

nature communications

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Five Year

The psychological, computational, and neural foundations of indebtedness

[Xiaoxue Gao](#) ✉, [Eshin Jolly](#), [Hongbo Yu](#), [Huiying Liu](#), [Xiaolin Zhou](#) ✉ & [Luke J. Chang](#) ✉

*The neurocognitive bases of **social emotions**: gratitude, guilt, indebtedness etc.
The neurocognitive bases of **social behaviors/social decision-making**: inequity aversion, reciprocity, group-based decision-making, framing effect etc.*

Reporter : Yang Ziyang

2024.02.23

Introduction



Care about me?

OR

Expect return?

receipt of an unsolicited gift or favor

past research

Care about me?

Expect return?

Altruistic
(善意帮助)

Strategic
(策略性帮助)

Gratitude
(感激)

Guilt
(内疚)

Obligation
(义务感)



- a physician may preferentially prescribe medications from a pharmaceutical company that treated them to an expensive meal
- a politician might vote favorably on policies that benefit an organization, which provided generous campaign contributions

mentalizing process to infer the benefactor's intentions

Psychological Game Theory
tools for modeling these higher order beliefs (context of reciprocity)

Appraisal Theory
evoke different types of feelings

impact how the beneficiary responds

➤ induce a **negative feeling** of indebtedness

Introduction

impact how the beneficiary responds

Care about me?

Expect return?

Altruistic
(善意帮助)

repay the favor

Strategic
(策略性帮助)

Gratitude

Guilt

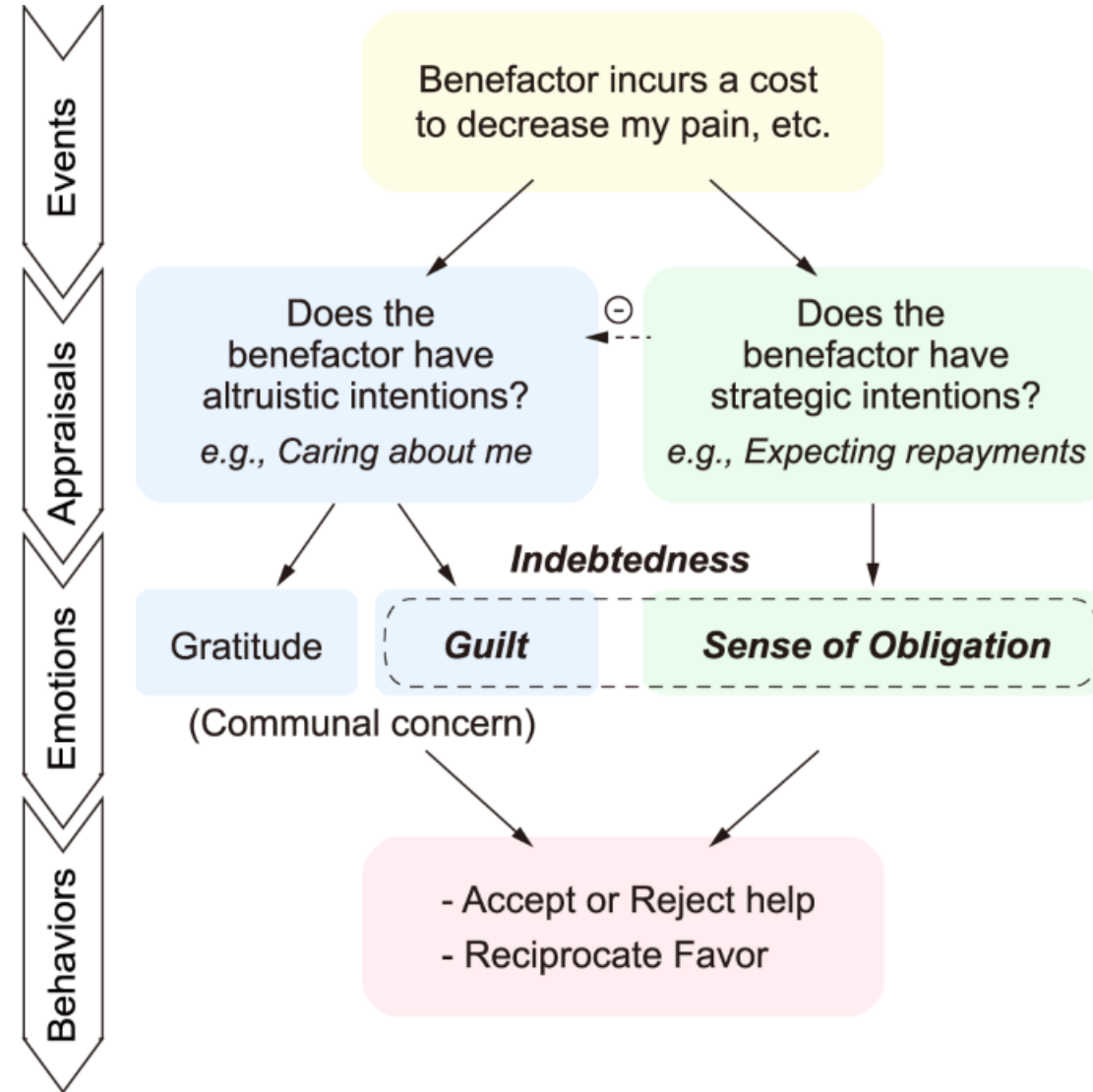
→ **Indebtedness** ←

Obligation



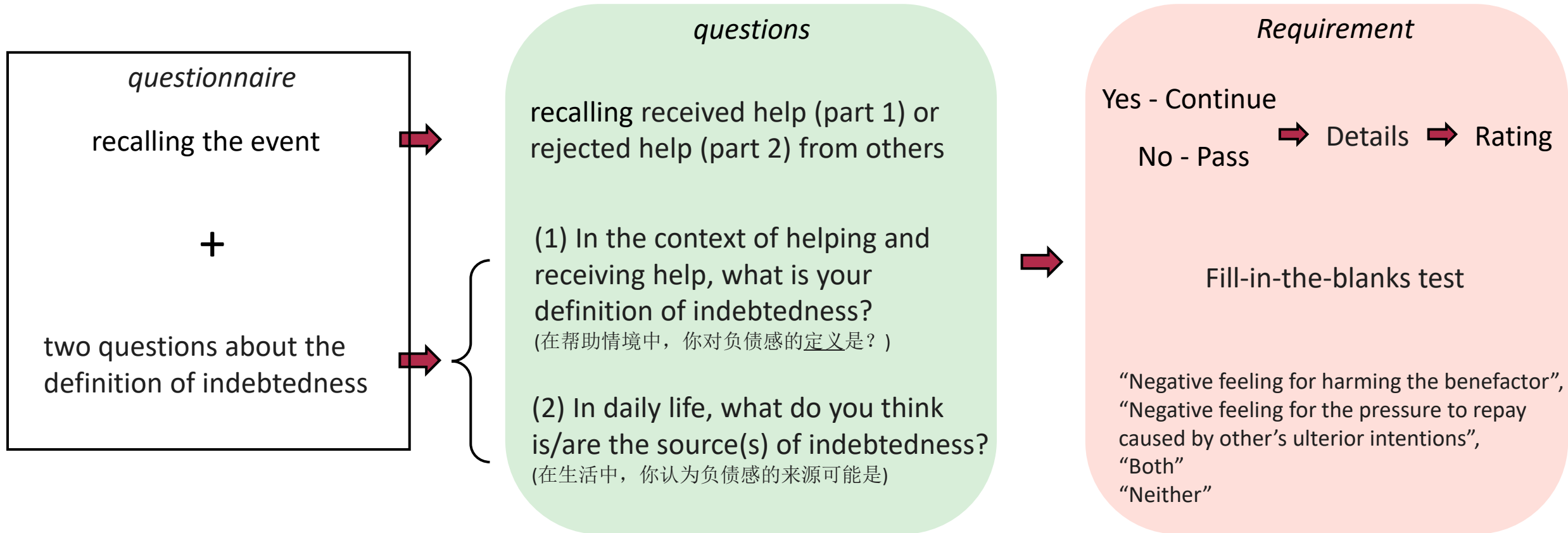
- Definition?
- Mechanism?
- How to interact with society?

