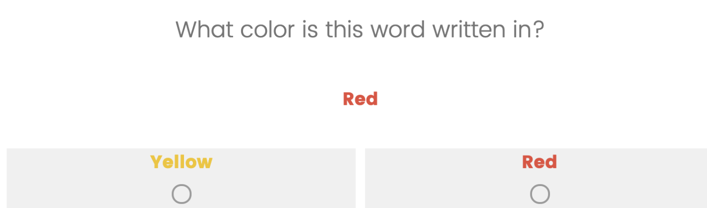

Figure 6. Example of a color Stroop task for the low cognitive load treatment

In each round of the **Flanker Test**, participants see 5 arrows on the screen, and they should only focus on the third (middle) arrow. The low cognitive load group only sees red arrows, and they need to select the direction that has the same direction as the middle arrow. In addition to the red arrows, the high cognitive load group sees blue arrows in some rounds: if the arrows are in red, they need to select the direction that has the same direction as the middle arrow, similar to the low load group. However, if the arrows are in blue, they need to select the direction that has the opposite direction as the middle arrow.

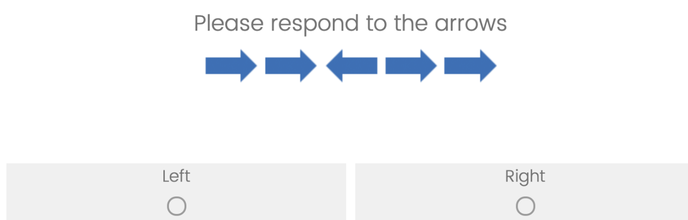

Figure 7. Example of a Flanker test task that may only appear in the high load treatment

Figure 8. Example of a Flanker test task that may appear in both high & low load treatments

These tasks were previously used in psychology and behavioral economics literature to manipulate cognitive and working memory load (Lavie et al. 2004, Conway et al. 2005). The sequence of the 3 parts, as well as the sequence of questions within each part are both randomized. All of the three type of cognitive tasks serve the same function to manipulate cognitive load, the variation aims to make the experiment less repetitive and more interesting to the participants.

The participants will be randomly assigned into high and low cognitive load groups. The only difference between the 2 groups is the cognitive load questions that they see. In this experiment, the decision questions as well as the sequence and timing per round are the same, as the following.

3.2.3 Sequence and Time Limit

Frequently in previous experiments that were conducted to test the effects of cognitive load on inter-temporal choice, tasks that require cognitive control are simultaneously performed with the decision tasks. Thus, in this experiment, the sequence and time limit by which the 2 questions will appear in each round is as follows:

1. The cognitive load task stimuli will first appear for 1 second, during which subjects do NOT need to make a choice, and will not be shown any options to do so
2. Then, subjects will answer a decision question within 4 seconds
3. Then, subjects will see a focus page before the cognitive load question reappears
4. Finally, cognitive load question reappears and subjects should answer within 1 second

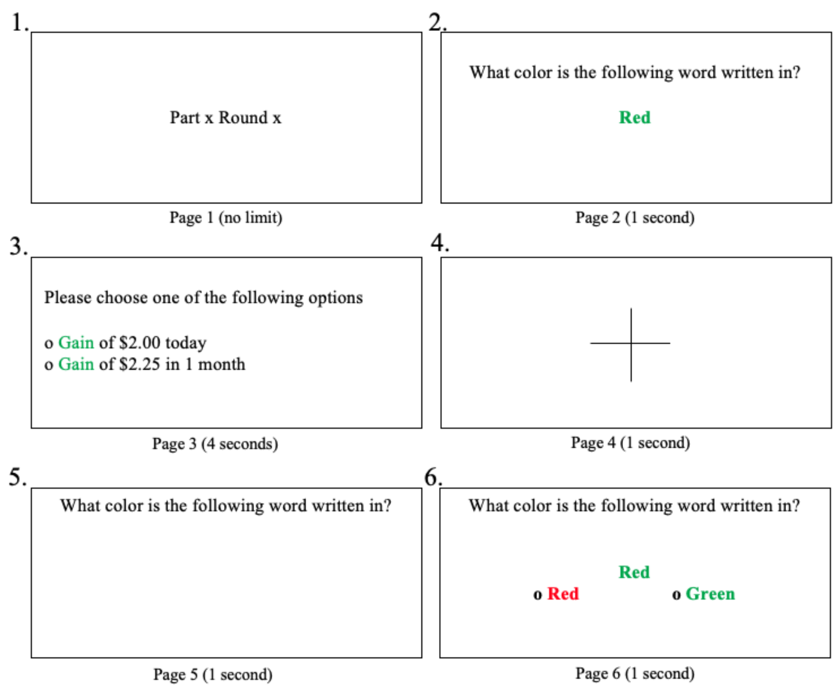

Figure 9. Sequence of Tasks in an Example Round

Imposing the strict time limits and having the Task A questions appear twice are designed to require subjects' processing/memorization of the cognitive load stimuli during the decision-making process for cognitive load manipulation.

