Visual Attention

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Overview

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Arieli et al. (2011)

How do people choose between lottery 1, which yields the prize $\$x_1$ with probability p_1, and lottery 2, which yields the prize $\$x_2$ with probability p_2?

$\$x_1$	$\$x_2$
With probability p_1	With probability p_2

Arieli et al. (2011)

1) **Holistic** procedures (expected utility theory): the decision maker treats the alternatives **holistically**.

- He evaluates the certainty equivalents of the alternatives and chooses the one with the higher certainty equivalent. Or, (if he is risk-neutral,) he computes the expectations of the two lotteries and chooses the one with the higher expectation.

There exists a function u such that lottery 1 is chosen if $u(x_1, p_1) > u(x_2, p_2)$.

Arieli et al. (2011)

2) **Component** procedures (bounded rationality theory): the decision maker compares prizes and probabilities **separately**.

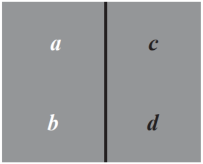
- In the case that one of the lotteries yields a larger prize with a higher probability, he will choose that lottery. Otherwise, he checks for similarity between the prizes and between the probabilities and uses that similarity to make the choice.
- For example, if the prize $\$x_1$ is much larger than the prize $\$x_2$ and the probabilities are similar, even though p_2 is (slightly) higher than p_1, he would choose lottery 1.

There exist functions f, g, and h, such that lottery 1 is chosen if $h(f(x_1, x_2), g(p_1, p_2)) > 0$.

Experimental Design

This study attempts to uncover procedures used by decision makers by following their **eye movements** while they deliberate over a choice.

- Participants were asked to choose between two alternatives, Left (L) and Right (R), by clicking on the mouse.
- Four quarters of screen: top left, top right, bottom left, and bottom right.
- Six categories of eye movements: left-vertical, right-vertical, top-horizontal, bottom-horizontal, descending-diagonal, and ascending-diagonal.



Experimental Design

- Decision makers who follow holistic procedures will show intensive vertical eye movements;
- Decision makers who follow component procedures will show intensive horizontal eye movements.

The study focuses on comparing the intensity of **horizontal and vertical eye movements** (i.e., saccades).

a	c
b	d

$\$x_1$	$\$x_2$
With probability p_1	With probability p_2

Result 1a

Decisions under risk: when the expectation calculation is relatively easy (U1 and U2), participants (slightly) tended to use a holistic procedure; when the expectation calculation is relatively difficult (U3 and U4), participants tended to use a component procedure.

The lotteries			α-values					
	L	R						
Panel A								
U1	\$3,000 0.15	\$4,000 0.11	**24%** (2%)	**23%** (2%)	18% (2%)	28% (2%)	4% (1%)	3% (1%)
U2	\$1,700 0.4	\$1,300 0.5	**20%** (2%)	**25%** (3%)	25% (2%)	23% (2%)	4% (1%)	2% (1%)
U3	\$637 0.649	\$549 0.732	17% (2%)	18% (2%)	**29%** (2%)	**30%** (2%)	2% (1%)	4% (1%)
U4	\$13,600 0.31	\$15,500 0.27	16% (2%)	18% (2%)	**33%** (2%)	**28%** (2%)	4% (1%)	2% (1%)

Result 1b

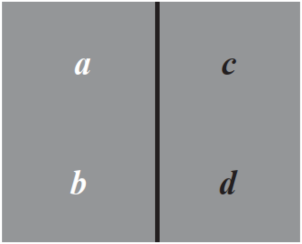
Decisions under risk: in another group of problems, a diagonal layout was used. Diagonal eye movements were used rarely in the original group of problems (U1-U4), but used intensively in this group (U5-U8), especially for the difficult ones (U6-U8).

$\$x_1$	**With probability p_2**
With probability p_1	$\$x_2$

	The lotteries		α-values					
	L	R						
Panel A								
U5	\$5,000 0.16	0.11 \$7,000	21% (2%)	21% (2%)	16% (2%)	10% (1%)	9% (1%)	23% (3%)
U6	\$2,468 0.26	0.53 \$1,234	19% (2%)	22% (2%)	16% (2%)	8% (1%)	14% (2%)	21% (3%)
U7	\$4,947 0.64	0.638 \$4,952	17% (2%)	17% (2%)	12% (2%)	8% (1%)	23% (2%)	24% (2%)
U8	\$621 0.87	0.82 \$652	16% (1%)	19% (2%)	13% (2%)	10% (1%)	19% (2%)	23% (2%)

Result 2

Difference calculations: the deliberation process of expectation calculation is multiplication. The deliberation process of difference calculation is subtraction and is more transparent than decision under risk. The participants were asked to indicate which difference is larger: $(a - b)$ or $(c - d)$.



Result 2

Difference calculations: when the difference calculation is relatively easy (D1), participants tended to use a holistic procedure; when the difference calculation is relatively difficult (D2), participants tended to use a component procedure.

The differences			α-values					
	L = a − b	R = c − d						
Panel A								
D1	251 222	187 153	38% (2%)	44% (2%)	13% (1%)	3% (1%)	2% (1%)	1% (0.3%)
D2	983,462 718,509	983,501 718,499	18% (3%)	22% (2%)	35% (3%)	20% (2%)	3% (1%)	3% (1%)

Result 2

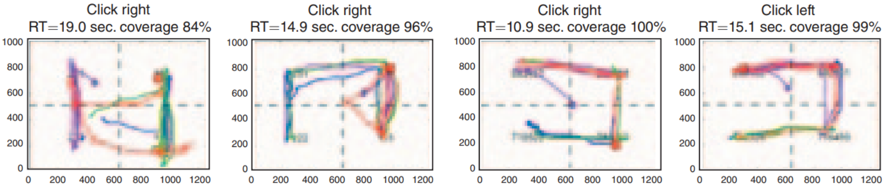


Figure: Eye movements for two participants while responding to “easy” D1 (left two boxes) and “hard” D2 (right two boxes)

Result 3

Intertemporal decisions: participants were asked to choose between receiving an amount of money on a particular date and a different amount of money on another date.

	The alternatives	
	L	*R*
Panel B		
T1	\$351.02 On 20-Jun-2009	\$348.23 On 12-Jul-2009
T2	\$467:39 On 17-Dec-2009	\$467.00 On 16-Dec-2009
T3	\$500.00 On 13-Jan-2009	\$508.00 On 13-Apr-2009

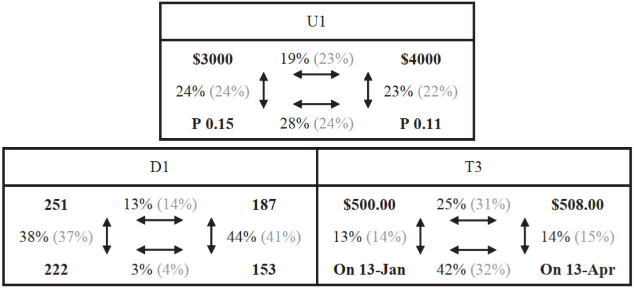
Result 3

Intertemporal decisions: about two-thirds of participants' eye movements were horizontal. They tended to use component procedures and base their intertemporal decisions on comparing monetary amounts and delivery dates separately.