Hypothesis: Conceptual model of indebtedness



Study 1

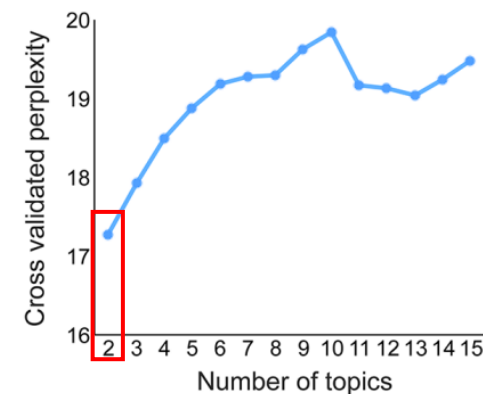
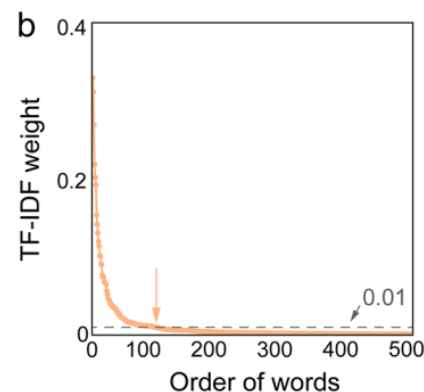
Participants describe memories of past emotional experiences in a large-scale online questionnaire, using regression analysis and topic modeling.



- Participants (1808 graduate and undergraduate students) were recruited, leaving 1619 participants (812 females)

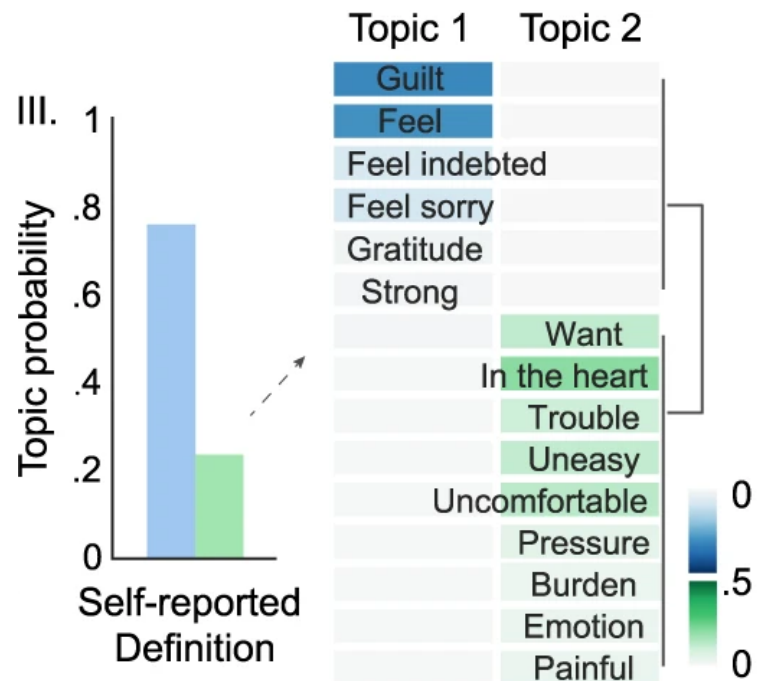
In the context of helping and receiving help, what is your definition of indebtedness?(在帮助情境中，你对负债感的定义是?)

利益	Benefit	0.131	36.3	7.5	6.3	2.5	47.5
内心	In the heart	0.114	3.8	43.8	0.0	2.5	50.0
因为	Because	0.077	18.8	3.8	5.0	1.3	71.3
心存	In the heart	0.057	6.3	36.3	2.5	1.3	53.8
人情	Favor	0.040	17.5	20.0	7.5	2.5	52.5
东西	Things	0.029	7.5	1.3	2.5	8.8	80.0
心理	Psychological	0.029	7.5	38.8	1.3	2.5	50.0
事情	Things	0.028	5.0	0.0	8.8	5.0	81.3
或者	Or	0.024	7.5	0.0	1.3	1.3	90.0



Using **TF-IDF** (*Term Frequency-Inverse Document Frequency*), 100 words with the highest weight/frequency in the definitions of indebtedness were extracted

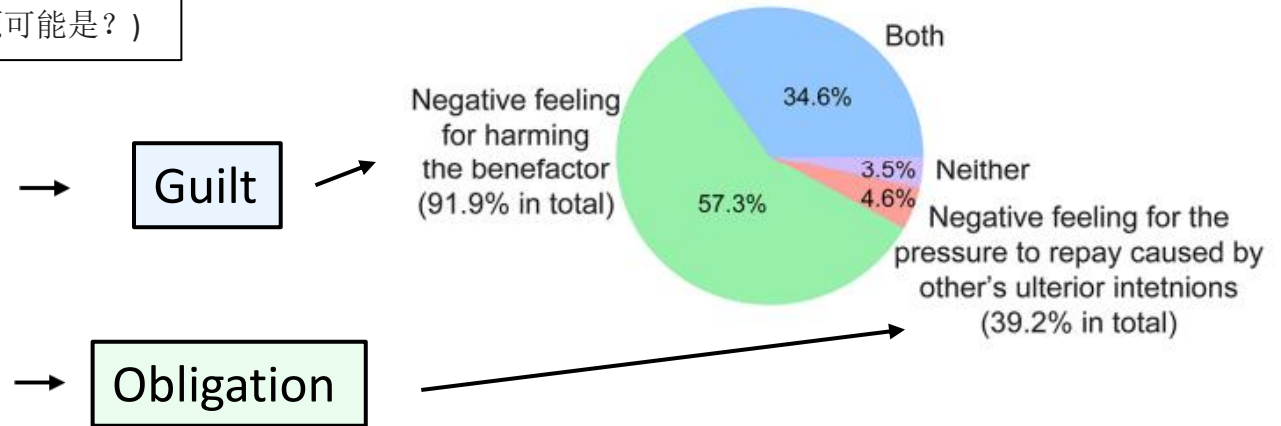
Latent Dirichlet Allocation (LDA) based **topic modeling** on the emotional words of indebtedness