3.2.4 Incentivization

In order to incentivize subjects to take the cognitive load tasks seriously so that the treatment effectively increases their cognitive load, there is a 60% accuracy threshold on cognitive load task accuracy in order to get the bonuses: If less than 60% of all cognitive load tasks are correctly answered, subjects will only receive a $1 participation upon finishing the study. If at least 60% of all cognitive load tasks are correctly answered, subjects will receive 1) a $3 default bonus upon finishing the study; 2) another $3 default bonus in 1 month; and 3) an additional bonus up to $3 of gains or losses, either today or in 1 month.

The additional bonus is based on the subjects' choices in the decision task: one round will be randomly selected by the computer, and they will receive their chosen amount and payment time option for that round.

The participants will have 2 practice rounds for each of the 3 parts of the experiment, where the payoffs won't be considered as part of the final reward. Their final payment, including participation payment and bonus, is a minimum of $1 and a maximum of $9, and the payment will be processed either upon completion of the study or in 1 month based on their answer for the randomly selected trial. Money earned will be transferred to their *Amazon Mechanical Turk* account.

4 Experimental Results

We analyze the frequency of choosing the early option in different conditions to test our hypotheses, but before that, we first analyzed the difference in cognitive load task accuracy in each cognitive load groups to establish that there is, indeed, a difference between treatments.

Table 2 shows the OLS results that compare the accuracy of cognitive load task answers for each treatment. We see the high cognitive load group performed significantly worse than the low load group (p=0.002), with an average of ∼83% compared to ∼90% . We confirm that the cognitive load manipulation is successful in making the task more difficult for the high load group. However, we note the high load group still performed relatively well, so future experiments may consider to further increase the difficulty in the high load group to induce potentially more significant results.

Table 2: Accuracy in cognitive load tasks

	Dependent variable:
	accuracy
high_load	−7.635
	(2.377)
	$p = 0.002$
Constant	90.109
	(1.655)
	$p = 0.000$
Observations	200
R^2	0.050
Adjusted R^2	0.045
Residual Std. Error	16.798 (df = 198)
F Statistic	10.320*** (df = 1; 198)

4.1 Summary Statistics

Figure 10 presents the main results of the experiment, i.e., the frequency of early choice for all 4 treatments. We expect from H0 that the frequency of choosing early is higher in the gain domain than the loss domain for both cognitive load groups. We also expect from the H1, H1.1, and H1.2 that cognitive load should increase impatience in the gain domain more than the loss domain. We see in Figure 10 that the observation of the experimental results are consistent with both of these predictions. Next, we formally test each of our hypotheses.

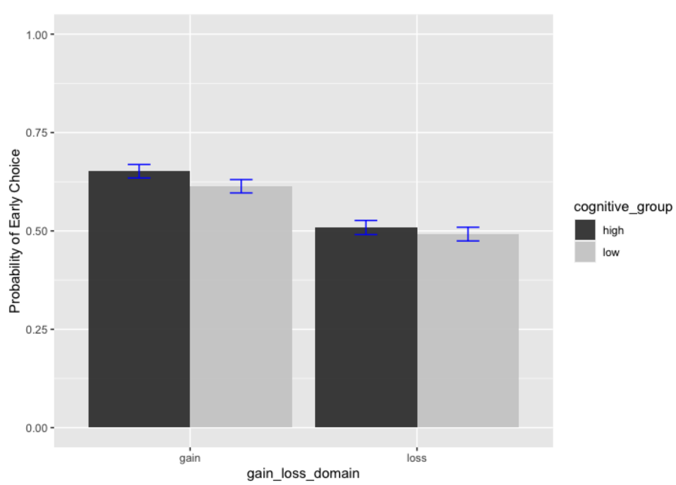

Figure 10. Summary Statistics

4.2 Testing H0

H0 predicts that an agent is more impatient in the gain domain than in the loss domain. Thus, within each of the two cognitive load treatments, we expect to see an increase in discounting in gain domain compared to loss domain. Table 3 reports the OLS and logit regression results across all 4 treatments (high & low cognitive load, gain & loss domain). The regressions are run with an interaction between the high/low cognitive load group and the gain/loss domain dummies. We control for the categorical data of late payment amount/early payment amount ratio, the round in which each observation is made in order to control for fatigue, and the individual fixed effects.