	α-values					
						
Panel A						
T1	16%	15%	24%	39%	3%	4%
	(1%)	(1%)	(1%)	(2%)	(1%)	(1%)
T2	13%	14%	36%	30%	5%	2%
	(1%)	(2%)	(2%)	(2%)	(1%)	(1%)
T3	13%	14%	25%	42%	3%	2%
	(2%)	(2%)	(3%)	(2%)	(1%)	(1%)

Result 4

The use of component procedures might be correlated with the level of **difficulty** of the deliberation process involved in the decisions.



- The levels of difficulty of the deliberation processes: intertemporal decisions (T) $>$ decisions under risk (U) $>$ difference calculations (D);
- The intensities of horizontal eye movements involved in decisions: intertemporal decisions (T) $>$ decisions under risk (U) $>$ difference calculations (D).

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Wang et al. (2010)

The sender-receiver game (or "cheap talk" game): one agent has an incentive to exaggerate the truth to another agent.

- A sender learns the true state (a number S) and sends a costless message M to a receiver who then chooses an action A.
- Their payoffs depend only on the true state S and the receiver's action A so the message M is "cheap talk."
- The receiver prefers to choose an action that matches the state S, but the sender wants the receiver to choose an action closer to $S + b$.
- The bias b is a **known** bias parameter to both the sender and the receiver (the value of b is varied across rounds in the experiment).
- When $b = 0$, senders prefer that receivers choose S, so they always just announce S (i.e., $M = S$), and receivers believe them and choose $A = M$.
- When $b > 0$, senders would prefer to exaggerate and announce $M > S$ if they think receivers would believe them.

Wang et al. (2010)

Two central issues in the sender-receiver game:

- How well can uninformed receivers infer the private information S from the messages M of informed senders?
- What will informed senders do anticipating the behavioral inference of the uninformed receivers?

Experimental Design

The sender-receiver game experiment:

- In each round of the experiments, one player always acts as the sender, and the other as the receiver.
- Only the sender's eye movements and pupil dilation are eye-tracked.
- At the beginning of the round, the sender is informed about the true state S uniformly drawn from the state space $\mathbb{S} = \{1, 2, 3, 4, 5\}$.
- The sender is informed about the bias b, which is either 0, 1, or 2.
- The receiver knows the bias b, but not the realization of the state S.
- The sender then sends a message M to the receiver, from the message space $\mathbb{M} = \{1, 2, 3, 4, 5\}$.
- After receiving a message from the sender, the receiver chooses an action A from the action space $\mathbb{A} = \{1, 2, 3, 4, 5\}$.

Experimental Design

- The true state S and the receiver's action A determine the two players' payoffs according to $u_R = 110 - 20|S - A|^{1.4}$ and $u_S = 110 - 20|S + b - A|^{1.4}$.
- The receiver earns the most money if her action matches the true state S.
- The sender prefers the receiver to choose an action equal to $S + b$.
- The game structure and the payoff structure are made known to both senders and receivers.
- The same game is played 45 rounds with random states S and random choices of bias $b = 0$, 1, or 2 with known probabilities $(0.2, 0.4, 0.4)$ in each round.

Experimental Design

Figure: Sender screen (payoff table) for $b = 1$ and $S = 4$

Experimental Design

The equilibrium model for the sender-receiver game:

- When $b = 0$

  The most informative equilibrium requires the sender to tell the truth $M = S$ and receiver to choose $A = M$;

- When $b = 1$

  The most informative equilibrium requires the sender to send messages 1 when $S = 1$, and send any one from $\{2, 3, 4, 5\}$ when S is from $\{2, 3, 4, 5\}$, while the receiver should choose action $A = 1$ when seeing $M = \{1\}$, and $A = 3$ or 4 when seeing $M = \{2, 3, 4, 5\}$;

- When $b = 2$

  The most informative equilibrium requires the sender to send an uninformative message, while the receiver ignores the message and chooses $A = 3$ based on her prior beliefs.

Experimental Design

The level-k model for the sender-receiver game:

- $L0$ senders (who has the lowest level of sophistication) simply tell the truth, and $L0$ receivers best respond to $L0$ senders by following the message;
- $L1$ senders best respond to the $L0$ receivers by inflating the message (stating their preferred states), and $L1$ receivers best respond to $L1$ senders by discounting the message;
- $L2$ senders best respond to the $L1$ receivers ...
- Moving up the hierarchy, such procedure is continued until we reach the most informative equilibrium (EQ) prediction.

Experimental Design

The level-k model for the sender-receiver game:

Sender message (condition on state)						Receiver action (condition on message)					
State	1	2	3	4	5	Message	1	2	3	4	5
$b = 0$											
$L0/EQ$ sender	1	2	3	4	5	$L0/EQ$ receiver	1	2	3	4	5
$b = 1$											
$L0$ sender	1	2	3	4	5	$L0$ receiver	1	2	3	4	5
$L1$ sender	2	3	4	5	5	$L1$ receiver	1	1	2	3	4
$L2$ sender	3	4	5	5	5	$L2$ receiver	1	1	1	2	4
EQ sender	4	5	5	5	5	EQ receiver	1	1	1	1	4
$b = 2$											
$L0$ sender	1	2	3	4	5	$L0$ receiver	1	2	3	4	5
$L1$ sender	3	4	5	5	5	$L1$ receiver	1	1	1	2	4
$L2$ sender	4	5	5	5	5	$L2$ receiver	1	1	1	1	4
EQ sender	5	5	5	5	5	EQ receiver	1	1	1	1	3

Figure: Behavioral predictions of the level-k model

Result 1

- "Trustworthiness" of the sender (or "informativeness" of the sender's message M):

  (1) Measured by correlation between the true state S and the sender's message M;

  (2) Measured by the receiver's payoffs (compared with the payoffs predicted by the equilibrium theory).

- "Trust" of the receiver:

  Measured by correlation between the sender's message M and the receiver's action A.

Result 1a

"Overcommunication" (too much truth telling): as the bias b increases, the information transmitted (measured by correlations among S, M, and A) decreases. However, when the bias $b = 2$, correlations among S, M, and A are higher than that predicted by the equilibrium theory.

Bias	Eyetracked	$r(S,M)$		$r(M,A)$		$r(S,A)$		Predicted $r(S,A)$
0	Yes	0.92	0.93	0.90	0.92	0.86	0.86	1.00
	No	0.94		0.94		0.88		
1	Yes	0.68	0.64	0.73	0.71	0.53	0.49	0.65
	No	0.51		0.61		0.35		
2	Yes	0.41	0.34	0.52	0.58	0.34	0.32	0.00
	No	0.23		0.63		0.28		

Figure: Information transmission: correlations between states S, messages M, and actions A (denoted as $r(S,M)$, $r(M,A)$, and $r(S,A)$)

Result 1b

(?) "Overcommunication" (too much truth telling): as the bias b increases, the information transmitted (measured by receiver payoffs) decreases. When the bias $b = 2$, receiver payoffs are almost the same as that predicted by the equilibrium theory.