[illegible]

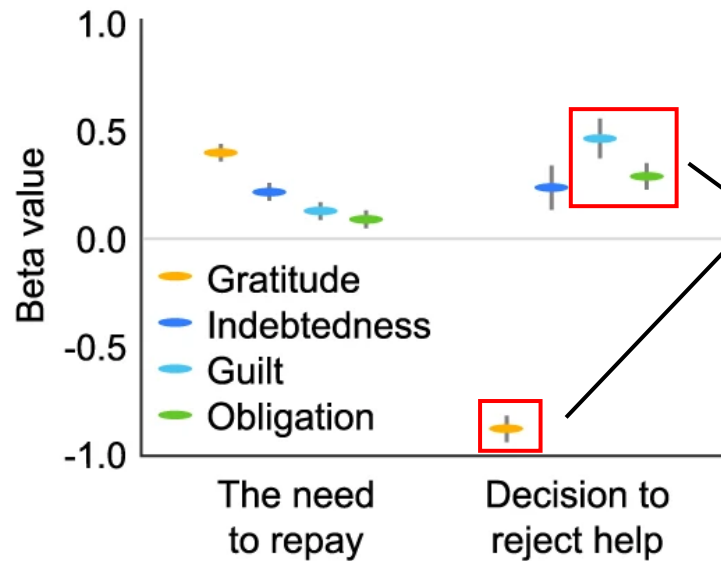
Result

In daily life, what do you think is/are the source(s) of indebtedness? (在生活中, 你认为负债感的来源可能是?)

- A. “Negative feeling for harming the benefactor”
(因为他人为了帮助你付出了一定的代价而感到不安, 因此感受到的负面情绪),
- B. “Negative feeling for the pressure to repay caused by other’s ulterior intentions”
(因为他人的帮助另有所图(如需要更多偿还)而感到偿还的压力, 因此感受到的负面情绪),
- C. “Both” (以上两者都有)
- D. “Neither”(以上两者都没有)



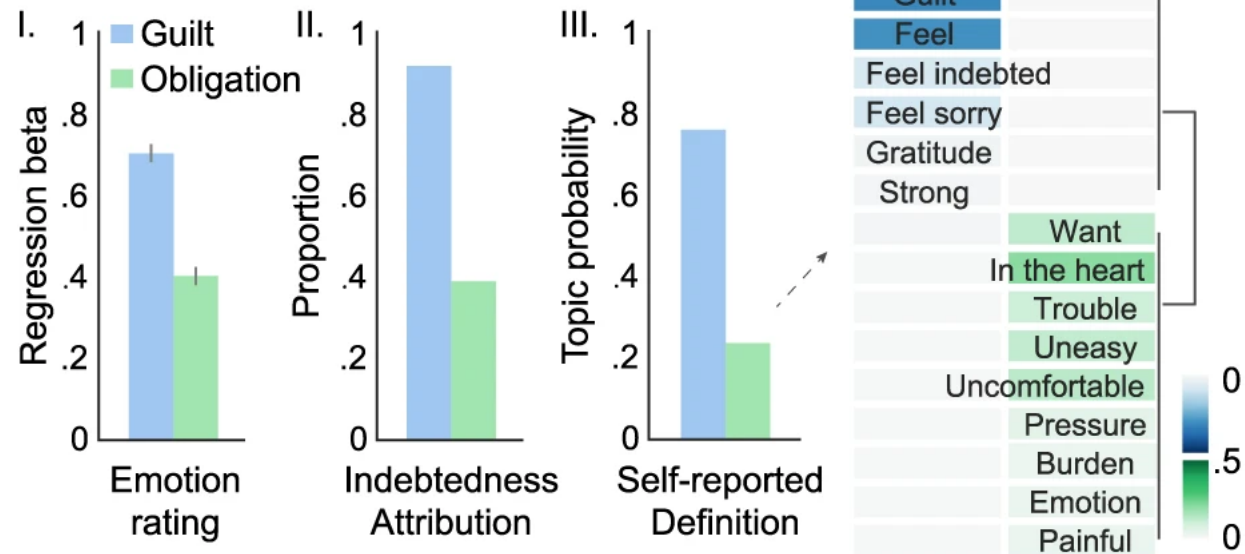
b The effects of emotions on behaviors



- Only **gratitude** appears to be associated with increasing the likelihood of accepting help.
- The **guilt** and **obligation** components of indebtedness instead appear to be associated with increasing the likelihood of rejecting help.