Table 3: Frequency of Early Choice - All 4 Treatments

	Dependent variable:	
	early_choice	
	OLS	*logistic*
	(1)	(2)
high_load	0.014	0.060
	(0.025)	(0.108)
	$p = 0.577$	$p = 0.581$
gain_domain	0.119	0.512
	(0.025)	(0.106)
	$p = 0.00001$	$p = 0.00001$
round	−0.003	−0.013
	(0.002)	(0.008)
	$p = 0.124$	$p = 0.103$
high_load:gain_domain	0.023	0.109
	(0.035)	(0.152)
	$p = 0.519$	$p = 0.477$
Constant	0.442	−0.250
	(0.093)	(0.392)
	$p = 0.00001$	$p = 0.524$
Observations	3,038	3,038
R^2	0.069	
Adjusted R^2	0.033	
Log Likelihood		-1,966.625
Akaike Inf. Crit.		4,161.251
Residual Std. Error	0.487 (df = 2924)	
F Statistic	1.923*** (df = 113; 2924)	

The coefficient associated with gain_domain is an estimate for the effect of gain domain under low cognitive load. The significant, positive effect supports H0. In addition, we analyze the sum of the coefficients associated with gain_domain and the interaction term, which is an estimate for the effect of gain domain under high cognitive load. Again, we see a significant, positive effect, further supporting H0 that being in the gain domain increases impatience significantly in both cognitive load treatments.

4.3 Testing H1

The **main hypothesis** that this paper investigates is that cognitive load has a positive *differential* effect on discounting in the gain compared to that in the loss domain.

Figures 11 and 12 show the change of frequency of choosing the early choice (y-axis) across various late payment amounts (x-axis). Figure 11 compares the difference between the two cognitive load groups in the gain domain, and Figure 12 compares that in the loss domain. The red point at approximately (x=3.00, y=0.2) in Figure 11, for example, means that when choosing between an early payment of $2.00 and a late payment of $3.00, the frequency of choosing the early option in the low cognitive load group is 0.2.

Figure 11 shows that the high cognitive load group is consistently choosing the early option more frequently than the low cognitive load group, especially when the late payment is higher than the early payment of $2, and the positive effect of cognitive load on impatience becomes increasingly significant as the late payment increases.

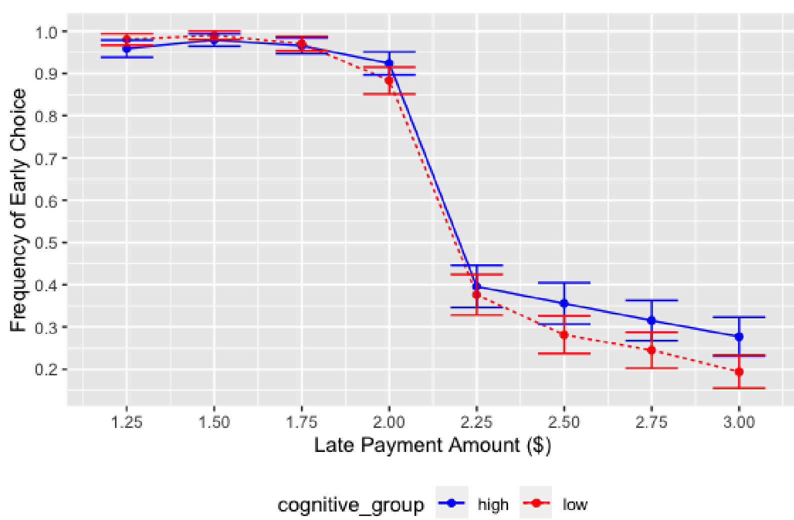

Figure 11. Frequency of Early Choice in the Gain Domain

In the loss domain, theory predicts that higher cognitive load makes people less impatient, so we expect the red line to be above the blue line. However, Figure 12 shows that the overall difference is small and does not confirm the prediction. Higher cognitive load marginally increases impatience in the loss domain when the late payment amount is a smaller loss than the early loss of -$2. However, such increase appears to be less salient than in the gain domain, suggesting that higher cognitive load increases discounting more in the gain domain than in the loss domain. This is along the same direction as theory.

Interestingly, note that the differential effect of cognitive load in each group becomes more significant and in line with theory when the absolute values of the late payments are large. Specifically, for late payment=-$3, high cognitive load group has a discount rate that is **below** the low load group, choosing the Early Choice less frequently. On the other hand, in the gain domain, as previously mentioned, high cognitive load group has a discount rate that is increasingly **above** the low load group as the late payment increases to $3. Further experiments with more flexible budget could study if the trends continue into even larger absolute amount of late payments, e.g. $3.25, $3.5, $3.75, by increasing the default bonuses to more than $3.