Bias	Eyetracked	u_S (SD)	(combined)	u_R (SD)	(combined)	Pred. u_R (SD)
0	Yes	101.13 (18.68)	101.30[a] (17.28)	100.85 (19.28)	101.27[a] (17.69)	110.00 (0.00)
	No	101.89 (14.89)		102.07 (15.23)		
1	Yes	71.81 (39.56)	73.28 (37.46)	87.88 (28.63)	86.88 (27.59)	91.40 (19.39)
	No	75.44 (35.11)		84.44 (25.62)		
2	Yes	43.39 (52.17)	43.31 (52.79)	80.78 (27.17)	80.55 (27.57)	80.80 (20.76)
	No	43.21 (53.37)		80.21 (29.11)		

Figure: Sender's and receiver's payoffs (denoted as u_S and u_R)

Result 2a

Attention to own payoffs: senders look at their own payoffs longer (when looking at the payoff table screen), though senders need to look carefully at receiver payoffs in order to determine the message.

Bias b	Response time: Periods 1–15	Response time: Periods 31–45	State	Sender payoffs	Receiver payoffs	Sender-to-receiver ratio
0	9.78	7.24	0.83	2.93	1.71	1.72
1	11.77	8.76	0.81	3.80	2.66	1.43
2	16.84	8.99	0.91	4.67	3.26	1.43
all	13.47	8.52	0.86	3.99	2.72	1.47

Figure: Average sender fixation durations (in seconds) across game parameters

Result 2b

"Curse of knowledge": sender look about five times longer at payoffs in the rows corresponding to the true state than those of the four other state rows. The sender cannot fully think like a receiver (who does not know the true state).

Bias b	True state rows	Other state rows	True-to-other ratio
0	2.76	0.47	5.89
1	3.88	0.64	6.02
2	4.29	0.91	4.70
overall	3.83	0.72	5.33

Figure: Average sender fixation durations (in seconds) per row depending on states

Result 2c

Each box in the fixation icon graph represents the **visual attention** paid to the payoff corresponding to a different state-action combination.

- Panels A and B represent attention to the sender payoff boxes and the receiver payoff boxes, respectively.
- The width of the box measures the average number of fixations on that box.
- The height of the box measures the average total looking time in that box.
- Boxes which are wide and tall were looked at repeatedly (wide) and for a longer time (tall).

The senders are also classified into $L0$, $L1$, or $L2$ type based on their behavioral data, assuming they remain the same type across different biases.

Result 2c

Level-k fixation patterns for $b = 1$, $L1$ sender: $L1$ senders looked at their own payoffs more frequently and longer than the payoffs of receivers. Senders' fixations are also more frequent and longer for actions that are equal to the actual state S or $S + 1$ (the patterns for $b = 2$ are similar and thus omitted).

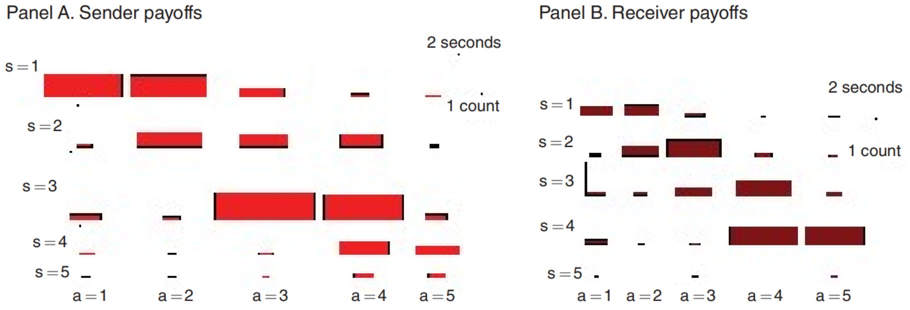

Figure: Fixation icon graph for $b = 1$, $L1$ sender

Result 2c

Level-k fixation patterns for $b = 1$, $L2$ sender: $L2$ senders looked at their own payoffs more frequently and longer than the payoffs of receivers. When the state S is $\{1, 2, 3\}$, they tend to look at their payoffs from actions corresponding to S, $S + 1$, and $S + 2$. However, when the state is $\{4, 5\}$, this pattern no longer exists as states $S + 2$ and $S + 1$ do not exist.

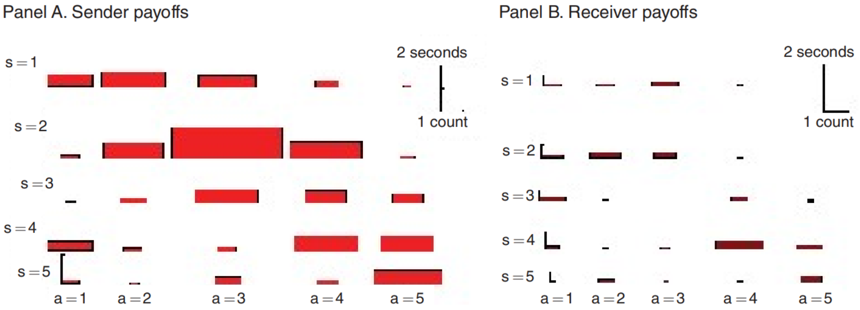

Figure: Fixation icon graph for $b = 1$, $L2$ sender

Result 3

Pupil dilation:

- People's pupils dilate under stress, cognitive difficulty, arousal, and pain.
- Pupil dilation might be used to infer deceptive behavior because senders find deception stressful (because of guilt) or cognitively difficult.

Result 3

Pupil dilation: α is the average pupil size and β_{1b} are the effect (on pupil size) of deviating from reporting the true state (deceiving more) when $b =$ 0, 1, or 2. Immediately after the decision was made, the pupil dilated for all biases b. Before the decision was made, the pupil dilated only when $b = 2$.

Y	$PUPIL_i$	−1.2~ −0.8 sec	−0.8~ −0.4 sec	−0.4~ 0.0 sec	0.0~ 0.4 sec	0.4~ 0.8 sec
constant	α	107.27	108.03	106.19	109.56	108.67
		(2.81)	(2.55)	(2.57)	(2.05)	(2.16)
$LIE\_SIZE \times BIAS_b$ interactions	β_{10}	2.83	2.36	3.07	5.35***	5.57**
		(1.85)	(2.23)	(2.46)	(1.76)	(2.19)
	β_{11}	−1.02	−0.46	−0.36	2.16*	2.64**
		(1.26)	(1.31)	(1.28)	(1.21)	(1.15)
	β_{12}	2.06**	1.52*	1.47**	1.83**	2.00***
		(0.86)	(0.79)	(0.75)	(0.75)	(0.74)
	N	414	415	414	415	414
	χ^2	323.86	235.43	194.40	258.49	352.49
	R^2	0.291	0.299	0.263	0.365	0.438

Figure: Pupil size regressions for 400 ms intervals (**0.0 sec is the decision time**)

Result 4

Lie detection: could receivers predict the true state S better using only senders' messages M and fixation patterns?