Result

a Definition of indebtedness

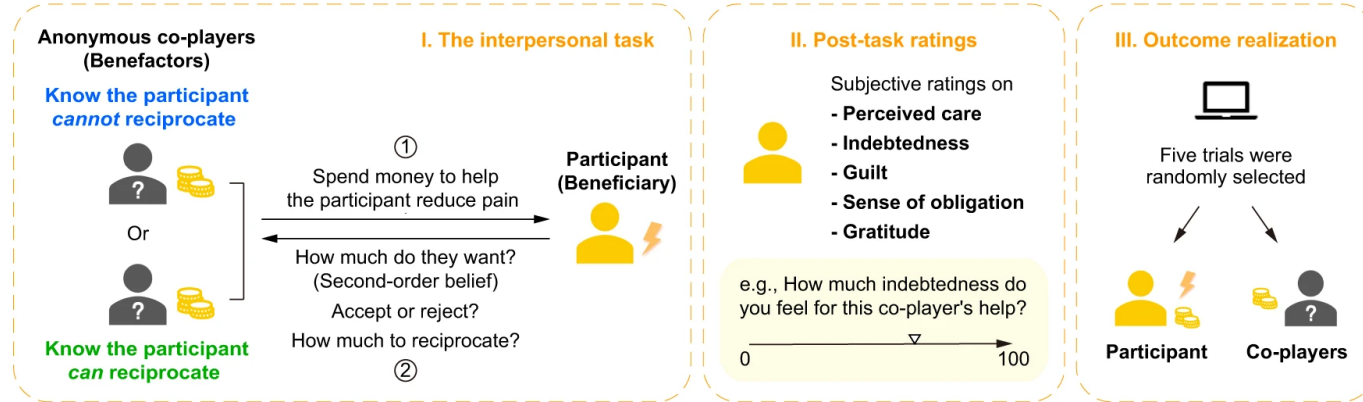


Indebtedness is a mixed feeling comprised of guilt and obligation

Design

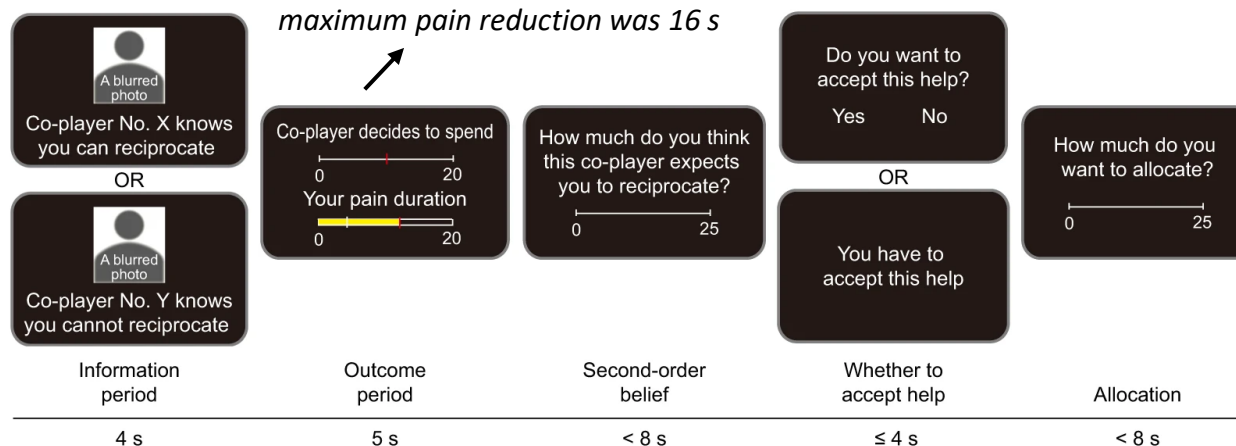
multiple single-shot rounds of the interpersonal task

a Procedures for Study 2



The participant was instructed that each co-player: (a) had come to the lab before the participant, (b) had been endowed with 20 yuan, and (c) had decided whether and how much to spend from this endowment to help the participant reduce the duration of pain (i.e., benefactor's cost, D_A)

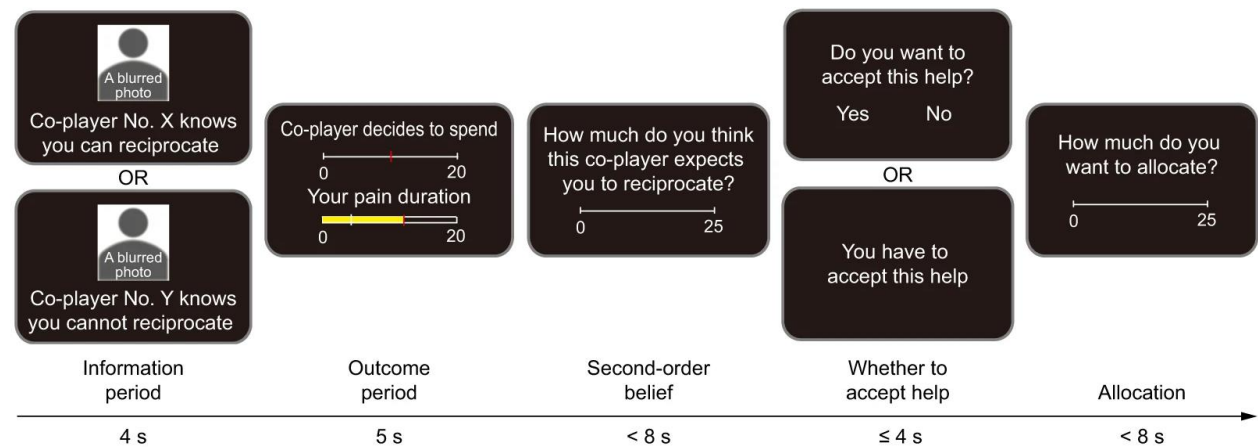
b Detailed procedure for the interpersonal task



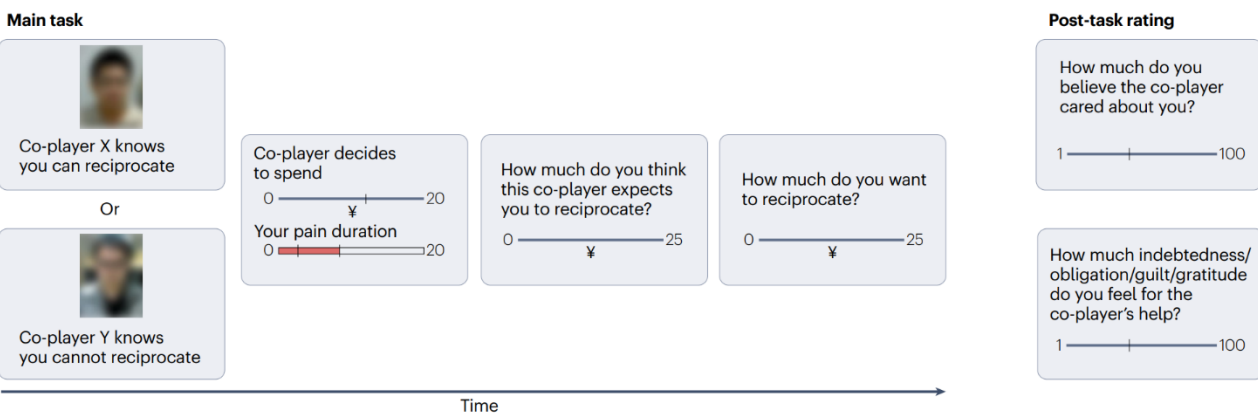
believe that the co-player expected repayments in Repayment possible condition

Design

Study 2a



Study 2b



In Study 2a, we manipulated

the participant's beliefs about the benefactor's intentions

the benefactor's cost in a within-subject design.

Conditions	Benefactor knows: Repayment impossible vs. Repayment possible	Cost	5, 7, 8, 9, 10, 11, 12,14, 15, 16, 18, 20
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In Study 2b, additionally manipulated we the exchange rate between the co-player's cost and participant's pain reduction (i.e., the efficiency) in a within-subject design.

