Eye Movement Analysis of Time Discounting

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Abstract

This paper reveals the process of solving a time discounting task with eye tracking. There is a hypothesis that time discounting anomalies such as present bias result not from calculating present discount values of smaller-earlier and larger-later rewards, but from separately comparing attributes such as the timing of receipts and the amounts of rewards. However, our eye movement data show that the proportion of saccades when comparing each option holistically, which implies subjects calculate present discount values, is significant large and is nearly equal to that of saccades when comparing attributes separately. The saccade comparing an earlier option holistically is initially a high likelihood, and then the saccades gradually combine the saccades comparing each option holistically with the saccades comparing attributes separately at the same likelihood. Combining our experimental results and previous research, we support the attention-focusing hypothesis, which implies that when the timing of receipts is written as a delay, subjects are more prone to calculate the discounting rate than when it is written as a date.

Keywords: time discounting, eye tracking, attention-focusing hypothesis

JEL Classification Number: D81, D87

1. Introduction

Traditional economics assumes that the time discounting function is an exponential form and the time discounting rate is a constant over time. Constant discounting implies time consistent preferences with later preferences confirming earlier preferences. However, many studies show that the time discounting rate varies across conditions such as delay, interval, and magnitude of reward, and subjects are often time inconsistent (Frederick et al., 2002). These anomalies are explained by hyperbolic discounting function, which imposes declining discount rates (Laibson, 1997). In terms of psychophysics, Takahashi (2005) argued that hyperbolic discounting function is derived from exponential discounting and Weber-Fechner's Law according to which an external stimulus is scaled into a logarithmic internal representation of sensation rather than a linear internal representation. He argued that if time perception transforms into a logarithmic form, the discounting function formulates a generalized quasi-hyperbolic function even if subjects discount the future exponentially. Anomalies such as preference reversal can be explained by logarithmic time perception (Takahashi, 2009)

Although these models assume that subjects calculate present discount values for each reward, subjects may not calculate present discount values when answering a hypothetical question on time discounting: which do you prefer, a smaller-earlier reward or a larger-later reward? There is a possibility that subjects compare the attributes of each option separately, which means they choose an option after comparing the timing of receipts and the amount

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of reward separately (Scholten and Read, 2006; Kinari et al., 2009). Such a comparison method is related to the attention-focusing hypothesis (Read et al., 2005). This hypothesis is that an evaluation depends on the attention allocated to the amount of reward versus the timing of receipts, with the amount of reward relatively more attention under a date than a delay description. To understand the decision making process it is important to know what subjects focus upon when determining their choices. However, we cannot understand the decision making process and the allocation of attention by analyzing behavioral data such as “choose an earlier option” or “choose a later option.” If we use the eye tracker, we can obtain eye movement data and speculate on the attention and the process. This paper reveals the process of solving a time discounting task with eye tracking, and conjectures whether subjects calculate present discount values or compare each attribute when determining their choices.

Arielie et al. (2009) showed that subjects evaluate the amounts of reward and timing of receipts separately when solving a time discounting task by eye tracking. Their subjects were asked to choose between an earlier option and a later option by clicking on a mouse. The amount of reward for each option was displayed at the top of a screen and the timing of receipts was displayed at the bottom. They regarded vertical saccades to be calculating present discount values and horizontal saccades to be comparing each attribute. The horizontal saccade that implied comparing the timing of receipts represented about 40 percent of the total and the horizontal saccade that implied comparing the amount of rewards represented about 30 percent of the total. Therefore, they concluded that people compare each attribute to solve a time discounting task rather than calculate present discount values.

Arielie et al. (2009), however, has some drawbacks. First, it is difficult to calculate the delay from the experimental day, because the timing of receipts is written as a calendar date. There is a possibility that the proportion comparing the timing of receipts is high because of the degree of difficulty of the task. In this experiment the timing of receipts is written as the number of days to simplify calculating the delay. If horizontal saccades that implied comparing the timing of receipts remain a large proportion, it appears that the subjects do not calculate present discount values when determining their choices.