- We pretend we don't know the true state S, forecast it from observables, then use knowledge of the true state to evaluate predictive accuracy.
- Out-of-sample validation is used to evaluate how well these specifications could predict new data.
- The predictive model is trained with $2/3$ of observations, and the model forecasts on a holdout sample of the remaining $1/3$ of observations.

Result 4

Lie detection: fixation pattern data help receivers predict deception and uncover the underlying true states S. For the receivers, the error rates in predicting states are lower, the sizes of errors are smaller, and the average predicted payoffs are higher in the holdout sample than those in the actual data (i.e., the actual action A of receivers reflects their predictions of S).

	Actual data	Holdout sample
Percent of wrong prediction ($b = 1$)	58.5	28.9
Percent of errors of size $(1, 2, 3+)$ ($b = 1$)	(61, 28, 11)	(79, 19, 2)
Average predicted payoff ($b = 1$)[b]	87.5 (28.8)	101.7† (2.1)
Percent of wrong prediction ($b = 2$)	77.9	37.9
Percent of errors of size $(1, 2, 3+)$ ($b = 2$)	(60, 30, 10)	(72, 24, 4)
Average predicted payoff ($b = 2$)[b]	80.9 (26.9)	98.0† (2.2)

Figure: True states predictions with fixation pattern data

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Polonio et al. (2015)

Traditional game theory assumes agents to be fully rational and self-interested.

- Bounded rationality theory (e.g., level-k theory)

  It relaxes the assumption of **full rationality**;

  It can explain out-of-equilibrium outcomes assuming individuals being boundedly rational and performing different levels of iterative strategic thinking due to limited cognitive capacities.

- Social preference theory (e.g, altruism, reciprocity, and fairness)

  It relaxes the assumption of **self-interest**;

  It can account for the fact that individuals often have positive or negative attitudes towards others, and may go out of equilibrium to benefit or harm others.

Polonio et al. (2015)

Predictions in terms of strategic decision making:

- Traditional game theory

  Players always play in equilibrium;
- Bounded rationality theory

  Players may not play in equilibrium because they fail to process relevant information;
- Social preference theory

  Players may observe the payoffs of the other player, regardless of whether these payoffs are strategically relevant.

Polonio et al. (2015)

Strategic sophistication: the extent to which players consider the game structure and the other players' payoff structure in the game before deciding their strategy.

- Can players' visual patterns of information acquisition reveal their strategic sophistication and social motives?
- Are the visual patterns of information acquisition consistent with traditional game theory, bounded rationality theory and/or social preference theory?

Experimental Design

Ninety participants took part in the experiment individually.

- Each participants was randomly assigned to the role of “row player” or “column player” in games.
- Each participant played 32 games divided into four blocks of 8 trials each.
- The order of the blocks were fixed but the games within each block were randomized.
- No feedback was provided, and each game was played only once.
- One game and one counterpart were randomly selected, and participants were paid according to their choice and that of the selected counterpart.

Experimental Design

Four classes of games (eight 2X2 games for each class)

- 1) Dominance solvable “self” games (DSS);
- 2) Dominance solvable “other” games (DSO);

Dominant Solvable Self

DSS 1

	i	ii	
I	**6,3**	2,2	D
II	5,5	1,6	

DSS 2

	i	ii	
I	3,3	**7,4**	D
II	2,7	6,6	

DSS 3

	i	ii	
I	7,7	3,8	
II	**8,5**	4,4	D

DSS 4

	i	ii	
I	4,9	8,8	
II	5,5	**9,6**	D

DSS 5

	i	ii	
I	1,6	5,5	
II	2,2	**6,3**	D

DSS 6

	i	ii	
I	6,6	2,7	
II	**7,4**	3,3	D

DSS 7

	i	ii	
I	4,4	**8,5**	D
II	3,8	7,7	

DSS 8

	i	ii	
I	**9,6**	5,5	D
II	8,8	4,9	

Dominant Solvable Other

DSO 1

	i	ii	
I	3,2	**4,4**	D
II	5,5	3,6	

DSO 2

	i	ii	
I	**5,5**	4,3	D
II	4,7	6,6	

DSO 3

	i	ii	
I	7,7	5,8	
II	5,4	**6,6**	D

DSO 4

	i	ii	
I	6,9	8,8	
II	**7,7**	6,5	D

DSO 5

	i	ii	
I	3,6	5,5	
II	**4,4**	3,2	D

DSO 6

	i	ii	
I	6,6	4,7	
II	4,3	**5,5**	D

DSO 7

	i	ii	
I	5,4	**6,6**	D
II	7,7	5,8	

DSO 8

	i	ii	
I	**7,7**	6,5	D
II	6,9	8,8	

Experimental Design

Four classes of games (eight 2X2 games for each class)

- 3) Prisoner's dilemma games (PD)
- 4) Stag hunt games (SH)

Prisoner's Dilemma

Game		i	ii	
PD 1	I	2,2	6,1	D
	II	1,6	5,5	
PD 2	I	7,2	3,3	D
	II	6,6	2,7	
PD 3	I	7,7	3,8	
	II	8,3	4,4	D
PD 4	I	4,9	8,8	
	II	5,5	9,4	D
PD 5	I	6,1	2,2	D
	II	5,5	1,6	
PD 6	I	3,3	7,2	D
	II	2,7	6,6	
PD 7	I	3,8	7,7	
	II	4,4	8,3	D
PD 8	I	8,8	4,9	
	II	9,4	5,5	D

Stag Hunt

Game		i	ii	
SH 1	I	4,1	5,5	RD
	II	6,6	1,4	PE
SH 2	I	2,5	7,7	PE
	II	6,6	5,2	RD
SH 3	I	6,3	7,7	RD
	II	8,8	3,6	PE
SH 4	I	4,7	9,9	PE
	II	8,8	7,4	RD
SH 5	I	6,6	1,4	PE
	II	4,1	5,5	RD
SH 6	I	7,7	2,5	PE
	II	5,2	6,6	RD
SH 7	I	7,7	6,3	RD
	II	3,6	8,8	PE
SH 8	I	8,8	7,4	RD
	II	4,7	9,9	PE

Experimental Design

Dominant strategies of the players:

- 1) Dominance solvable "self" games (DSS)

  Only the eye-tracked player had a strictly dominant strategy;
- 2) Dominance solvable "other" games (DSO)

  Only the counterpart player had a strictly dominant strategy;
- 3) Prisoner's dilemma games (PD)

  Both players had a strictly dominant strategy;
- 4) Stag hunt games (SH)

  No dominant strategies and both players could choose between a low-risk low-return choice and a high-risk high-return one.