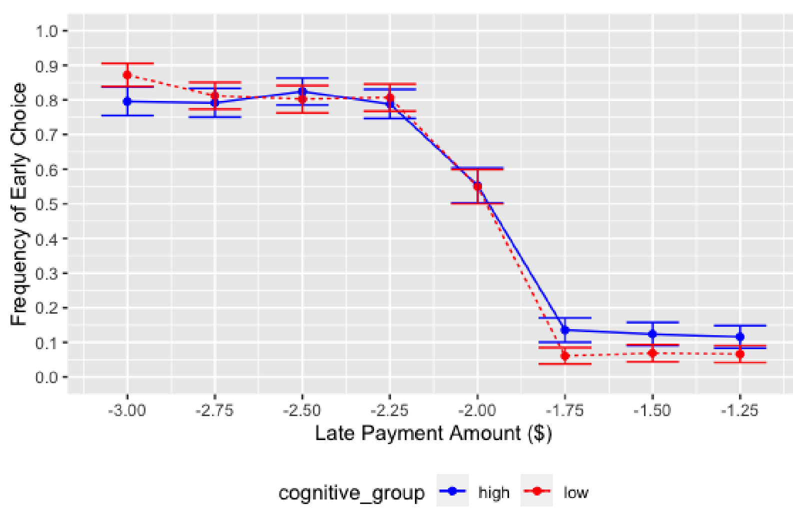

Figure 12. Frequency of Early Choice in the Loss Domain

To formally test the differential effect in H1, we analyze the same regressions given in Table 3, focusing on the coefficient associated with the interaction term, that is the *differential* effect of cognitive load in gain versus loss domains. Precisely, it is an estimate for how much higher/lower is the difference between high and low load in the gain domain than such difference in the low domain, i.e.,

$$\begin{aligned}\Big(&Prob(Early\_choice = 1|Gain\_domain\&High\_load)\\ &\qquad - Prob(Early\_choice = 1|Gain\_domain\&Low\_load)\Big)\\ &\qquad - \Big(Prob(Early\_choice = 1|Loss\_domain\&High\_load)\\ &\qquad\qquad - Prob(Early\_choice = 1|Loss\_domain\&Low\_load)\Big) \quad (7)\end{aligned}$$

The positive sign associated with this interaction term is consistent with theory's prediction that the difference between high and low load in the gain domain is higher than such difference in the low domain. However, we do not find such differential effect to be significant to support H1. It is possible that the sample size is not large enough or the difference in cognitive load treatments is not significant enough, and future experiments might show a significant result.

4.3.1 Testing H1.1 & H1.2

Next, we separate the gain and loss domains and investigate the effects of cognitive load in each domain independently to better understand each of the two effects that construct the differential effect analyzed above. We recall the the sub-hypothesis H1.1 that cognitive load increases discounting in the gain domain, and H1.2 that cognitive load decreases discounting in the loss domain.

Table 4 reports the OLS results of the cognitive load's effect on the frequency of early choice in the gain domain, controlling for the categorical data of the ratio of late and early payment amounts, and the round for fatigue. The standard error is clustered on the individual level.

The coefficient associated with gain_domain is an estimate of

$$\begin{aligned}&Prob(Early\_choice = 1|Gain\_domain\&High\_load)\\ &\qquad - Prob(Early\_choice = 1|Gain\_domain\&Low\_load) \quad (8)\end{aligned}$$

In line with theory, we find a marginally significant, positive effect of higher cognitive load on discounting, supporting H1.1 that in the gain domain, increased cognitive load makes an agent **more impatient**. She adopts **higher** discounting rate and views future outcomes to appear not as good.

Table 4: Effect of Cognitive Load in the Gain Domain

	Dependent variable:
high_load	0.030
	(0.018)
	$p = 0.093$
round	−0.004
	(0.002)
	$p = 0.023$
Constant	0.993
	(0.023)
	$p = 0.000$

Similarly, Table 5 reports the OLS results of the cognitive load's effect on the frequency of early choice in the loss domain. Here, the coefficient associated with gain_domain is an estimate of

$$Prob(Early\_choice = 1|Loss\_domain\&High\_load) \\ - Prob(Early\_choice = 1|Loss\_domain\&Low\_load) \quad (9)$$

Thus, we do not find a significant effect of cognitive load on discounting in the loss domain. We cannot reject the null hypothesis that when choices are in the loss domain, the effects of high and low cognitive load are the same. However, what is interesting about the above results for H1.1 and H1.2 is that the difference in these observation is along the same direction as theory, which predicts that the effect of increasing impatience due to cognitive load is lower in the loss domain than in the gain domain.