	Study 2a	Study 2b
Efficiency manipulation	1	0.5, 1, 1.5
Cost	5, 7, 8, 9, 10, 11, 12,14, 15, 16, 18, 20	4, 8, 12, 16, 20
Total trial number	48	56

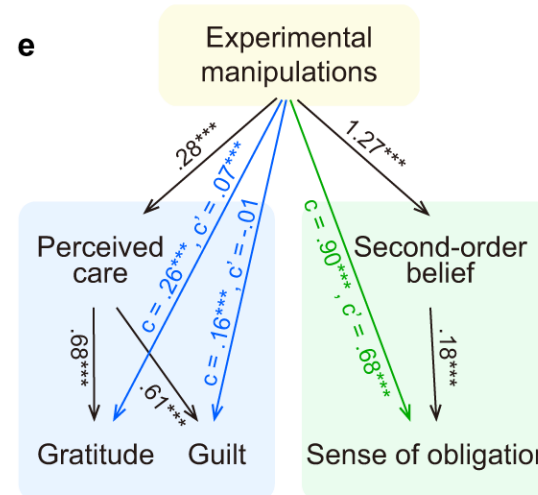
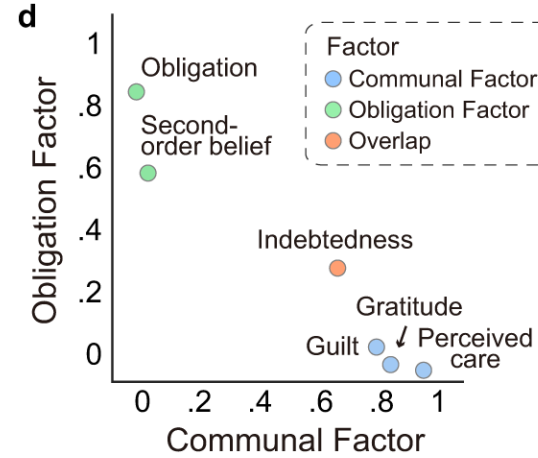
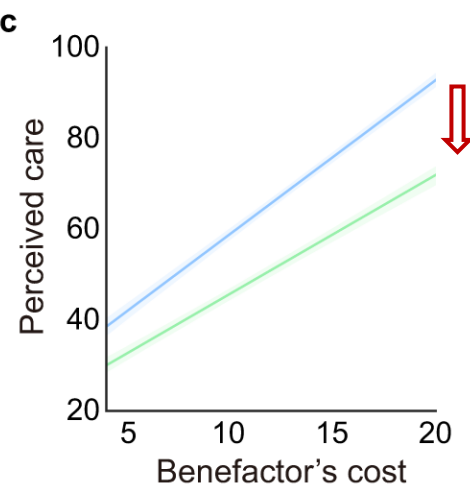
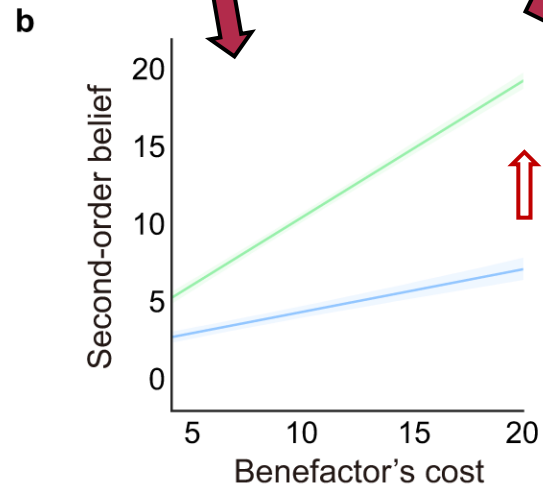
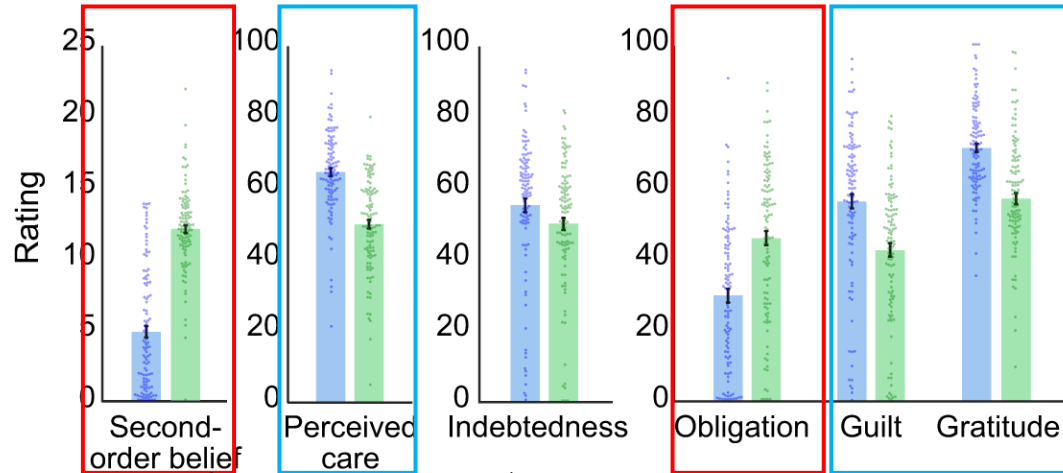
Result

appraisals



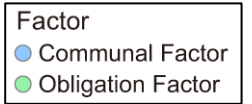
emotions

a Benefactor knows: — Repayment impossible — Repayment possible

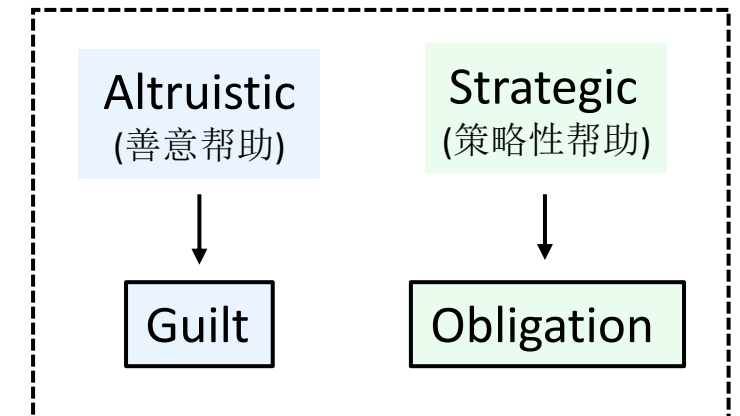


➤ Benefactor's intentions cause diverging components of indebtedness

➤ Factor analysis showed that participants' appraisals and emotions could be explained **by two independent factors**



➤ Simplified schematic representation of mediation analysis



Introduction

Altruistic
(善意帮助)

Strategic
(策略性帮助)

Guilt

Gratitude

Guilt

Obligation

different motivations



Obligation

- the beneficiary may feel gratitude for receiving help
- also be accompanied by the feeling of guilt for personally burdening the benefactor.
- Both feelings motivate reciprocity out of concern for the benefactor

- arises from external pressures, such as social expectations and reputational costs
- linked to feelings of pressure, burden, anxiety, and resentment

Computational Models to predict reciprocity and help-acceptance decisions



repay the favor

by quantifying the tradeoff between the latent motivations of self-interest, communal concern, and obligation based on appraisals induced by the interpersonal task

Result

receiving a favor D_A from a benefactor A,
the beneficiary B chooses an action D_B
that maximizes his/her overall utility U