Experimental Design

Equilibria of the games:

- 1) Dominance solvable "self" games (DSS)

  A unique NE in pure strategies (one step of iterated elimination of dominated strategies to reach the equilibrium);
- 2) Dominance solvable "other" games (DSO)

  A unique NE in pure strategies (two steps to reach the equilibrium, i.e., first the elimination of the dominated strategy of the counterpart, then the elimination of own dominated strategy);
- 3) Prisoner's dilemma games (PD)

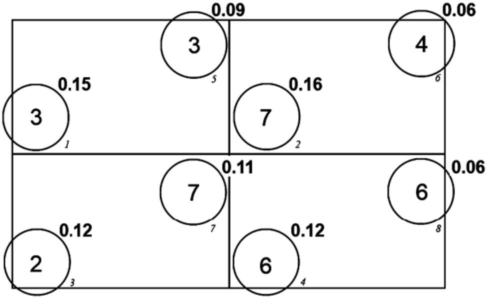
  A unique NE in pure strategies (one step of iterated elimination of dominated strategies to reach the equilibrium);
- 4) Stag hunt games (SH)

  Two pure strategies NEs (one Pareto-efficient, and one risk dominant) and one equilibrium in mixed strategies.

Experimental Design

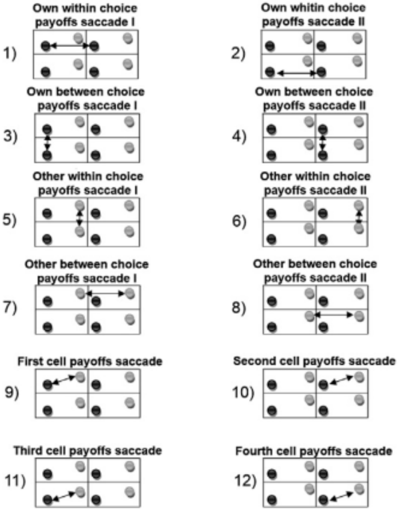
The matrix presented to the participants:

- The circles (not visible to the participants) represent the AOIs;
- Row player's payoffs are located at the bottom-left of each cell;
- Column player's payoff are located at the top-right of each cell;
- The numbers in *italic* are the corresponding labels;
- The numbers in **bold** are the proportions of fixation time of each AOI, averaged among participants.



Experimental Design

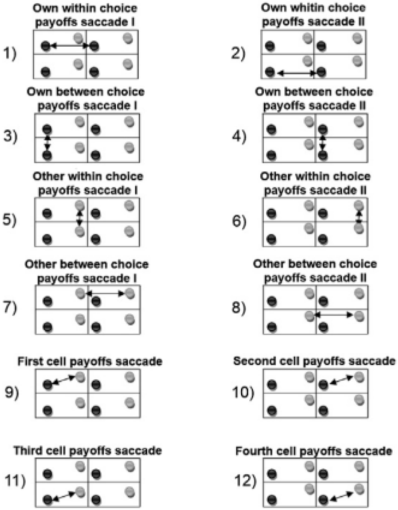
Classification of the 12 "relevant" saccades for row players.



- 1)-4) Own payoffs saccades: saccades between a player's own payoffs;
- 5)-8) Other payoffs saccades: saccades between the counterpart's payoffs;
- 9)-12) Intra-cell saccades: saccades between the payoffs of the two players, within the same cell.

Experimental Design

Classification of the 12 "relevant" saccades for row players.



- 1)-4) Own payoffs saccades were necessary to identify the presence of own dominant choices, and own strategies with the highest average payoff.
- 5)-8) Other payoffs saccades were necessary to identify the counterpart's dominant strategy and strategies with the highest average payoff.
- 9)-12) Intra-cell saccades were necessary to compare the two players' payoffs within a specific cell.

Experimental Design

Visual pattern of information acquisition: the sequence of saccades required to extract specific information about the payoff structure of the game.

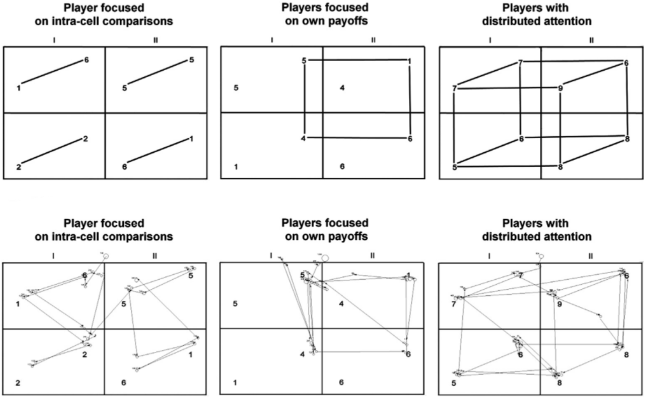
- Co-occurrence: (for a given player in a given game,) the number of times that two saccades occurred are highly and positively correlated;
- Sequentiality: (for a given player in a given game,) two saccades have a high probability of being performed sequentially.

If two saccades satisfy the two conditions above, then they belong to the same visual pattern of information acquisition.

Experimental Design

Classification of (column) players based on their patterns of saccades.

- 1) Players focusing on intra-cell comparisons;
- 2) Players focusing on own payoffs;
- 3) Players with distributed attention.



Result 0

Different games had different rates of equilibrium responses (learning effects due to non-randomization at the block level?).

	DSS	DSO	PD	SH
Equilibrium responses	0.70	0.35	0.68	0.45
(S.D.)	(0.35)	(0.34)	(0.39)	(0.37)
Response times	8765 ms	8565 ms	8353 ms	7679 ms
(S.D.)	(7736 ms)	(6638 ms)	(7285 ms)	(6167 ms)

Figure: Proportion of equilibrium responses (Pareto equilibrium in stag hunt games) and average response times

Result 1a

Co-occurrence of saccades:

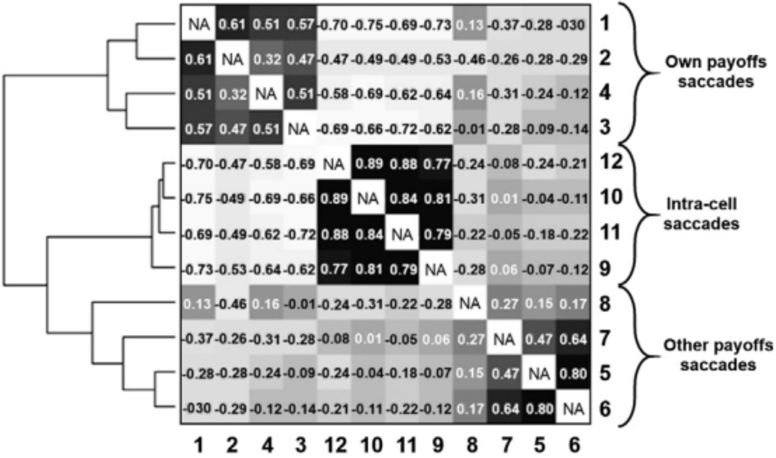


Figure: Clustering tree (left) and correlation map (right) for the 12 saccades

Result 1b

Sequentiality of saccades:

	Own payoffs saccades	Other payoffs saccades	Intra-cell saccades
1. Own within choice payoffs saccade I	0.74***	0.04	0.22
2. Own within choice payoffs saccade II	0.72***	0.07	0.21
3. Own between choice payoffs saccade I	0.66***	0.08	0.26
4. Own between choice payoffs saccade II	0.64***	0.08	0.28
5. Other within choice payoffs saccade I	0.07	0.54***	0.38
6. Other within choice payoffs saccade II	0.13	0.48**	0.39
7. Other between choice payoffs saccade I	0.12	0.56***	0.32
8. Other between choice payoffs saccade II	0.13	0.53***	0.33
9. First cell payoffs saccade	0.23	0.18	0.58***
10. Second cell payoffs saccade	0.27	0.19	0.53**
11. Third cell payoffs saccade	0.23	0.17	0.59***
12. Fourth cell payoffs saccade	0.26	0.19	0.54**

Figure: Probability for each of the 12 saccades to be followed by one type of saccade

Result 2

Different visual patterns of information acquisition are correlated with different strategic choices (equilibrium or out-of-equilibrium) depending on the structure of the game.

Games	Predictor variables	Estimates	Z value	p-Value
DSS	Own payoffs saccades	0.219	3.603	$p < 0.001$
	Other payoffs saccades	0.078	1.105	$p = 0.269$
	Intra-cell saccades	−0.169	−2.961	$p = 0.003$
N° of obs. = 442	AIC = 343	BIC = 368		$\log L = -166$
DSO	Own payoffs saccades	−0.080	−1.766	$p = 0.077$
	Other payoffs saccades	0.366	5.228	$p < 0.001$
	Intra-cell saccades	0.018	0.510	$p = 0.610$
N° of obs. = 442	AIC = 418	BIC = 443		$\log L = -203$
PD	Own payoffs saccades	0.332	3.300	$p < 0.001$
	Other payoffs saccades	0.153	1.621	$p = 0.105$
	Intra-cell saccades	−0.166	−2.480	$p = 0.013$
N° of obs. = 439	AIC = 300	BIC = 325		$\log L = -144$
SH	Own payoffs saccades	−0.227	−3.700	$p < 0.001$
	Other payoffs saccades	−0.076	−1.152	$p = 0.249$
	Intra-cell saccades	0.085	1.887	$p = 0.059$
N° of obs. = 440	AIC = 430	BIC = 454		$\log L = -208$

Figure: Binary dependent variable equals 1 if the strategic choice is an equilibrium choice (or Pareto equilibrium in stag hunt games), 0 otherwise; independent variables are the number of saccades

Result 3

For all the three types of players, they did not adapt their visual patterns of information acquisition to different classes of games.

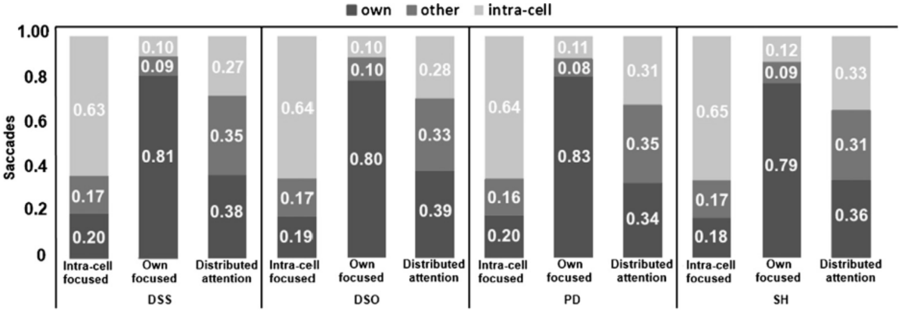
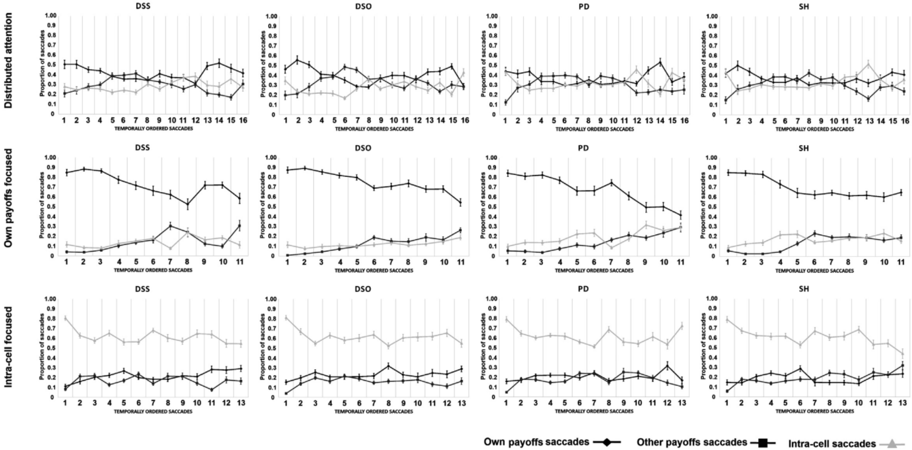


Figure: Proportion of each type of saccade for the three types of players

Result 4

For all the three types of players and all types of games, the temporal patterns of information acquisition remained constant.



Result 5

Level-k theory: in normal form games, players should adopt iterative decision rules that are based on a step-by-step reasoning procedure.

- $L0$ players simply randomize over the action space.

  $L0$ players do not need to look at the payoffs.
- $L1$ players, believe that all other players are $L0$ players and best respond to random play.

  $L1$ players do not need to look at the other player's payoffs.
- $L2$ players who perform two steps of thinking believe they are playing against $L1$ players.

  $L2$ players form a belief, look at other players' payoffs, and use their belief for best response.

Result 5

- Players having distributed attention could be $L2$ thinkers:

  They took into account the counterpart's payoffs, and exhibited a temporal pattern of visual analysis in accordance with an iterative step-by-step procedure (i.e., they looked first at their own payoffs, then at the payoffs of the counterpart, then again at their own);
- Players focusing on own payoffs could be $L1$ thinkers:

  They hardly looked at the counterpart's payoffs, and their temporal pattern of visual analysis stopped after considering their own payoffs;
- Players focusing on intra-cell comparisons could not be associated with any level-k thinkers:

  Their temporal pattern of visual analysis did not reflect any iterative decision rule.

Among the 60 players, 16 were $L2$ thinkers and 17 were $L1$ thinkers.

Result 6

Social preference theory: in normal form games, a player motivated by fairness or competition may look at the payoffs of the counterpart, regardless of whether these payoffs are strategically relevant.

- **Cooperative** players tend to maximize the sum of their own and their partner's payoffs.
- **Competitive** players tend to maximize the difference between their own and their opponent's payoffs.
- Both types of players need to compare their own payoffs with those of their counterpart and focus on intra-cell comparisons.