Table 5: Effect of Cognitive Load in the Loss Domain

	Dependent variable:
high_load	0.013
	(0.019)
	$p = 0.514$
round	−0.001
	(0.002)
	$p = 0.514$
Constant	0.097
	(0.028)
	$p = 0.001$

4.4 Testing H2

Finally, we hypothesized that the high cognitive load group exhibits more multiple-switching behavior due to a higher variance in posterior distribution due to increased variance in simulation noise. Figure 13 reports the multiple-switching behavior in each cognitive load groups. In line with theory, the low cognitive load group shows a higher frequency of switching exactly once within each gain/loss domain, and the higher cognitive load group exhibits more extreme violations of monotonicity, switching as many as 5 and 6 times.

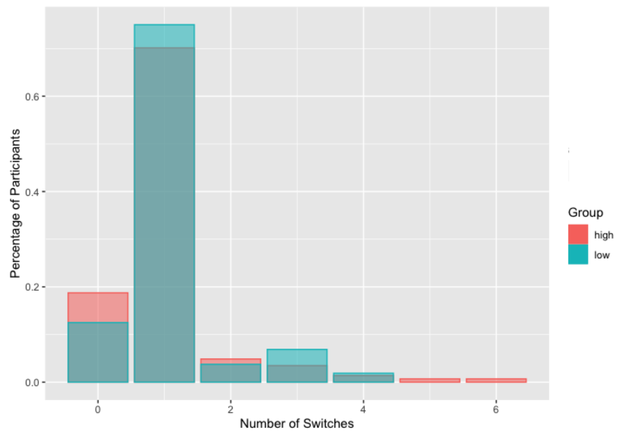

Figure 13. Monotonicity Violations

However, the message from Figure 13 is muted in the OLS regression reported in Table 6, where we regress the violation dummy which that takes the value of 1 if the switch is higher than 1, on cognitive load group. The difference in multiple-switching behavior is not significant between the two cognitive load groups. This might be because the sample size is not large enough, and further analysis that captures the data in more details such as the distance between switches might show more significant results.

Table 6: Monotonicity Violation

	Dependent variable:
	violation
Grouplow	0.014
	(0.037)
	$p = 0.710$
Constant	0.111
	(0.027)
	$p = 0.0001$
Observations	304
R^2	0.0005
Adjusted R^2	-0.003
Residual Std. Error	0.324 (df = 302)
F Statistic	0.139 (df = 1; 302)

5 Conclusions

This project presents the results of an experiment testing the recent theories on discounting being a perceptual bias in simulating future events, rather than a reflection of an agent's time-preference, specifically, it tests the differential effects of cognitive load in the gain and loss domains. As predicted by theory, the results show that people are more impatient in the gain domain than the loss domain, and such difference is exacerbated by higher cognitive load. Specifically, cognitive load increases impatience in the gain domain, but the effect of cognitive load on impatience in the loss domain is not significant. Although the differential effect is muted in the OLS and logit regressions, the positive sign associated with this interaction term is consistent with theory's prediction that the difference between high and low load in the gain domain is higher than such difference in the low domain.

By design and as shown in results, the experiment creates a difference between the cognitive load treatments, but future experiments should consider further increase the difference in cognitive load task difficulty for more significant effects. In addition, future study with more flexible budget should include larger absolute amount of late payments, which should induce more significant results regarding the differential effect if the trend we see in this experiment continues into larger absolute late payment amounts.

6 References

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A Appendix A

Figure 14 show the difference in frequency of early choice in the gain domain compared to the loss domain in for the high cognitive load group. For example, the blue dot at approximately (top x-axis =2.25, y-axis =0.4) means that the frequency of choosing the early reward of $2 when the late reward is $2.25 is 0.4 for the high cognitive load group; the black dot at approximately (bottom x-axis =-2.50, y-axis =0.8) means that the frequency of choosing the early loss of -$2 when the late loss is -$2.50 is 0.8 for the high cognitive load group