Second, Arielie et al. (2009) analyzed only the proportion of saccade in the total decision making. They did not indicate in which order subjects make a decision and did not analyze fixations. With regard to fixations, Shimojo et al. (2003) showed that when subjects were shown pairs of human faces and were instructed to decide which face was more attractive, their gaze was initially distributed evenly between the two faces, but then gradually shifted toward the face they eventually chose. They called this the “cascade effect.” We analyze dynamics of fixations and saccades and test whether there is such an effect in a time discounting task.

We also examine to what extent precise eye movement data predict a choice. Saito and Takeuchi (2009) noted that fixation time and frequency are closely related to the interest of subjects and correlate with preference. Shimojo et al. (2003) concluded that gaze is actively involved in preference formation. Their subjects tended to prefer the option of fixating longer and more frequently. This paper examines to what extent precise fixations and saccades predict a choice. It seems that if the prediction rate is high, we can elicit a more precise time discounting rate based on eye movement data.

The remainder of this paper is organized as follows: Section 2 explains experimental procedure. Section 3 shows experimental results. Section 4 concludes.

2. Experiment

2.1. Subjects

This experiment was conducted at Osaka University from October 9 to 16, 2012. The 43 subjects (20 males and 23 females; average age of 22.86) were paid 1000 yen in cash for participating in the experiment. All questions were presented with a Tobii TX300 Eye Tracker[1]. After experimental instruction, the eye tracker was calibrated for each subject and tracking was started.

2.2. Procedures

Subjects were asked a hypothetical question related to time discounting based on a questionnaire survey titled "Preference and Life Satisfaction Survey," which was conducted by the Osaka University's 21 Century Center of Excellence program. Subjects were required to choose one of two options displayed on the eye tracker screen in front of them. One was an option by which subjects receive a reward earlier and the other was an option by which subjects receive a reward later. There were three timings of receipts: today or 7 days, 90 days, or 97 days, and today or 28 days. There were nine rates of return: -10%, 0%, 5%, 15%, 50%, 102%, 205%, 510%, and 5,110%. The amount of reward for the earlier option was randomly assigned from 3,000 yen to 3,009 yen. The amount of reward for the later option was calculated by adding an amount tantamount to nine rates of return to the amount of reward of the earlier option. Figure 1 shows the experimental paradigm. Before each question was presented, a blank screen appeared for 4 seconds, then a blank screen, on which a cross sign was displayed, appeared for 1 second. If the subject preferred one option displayed to the left (right) side to the other option displayed to the right (left) side, they clicked the left (right) mouse button. There were no time restrictions on determining choice. After the subjects clicked the mouse, the blank screen appeared again and the experiment was conducted with the same paradigm. Subjects undertook 27 trials. Each condition of receiving time was randomly presented right and left to avoid sequential order bias and to obtain global maximum time discounting (Kinari et al., 2009). The positions of earlier option and later option were randomly displayed at right and left to prevent eye movement from centering on one side.

2.3. Methods

Figure 2 (left) shows the definitions of saccades. It seems that vertical saccades show that subjects compare each option when calculating present discount values of earlier (①) and later (②) option[2]. On the other hand, it seems that horizontal saccades show that subjects compare the timing of receipts (③) and the amount of rewards (④) separately. Like Arielie et al. (2009), we define diagonal saccades (⑤ and ⑥). After counting the numbers of each saccade, the proportion of the total for each saccade is used as a variable. Figure 2 (right) shows the definition of areas of interest (AOI): the timing of receipts in the earlier option (today and at 90 days), the amounts of reward in the earlier option, the timing of receipts in the later option (at 7 days, at 28 days, and at 97 days), the amount of rewards in the later option. The fixation time in each AOI is used as a variable.

3. Results

3.1. Comparison of saccades

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[1] The sampling rate of the Tobii TX300 is 300 Hz and the maximum screen resolution is 1920 × 1080 pixels.

[2] Although the earlier option and the later option were displayed randomly from side to side, we define the vertical saccade ① (②) as calculating present discount values in the earlier (later) option.