Result 6

- Cooperative players

  Players focusing on the cell with symmetric payoffs that also maximized the sum of the two players' payoffs;
- Competitive players

  Players focusing more on the cell in which the difference between player's own payoff and the payoff of the counterpart was maximal, at the player's own advantage.

Among the 23 players focusing on intra-cell comparisons, 17 were cooperative players and 6 were competitive players.

Table of Contents

Fisher (2021)

- How is people's visual attention allocated throughout the intertemporal choice process?
- Can people's attention allocation **causally** influence their intertemporal choices?

For example, you plan to purchase a new phone. If you focus on the price, you would prefer to wait for a price discount; if you focus on the timing, you would prefer to use it immediately.

Fisher (2021)

There are two dimensions involved in an intertemporal choice:

- Attributes of the options (monetary amounts and delay dates);
- Options per se (earlier option vs. later option).

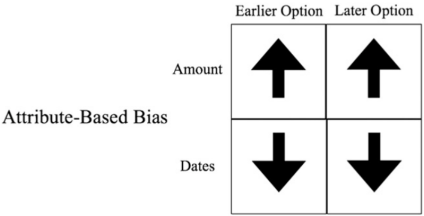
For each attribute, there are two choices:

- Monetary amounts: smaller amount vs. large amount;
- Delay dates: earlier date vs. later date.

Fisher (2021)

Attribute-based attentional bias: fixating on a particular attribute increases the relative weight of that attribute for both options equally.

- Shifting relative attention toward the earlier amount or later amount should increase the likelihood of making a patient choice (as the patient option has a larger monetary amount);
- Shifting relative attention toward the earlier date or later date should decrease the likelihood of making a patient choice (as the impatient option has a earlier receiving date).

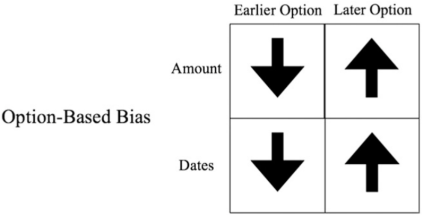


Arrows indicate how shifting attention to that region will impact the probability of making a patient choice.

Fisher (2021)

Option-based attentional bias: fixating on either attribute of a particular option increases the weight given to all attributes of that option, relative to the attributes of the other option.

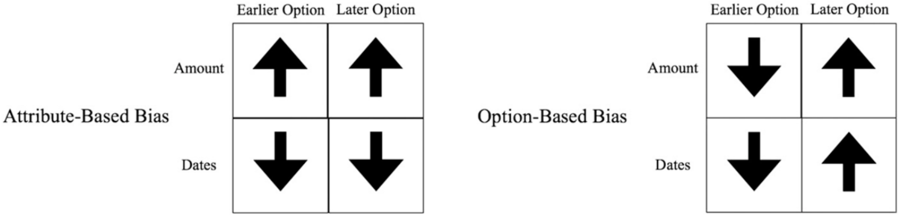
- Shifting relative attention toward the later amount or later date should increase the likelihood of making a patient choice;
- Shifting relative attention toward the earlier amount or earlier date should decrease the likelihood of making a patient choice.



Arrows indicate how shifting attention to that region will impact the probability of making a patient choice.

Fisher (2021)

- The two attentional biases both predict that shifting attention toward the later amount should increase the probability of making a patient choice;
- The two attentional biases both predict that shifting attention toward the earlier date should decrease the probability of making a patient choice;
- The predictions for shifting attention to the later date or earlier amount depend on which type of attentional bias is dominant.



Experiment 1: Correlational Test

Forty-three participants completed 216 trials of an intertemporal monetary choice task.

- In every trial, participants first stared at the central fixation cross for 500 ms. This was enforced to ensure that participants began every choice trial by fixating at the center of the screen.
- Afterward, the choice set was revealed, and participants had as long as they liked to make an intertemporal choice. Eye fixations were recorded at this point.
- After entering a response, participants saw feedback for 1.5 seconds and then moved to the next trial. Trials were separated by a two-second black screen.

Experiment 1: Correlational Test

Experiment 1: Correlational Test

In the choice screens, there are four ROIs: earlier amount, earlier date, delayed amount, and delayed date.

- The order of the questions was randomized for each participant;
- The location (left or right) for the sooner and delayed options was randomized every trial;
- The location (top or bottom) for the monetary amounts or time delays was randomized every trial;
- The attribute values used in the 216 trials were identical across all participants.

At the end of the experiment, one trial was selected at random, and the participant's choice in that trial was implemented.

Experiment 1: Correlational Test

The visual attention are measured as the fixation duration at each ROI.

- Relative attention: dividing the time spent looking at each ROI by the total time spent looking at all four ROIs;
- Absolute attention: absolute time to an ROI or the number of fixations made to an ROI.

The analyses are focused on the fixation locations during the choice screens.

Result 1a

Total fixation time patterns: 1) participants spent more time fixating to the upper ROIs than at the lower ones (the locations of the amount and delay features were randomized over trials); 2) participants spent more time fixating to the left than the right-hand locations (the locations of the sooner and delayed options were randomized every trial).

Panel A: Spatial			
	Left	Right	Left + right
Up	28.5	26.4	54.9
	(3.8)	(6.1)	(6.8)
Down	23.4	21.6	45.1
	(4.6)	(3.5)	(6.8)
Up + down	51.9	48.1	
	(5.3)	(5.3)	

Figure: Total fixation time to each ROI

Result 1b

Total fixation time patterns: participants spent more time fixating to the delayed option than the earlier option.

Panel B: Feature of interest			
	Earlier	Delayed	Earlier + delayed
Amount	25.1	26.4	51.5
	(3.2)	(5.6)	(8.3)
Delay	22.6	25.9	48.5
	(5.1)	(4.0)	(8.3)
Amount + delay	47.7	52.3	
	(3.5)	(3.5)	

Figure: Total fixation time to each ROI

Result 2a

First fixation location patterns: the majority of first fixations were to the top-left location.

Panel A: Spatial			
	Left	Right	Left + right
Up	72.1	15.2	87.3
	(26.9)	(22.1)	(14.8)
Down	9.4	3.3	12.7
	(13.3)	(6.3)	(14.8)
Up + down	81.5	18.5	
	(25.1)	(25.1)	

Figure: Percent of first fixations to each ROI

Result 2b

First fixation location patterns: there was no bias toward first looking at the delayed option. This suggests that participants were unable to identify the location of the delayed option through peripheral vision and use such information to influence the location of their first fixation.

Panel B: Feature of interest			
	Earlier	Delayed	Earlier + delayed
Amount	25.2	23.6	48.7
	(1.8)	(2.4)	(2.3)
Delay	24.3	26.9	51.3
	(2.4)	(2.5)	(2.3)
Amount + delay	49.5	50.5	
	(2.3)	(2.3)	

Figure: Percent of first fixations to each ROI

Result 3

Within-participant attentional effect on patient choice: 1) increases in attention to the earlier date were correlated with a decreased likelihood of choosing the patient option; 2) increases in attention to the delayed amount were correlated with an increased likelihood of choosing the patient option.