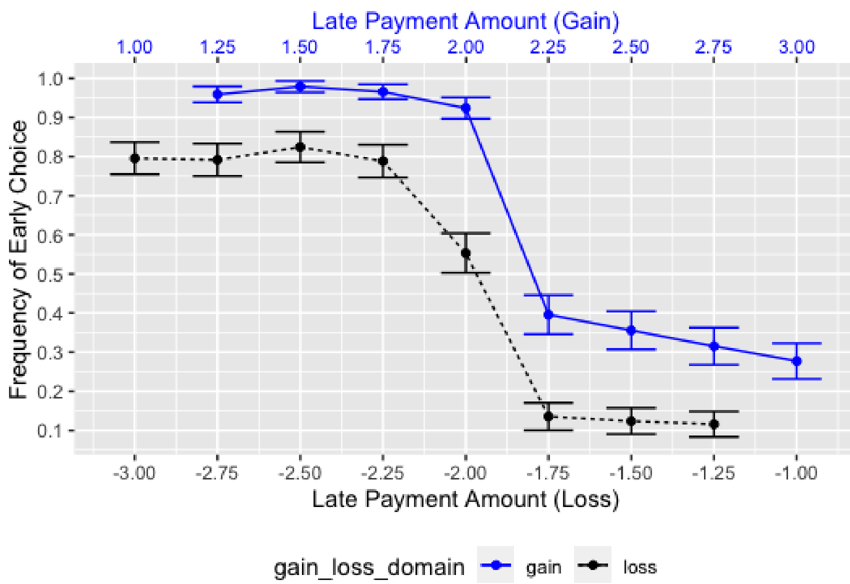


Figure 14. Frequency if Early Choice in the High Cognitive Load Group

Similarly, Figure 15 show the same comparison for the low cognitive load group. As discussed in text, consistent with H0, we see that being in the gain domain increases impatience significantly for both the high and low cognitive load groups.

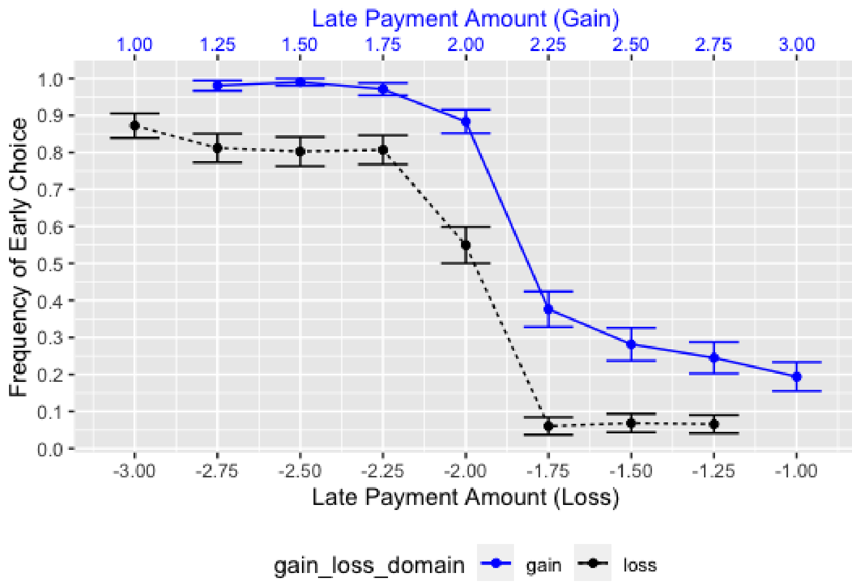


Figure 15. Frequency if Early Choice in the Low Cognitive Load Group

B Appendix B

Experimental Instructions

We report in Appendix B the instructions for a representative experiment with high cognitive load treatment. As discussed in the text, the experiment was posted on *MTurk*.

Please choose the color of the shapes below.

As stated in the HIT landing page, please do not participate in the experiment if you have difficulties with color vision.

<u>Please choose carefully: you won't be able to continue to start the experiment if they're not answered correctly in one try</u>.

Red	Blue	Yellow	Green
○	○	○	○

Red	Blue	Yellow	Green
○	○	○	○

Red	Blue	Yellow	Green
○	○	○	○

Red	Blue	Yellow	Green
○	○	○	○

General Instructions

Thank you for participating in this experiment on intertemporal choice. The experiment will last approximately <u>15 minutes</u>.

You will see 16 rounds of questions, in each round, you will answer 2 questions concurrently, and you'll be asked to respond quickly.

They're called Task A and Task B questions.

- <u>Task A questions involve time-sensitive cognitive tasks. There are right and wrong answers.</u>
- <u>Task B questions involve choosing between monetary payments at different dates. There are no right or wrong answers. You should choose the option you genuinely prefer.</u>

General Instructions

If **at least** 60% of all Task A questions are correctly answered, you will receive a $3 default bonus upon finishing the study, another $3 default bonus in 1 month, and an additional up to $3 of gains or losses, either today or in 1 month.