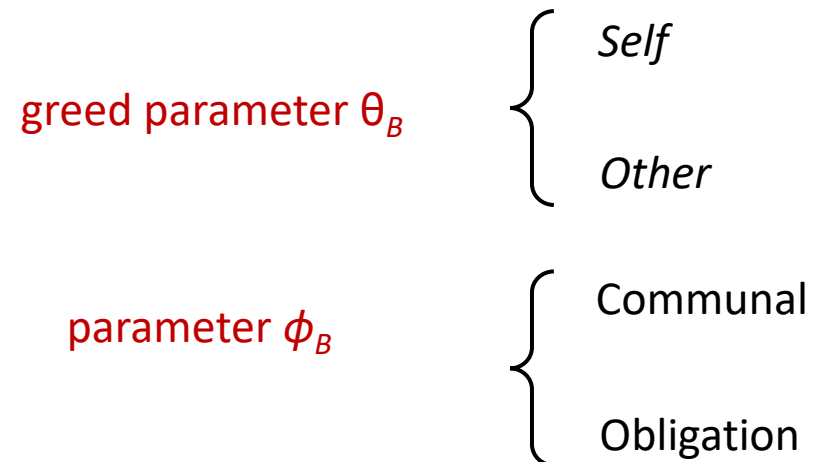


$$U(D_B) = \theta_B * \overset{\text{Self}}{\pi_B} + (1 - \theta_B) * \left(\overset{\text{Other}}{\phi_B * U_{Communal} + (1 - \phi_B) * U_{Obligation}} \right)$$



This utility is comprised of a mixture
of values arising from self-interest π
weighted by a **greed parameter θ**

feelings of communal concern $U_{Communal}$ and
obligation $U_{Obligation}$, which are inferred from the
appraisals of D_A and weighted by the **parameter ϕ**



Result

- a favor D_A from a benefactor A
- beneficiary B chooses an action D_B

$$U(D_B) = \theta_B * \pi_B + (1 - \theta_B) * (\phi_B * U_{Communal} + (1 - \phi_B) * U_{Obligation})$$

$U_{Communal}$ in terms of the appraisal of how much B believes A cares about their welfare (i.e., perceived care ω_B).

$U_{Obligation}$ as the appraisal of the amount of money that B believes A expects them to return (i.e., B 's second-order belief E_B'') normalized by B 's endowment size γ_B .

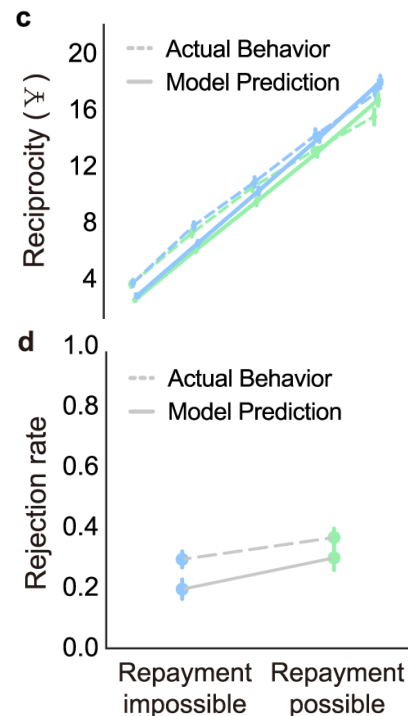
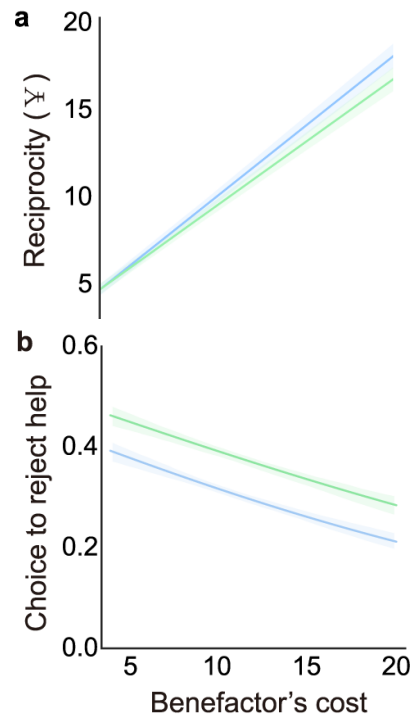
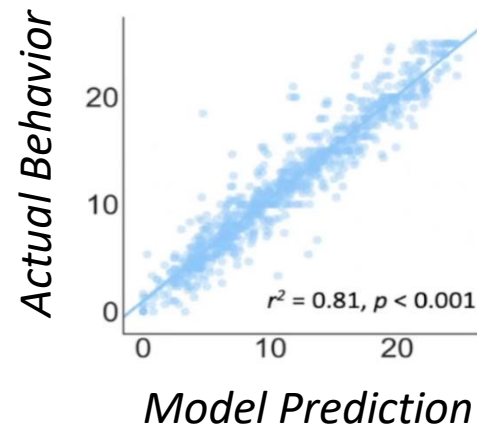
$$U_{Communal} = \begin{cases} -\left(\frac{\omega_B * \gamma_B - D_B}{\gamma_B}\right)^2 & \text{Reciprocity model} \\ \omega_B & \text{Help - acceptance model} \end{cases}$$

$$\omega_B = \frac{D_A - \kappa_B * E_B''}{\gamma_A}$$

$$U_{Obligation} = \begin{cases} -\left(\frac{E_B'' - D_B}{\gamma_B}\right)^2 & \text{Reciprocity model} \\ -\frac{E_B''}{\gamma_B} & \text{Help - acceptance model} \end{cases}$$

$$E_B'' = \begin{cases} 0 & \text{Repayment impossible condition} \\ D_A & \text{Repayment possible condition} \end{cases}$$