Table 1 shows the proportion of each saccade with comparing the results of Arielie et al. (2009)[3]. The proportion of vertical saccade which implies subjects calculate present discount values is almost the same as that of horizontal saccade which implies they compare attributes such as the timing of receipts and amount of reward in the total decision making. This result differs from Arielie et al. (2009) in that subjects mainly compare attributes when determining choice. These results are consistent with the attention-focusing hypothesis that using the number of days draws our attention to how long we will wait, while using calendar dates draws it to the timing of receipts and the amount of reward, because it is written as the number of days in this paper while the timing of receipts was written as a calendar date in Arielie et al. (2009).

3.2. Dynamics of saccades and fixations

Figure 2 (left) cumulatively plots the likelihood of each saccade. This figure shows that the saccade comparing an earlier option holistically is initially a high likelihood, and then the saccades gradually combine the saccade comparing each option holistically with the saccade comparing attributes separately at the same likelihood. Figure 2 (right) cumulatively plots the likelihood of fixation that is eventually chosen[4]. This figure shows that there is no cascade effect; however, the likelihood fixating on the option that is chosen is always over 50 percent. It seems that subjects initially make an educated guess as to which option they should choose. This implies that subjects make a decision following "system 1," which is a fast, automatic, effortless, and emotional process (Kahneman, 2003).

3.3. Choice prediction model

Table 2 shows the choice prediction model. This table shows that the longer subjects fixate on the timing of receipts and the amounts of reward in the earlier (later) option, the more they choose the earlier (later) option. This table also shows that fixations are more suitable than saccades for predicting choice because the correct perdition rate is higher in column 1 than in column 2, 3, and 4.The eye movement data can predict a choice about 70%.

4. Conclusion

We reveal the process of solving time discounting tasks by eye tracking and the eye movement data imply that subjects do not only calculate the present discount values but also compare attributes separately. Combining our results with Arielie et al. (2009), we can support the attention-focusing hypothesis.

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[3] Although this result cannot be compared naively to Arielie et al. (2009) because they defined saccade not as the number of saccades but as time spent from one AOI to the other AOI, it seems that either definition is comparable.

[4] Although the likelihoods of fixations and saccades until the 10 percentile are calculated, they do not plot a line because there are many missing values.

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Figure 1 Experimental paradigm [5]

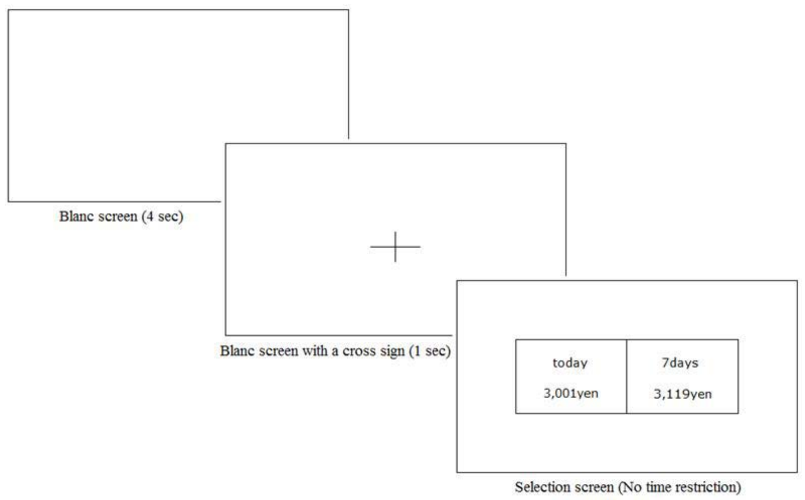
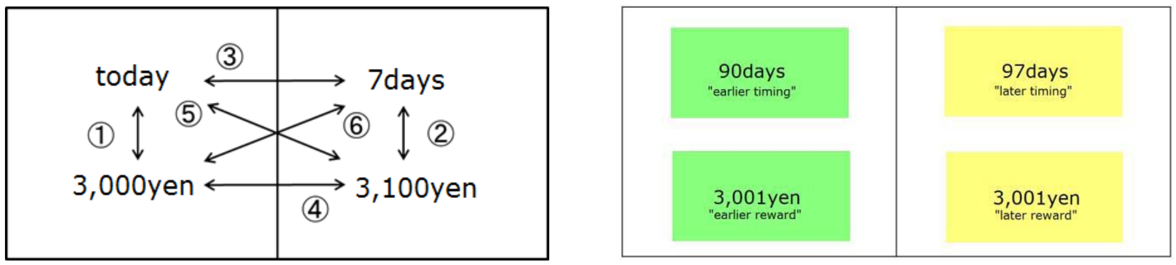