If **less than** 60% of all Task A questions are correctly answered, you will only receive a $1 participation upon finishing the study.

The additional bonus is based on your choices in Task B: one round will be randomly selected by the computer, and you will receive your chosen amount and payment period for that round. Therefore, you should take each question seriously.

The final payment will range between $1 and $9. Money earned will be transferred to your Amazon Mechanical Turk account.

Comprehension Question

What do you need to do in order to get the bonus?

- ○ I always get it
- ○ I get it only if 60% or more of all Task A questions are correctly answered
- ○ I get it only if 100% of all Task A questions are correctly answered

---

General Instructions

For each Task B question, you will see 2 choices between bonuses at different dates.

Please choose one of the following options

- ○ Gain of $2.00 today
- ○ Gain of $2.25 in 1 month

The dollar amount of the bonuses will change for each round.

Each Task B question will disappear after **4 seconds**.

If you fail to make a choice within the time limit, you will automatically move on to the next round. If the round where you did not make a choice is selected for the final payment, **you will automatically lose the default bonus of $3 in 1 month**. Therefore, you should try to make a selection within the time limit.

You can press the up arrow key to choose the top option, and the down arrow key to choose the bottom option.

General Instructions

There is an equal amount of Task B questions throughout the experiment that you may **gain or lose** some money from your base bonuses.

Please see below an example gain question.

Please choose one of the following options

- ◯ Gain of $2.00 today
- ◯ Gain of $2.25 in 1 month

If this question is selected for payment

- If you choose the top option, your default bonus of $3 today will be increased by $2 to $5 ($3+$2), and your default bonus of $3 in 1 month will remain unchanged.
- If you choose the bottom option, your default bonus of $3 today will be unchanged, and your default bonus of $3 in 1 month will be increased by $2.25 to $5.25 ($3+$2.25).

General Instructions

Please see below an example loss question.

Please choose one of the following options

- ◯ Loss of $2.00 today
- ◯ Loss of $2.25 in 1 month

If this question is selected for payment

- If you choose the top option, your default bonus of $3 today will be reduced by $2 to $1 ($3-$2), and your default bonus of $3 in 1 month will remain unchanged.
- If you choose the bottom option, your default bonus of $3 today will be unchanged, and your default bonus of $3 in 1 month will be reduced by $2.25 to $0.75 ($3-$2.25).

Comprehension Question

Imagine you were shown this question, and it's selected for payment.

Please choose one of the following options

- ◯ Gain of $2.00 today
- ◯ Gain of $3.00 in 1 month

If you choose the option on the top, what do you get today and next month as your total payment?

- ◯ $2 today and $3 in 1 month
- ◯ $5 today and $3 in 1 month
- ◯ $5 today and $0 in 1 month

If you choose the option on the bottom, what do you get today and next month as your total payment?

- ◯ $0 today and $3 in 1 month
- ◯ $3 today and $3 in 1 month
- ◯ $3 today and $6 in 1 month

Part 1 Instructions

Part 1 consists of 6 rounds.

For the Task A questions in this round, you'll see a set of 5 arrows at once in either red or blue.
You should only focus on the third (middle) arrow.
If the arrows are in **red**, you should choose the **same** direction as the middle arrow.
If the arrows are in **blue**, you need to choose the **opposite** direction of the middle arrow.

Please respond to the arrows

Left	Right
◯	◯

In the example above, the correct answer is "Right". The arrows are in blue, so you should choose the opposite direction of the left middle arrow.

Part 1 Instructions

The sequence and time limit by which Task A will appear is as follows:

1. The arrows will first appear for **1 second**, during which **you are not allowed to make a choice**.
2. Then, you will answer a Task B question within a time limit of **4 seconds**.
3. Then, you will see a focus page with a cross in the middle for you to get ready to answer the Task A question.
4. Finally, Task A question will reappear and you should make your choice within **1 second** before the options disappear. If you fail to make a choice within the time limit, your answer will not be recorded as correct.

Part 1 Instructions

Please note that, in each round, you will see Task A twice, you don't need to make a choice when you see them for the first time, but you will need to make a choice the second time.

You can press the left arrow key to choose the option on the left, and the right arrow key to choose the option on the right.

During both practice and actual rounds, you can click the "next" button or press the right arrow key to proceed to the next round.

The time available for each question will be limited. Please keep your hand on the arrow keys so you can quickly respond, as shown in the picture below.