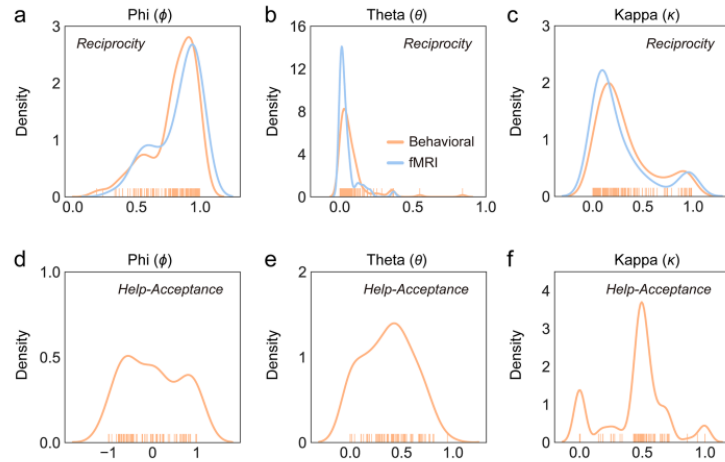
Result



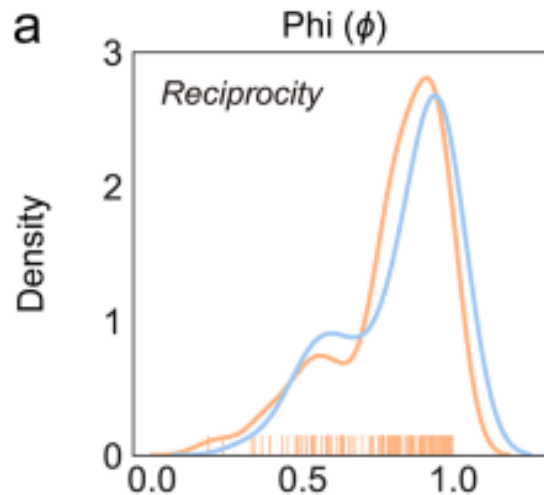
Model	Model description	Average Sum of Squared Error		
		Study 2a	Study 2b	Combined
Model 1.1	Nonlinear version	4331.00	3938.60	4123.90
Model 1.2	Linear version	5550.93	7177.44	6409.36
Model 1.3	Only communal concern	4773.74	5085.24	4938.14
Model 1.4	Only obligation	40365.60	33791.45	36895.91
Model 1.5	Three separate parameters independently weighted communal concern and obligation	4521.81	4134.60	4317.45
Model 1.6	Three separate parameters independently weighted greedy, communal concern and obligation	4466.52	3840.01	4135.86
Model 1.7	Reciprocity according to benefactor's cost	5475.37	5003.66	5226.41
Model 1.8	Inequity aversion model	13726.42	10080.51	11802.19

Result

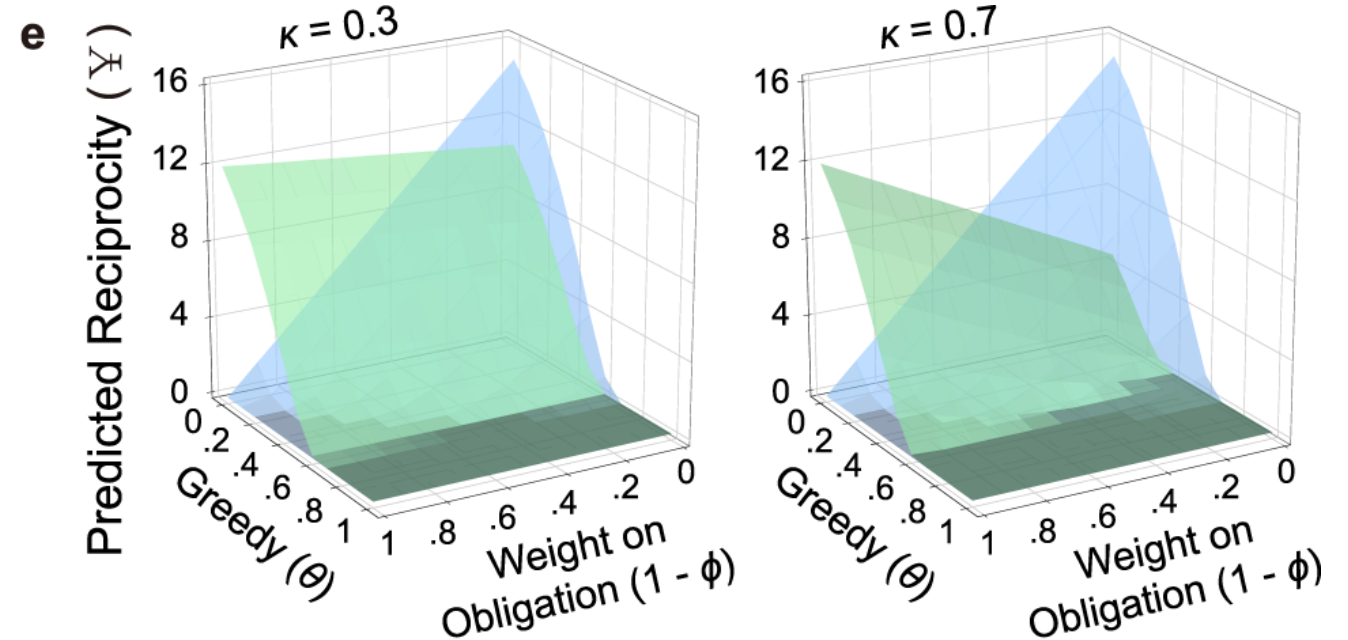
$$U(D_B) = \theta_B * \pi_B + (1 - \theta_B) * (\phi_B * U_{Communal} + (1 - \phi_B) * U_{Obligation})$$



Distributions of model parameters



Benefactor knows: — Repayment impossible — Repayment possible



Model **simulations** for predicted reciprocity behavior in Repayment impossible and Repayment possible conditions at different parameterizations

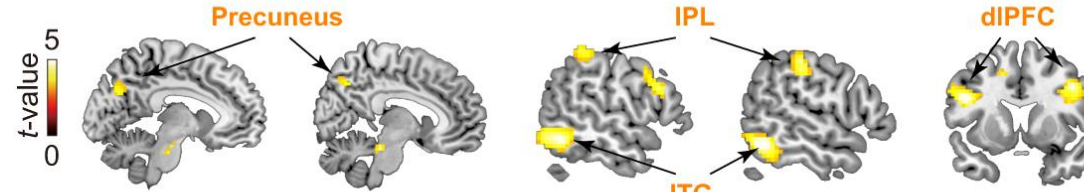
$K(\text{strategic intention}) \uparrow$ $1 - \Phi(\text{Weight on obligation}) \uparrow$ Reciprocity \uparrow

Result

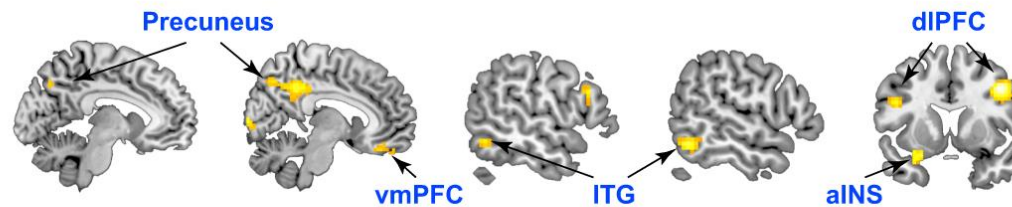
MVPA

meta-analytic decoding using the *Neurosynth* database

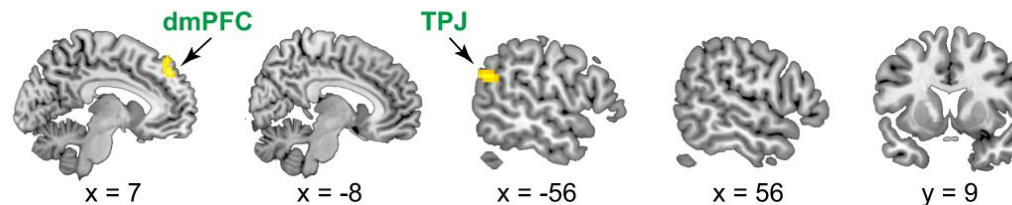
a Regions related to reciprocity processing