Figure 2 Definition of saccades (left) and AOIs (right)



[5] The original stimuli were written in Japanese.

Table 1 Proportion of each saccade

	① Earlier	② Later	③ Timing	④ Reward	⑤ Diagonal	⑥ Diagonal
Kurokawa and Ohtake(2013)	19.7%	25.2%	13.9%	33.4%	3.0%	5.0%
Arieli et al. （2009）	14.3%	14.0%	37.0%	28.3%	2.7%	3.7%

Figure 3 Dynamics of each saccade (left) and fixations (right) [6]

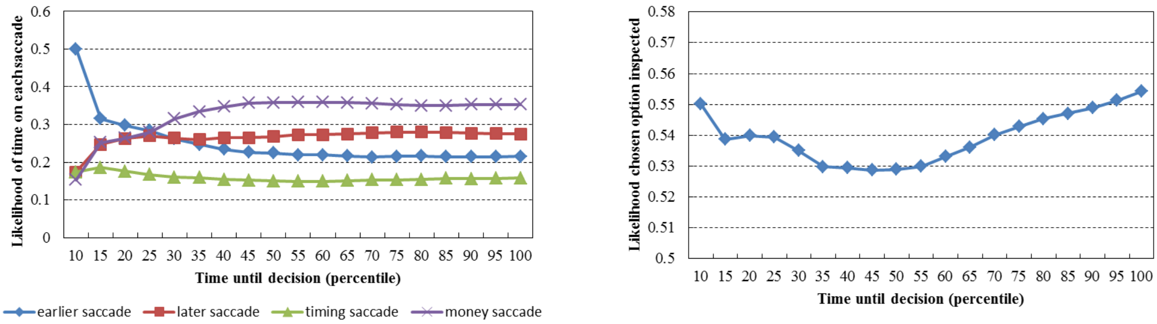


Table 2 Choice prediction model

	(1)	(2)	(3)	(4)	(5)
AOIs					
Earlier timing	3.675***				3.072***
	[0.614]				[0.723]
Earilier reward	3.834***				4.087***
	[0.564]				[0.624]
Later timing	-4.245***				-4.253***
	[0.595]				[0.673]
Later reward	-2.087***				-2.045***
	[0.441]				[0.462]
Saccade					
① Earlier		5.645***		7.418***	5.554***
		[1.021]		[1.367]	[1.579]
② Later		-2.717***		-1.690	2.925**
		[0.884]		[1.204]	[1.442]
③ Timing			0.445	0.027	2.685*
			[0.979]	[1.342]	[1.608]
④ Reward			0.446	2.624**	1.851
			[0.804]	[1.214]	[1.464]
Constant	-1.627**	-1.67***	-1.446***	-3.216***	-4.394***
	[0.633]	[0.519]	[0.531]	[1.068]	[1.323]
N	778	778	778	778	778
Log likelihood	-292.7	-345.5	-377.4	-341.9	-285.5
Correct prediction	68.6%	64.9%	64.0%	64.8%	68.9%

Note: Dependent variable: choice=1 if subjects choose the earlier option and choice=0 if subjects choose the later option. ***, **, and * indicate that the values are statistically significant at the 1%, 5%, and 10% levels, respectively. Values in parentheses are standard errors. Only the results of the random effect model are shown because it is not rejected compared to the fixed effect model by the Hausman specification test.

[6] Reaction time is normalized because it differs with each subject and each trial.