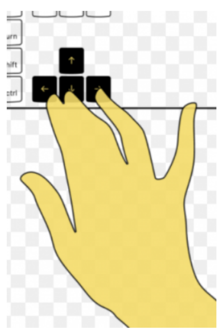


image source: https://tonsky.me/blog/cursor-keys/

Part 1 Instructions

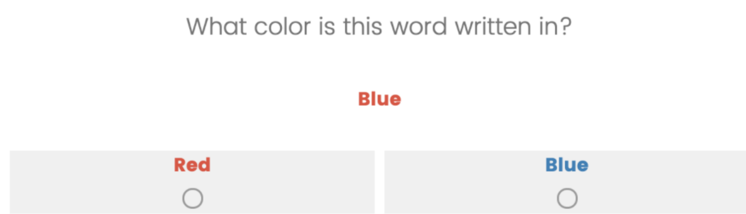
You will now play 2 practice rounds, which will not count towards your final payment.

Reminder:
If the arrows are in **red**, you should choose the **same** direction as the middle arrow.
If the arrows are in **blue**, you need to choose the **opposite** direction of the middle arrow.

Part 2 Instructions

Part 2 consists of 5 rounds.

For the Task A questions in this round, you'll see a word written in either red, blue, yellow, or green. You are asked to choose what color is the word written in regardless of what the word means.



In the example above. The correct answer would be **"Red"** because it's written in the red color, although the word says "Blue".

Be careful, sometimes the words are written in a different color than what the word says. What the word means should not matter for your choice.

Part 2 Instructions

The sequence and time limit by which Task A will appear is as follows:

1. The color words will first appear for **1 second**, during which **you are not allowed to make a choice**.
2. Then, you will answer a Task B question within a time limit of **4 seconds**.
3. Then, you will see a focus page with a cross in the middle for you to get ready to answer the Task A question.
4. Finally, Task A question will reappear and you should make your choice within **1 second** before the options disappear. If you fail to make a choice within the time limit, your answer will not be recorded as correct.

Part 2 Instructions

Please note that, in each round, you will see Task A twice, you don't need to make a choice when you see them for the first time, but you will need to make a choice the second time.

You can press the left arrow key to choose the option on the left, and the right arrow key to choose the option on the right.

During both practice and actual rounds, you can click the "next" button or press the right arrow key to proceed to the next round.

The time available for each question will be limited. Please keep your hand on the arrow keys so you can quickly respond, as shown in the picture below.

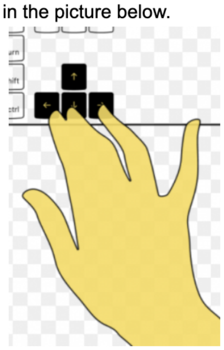
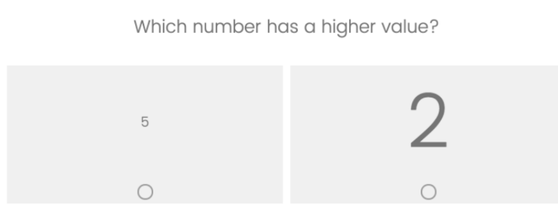


image source: https://tonsky.me/blog/cursor-keys/

Part 3 Instructions

Part 3 consists of 5 rounds.

For the Task A question in this round, you'll see 2 numbers in big or small font sizes. You are asked to choose which number **has a higher value**.



In the example above. The correct answer is 5, although the choice "2" is written in a bigger font.

Be careful, sometimes the number with a higher value might appear in smaller font size. Font sizes should not matter for your choice.

Part 3 Instructions

The sequence and time limit by which Task A will appear is as follows:

1. The numbers will first appear for **1 second**, during which **you are not allowed to make a choice**.
2. Then, you will answer a Task B question within a time limit of **4 seconds**.
3. Then, you will see a focus page with a cross in the middle for you to get ready to answer the Task A question.
4. Finally, Task A question will reappear and you should make your choice within **1 second** before the options disappear. <u>If you fail to make a choice within the time limit, your answer will not be recorded as correct.</u>

Part 3 Instructions

Please note that, in each round, you will see Task A twice, you don't need to make a choice when you see them for the first time, but you will need to make a choice the second time.

<u>You can press the left arrow key to choose the option on the left, and the right arrow key to choose the option on the right.</u>

During both practice and actual rounds, you can click the "next" button or <u>press the right arrow key</u> to proceed to the next round.

The time available for each question will be limited. Please keep your hand on the arrow keys so you can quickly respond, as shown in the picture below.

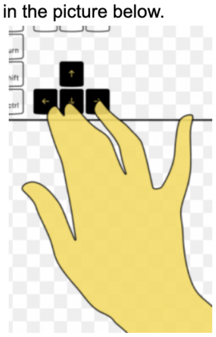


image source: https://tonsky.me/blog/cursor-keys/