	Coefficient estimates					
ROI	Relative attention					Absolute attention
Constant	−0.50	−1.79**	0.69	−0.92*	—	−0.98*
	(0.35)	(0.34)	(0.37)	(0.39)	—	(0.48)
Earlier amount	−0.66	—	—	—	−1.14*	−0.22
	(0.46)	—	—	—	(0.47)	(0.13)
Delayed amount	—	4.15**	—	—	2.22**	1.57**
	—	(0.61)	—	—	(0.75)	(0.25)
Earlier date	—	—	−6.27**	—	−5.45**	−2.36**
	—	—	(0.68)	—	(0.63)	(0.53)
Delayed date	—	—	—	0.89	0.72	0.86**
	—	—	—	(0.53)	(0.48)	(0.17)

Result 4a

Between-participant attentional effect on patient choice: 1) there was a positive correlation between relative attention to the delayed amount and the likelihood of making a patient choice; 2) there was a negative correlation between relative attention to the earlier date and the likelihood of making a patient choice.

	Coefficient estimates					
ROI	Relative attention					Absolute attention
Panel A: Fraction patient						
Constant	–0.54	–0.63**	1.53**	1.08**	—	0.61**
	(0.40)	(0.20)	(0.17)	(0.33)	—	(0.12)
Earlier amount	3.83*	—	—	—	–0.43	0.01
	(1.56)	—	—	—	(1.59)	(1.19)
Delayed amount	—	3.99**	—	—	2.42	1.52
	—	(0.73)	—	—	(1.24)	(0.97)
Earlier date	—	—	–4.90**	—	–4.32**	–4.00**
	—	—	(0.74)	—	(1.22)	(0.97)
Delayed date	—	—	—	–2.52	3.37**	1.40
	—	—	—	(1.27)	(1.09)	(0.77)
R^2	0.13	0.42	0.52	0.09	—	0.53

Result 4b

Between-participant attentional effect on patient choice: about half of the individual differences in patient choices can be explained by the differences in relative attention to four ROIs.

	Coefficient estimates					
ROI	Relative attention					Absolute attention
Panel A: Fraction patient						
Constant	–0.54	–0.63**	1.53**	1.08**	—	0.61**
	(0.40)	(0.20)	(0.17)	(0.33)	—	(0.12)
Earlier amount	3.83*	—	—	—	–0.43	0.01
	(1.56)	—	—	—	(1.59)	(1.19)
Delayed amount	—	3.99**	—	—	2.42	1.52
	—	(0.73)	—	—	(1.24)	(0.97)
Earlier date	—	—	–4.90**	—	–4.32**	–4.00**
	—	—	(0.74)	—	(1.22)	(0.97)
Delayed date	—	—	—	–2.52	3.37**	1.40
	—	—	—	(1.27)	(1.09)	(0.77)
R^2	0.13	0.42	0.52	0.09	—	0.53

Experiment 2: Causal Attribute Biases Test

Experiment 1 is purely correlational and cannot rule out the possibility of **reverse causality** between visual attention and intertemporal choice (i.e., time preference might influence the visual attention allocation on four ROIs).

- Experiment 2: causal attribute biases test

  The experiment exogenously manipulated the relative attention paid to different attributes and tested whether this altered the likelihood that participants made a patient choice.

Experiment 2: Causal Attribute Biases Test

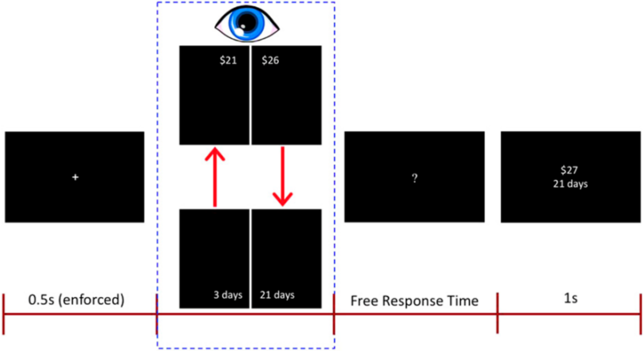
Trial structure for choice task:

- First, participants fixated on a central fixation cross for 500 ms.
- Next, they saw a pair of screens that alternated for a fixed length of time, depending on which of the four conditions was implemented.
- After switching between the two screens for a minimum of five seconds, participants were shown a question mark and had as long as they liked to enter a choice.
- Afterward, feedback was shown for one second, and participants continued to the next trial.

Exposure structure for the four different conditions:

- The length of each screen appeared was varied;
- The order of each screen appeared was varied.

Experiment 2: Causal Attribute Biases Test



		Order	
		Amounts 1st	Delays 1st
Length on Screen	Amounts > Delays	2s **A** / 0.5s **D**	0.5s **D** / 2s **A**
	Delays > Amounts	0.5s **A** / 2s **D**	2s **D** / 0.5s **A**

Experiment 3: Causal Option Biases Test

In Experiment 2, participants might internally decide before the exposure time terminated, and attention might not have varied as much across conditions as intended.

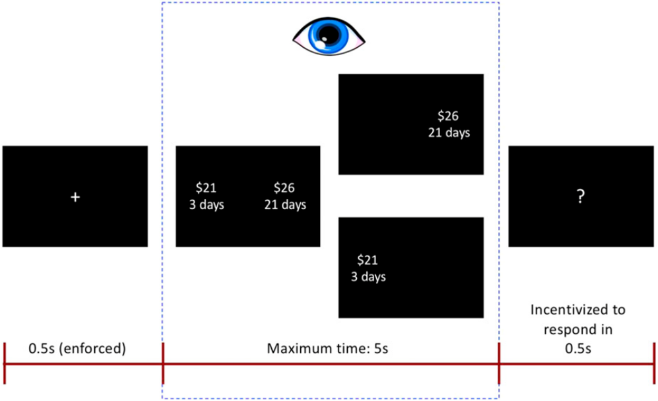
- Experiment 3: causal option biases test

  Participants were free to fixate between the earlier and delayed outcomes, but once a specified accumulation time had been reached for an option, where one option had a larger accumulation time than the other, it was removed from the computer screen.

Experiment 3: Causal Option Biases Test

- First, participants fixated on a central fixation cross for 500 ms.
- Next, they saw both choice options presented for 3.5 seconds and were free to fixate between them.
- Then, one option was randomly chosen as the target, and the other was the nontarget.
- Once the target option was fixated at for 1.2 seconds, it disappeared from the screen leaving only the nontarget visible.
- Once the nontarget option was attended to for a total of 0.3 seconds, it also disappeared.
- A question mark appeared in the center of the screen, which was the participant's cue to enter their response.
- After doing so, feedback was shown, and they continued to the next trial.

Experiment 3: Causal Option Biases Test



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