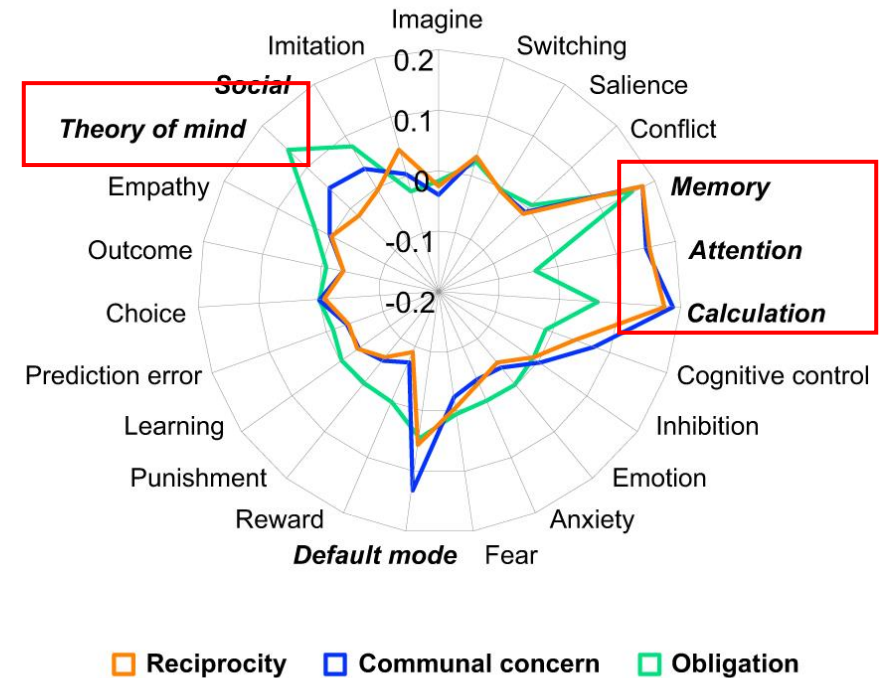
b Regions related to communal concern processing



c Regions related to obligation processing



d



Communal feelings related activity was similar to the reciprocity results, but was additionally associated with "Default mode" term.

linked to gratitude, positive social value, and kind intention

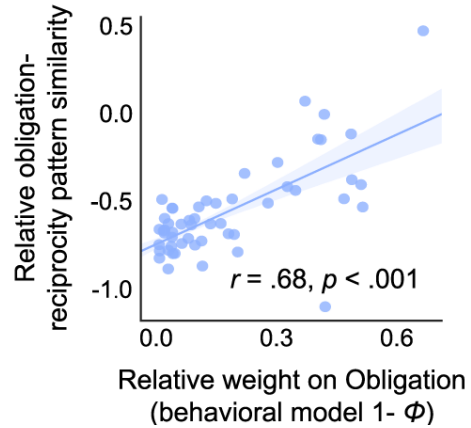
Obligation activity was highly associated with terms related to "Social," "Theory of mind (ToM)," and "Memory"

observed when representing other peoples' intentions or strategies

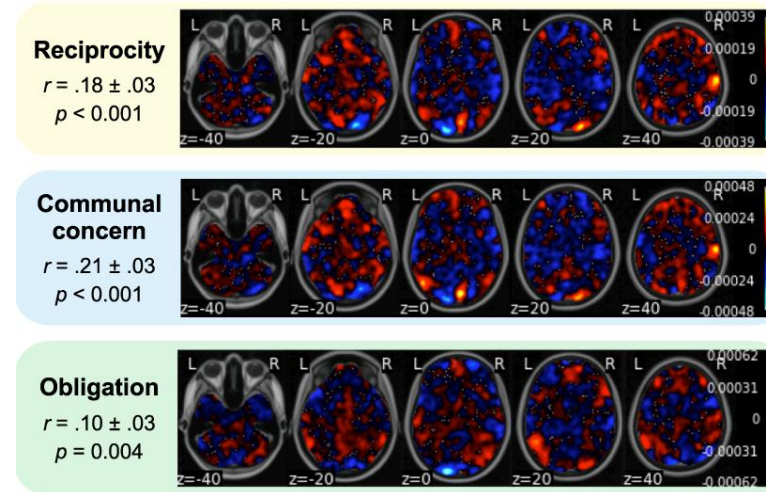
Result

Neural utility model of indebtedness

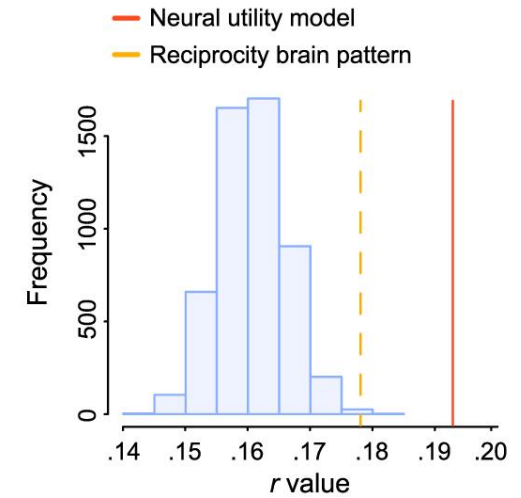
c Individual differences in spatial alignment of multivariate patterns



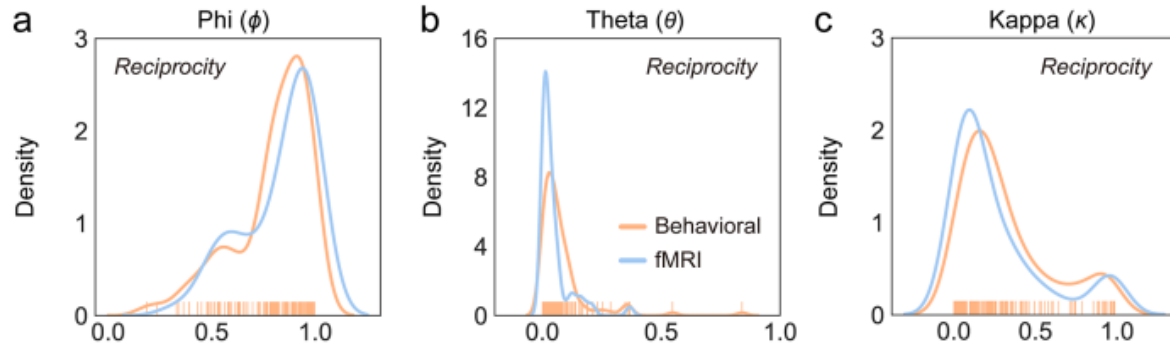
a Multivariate patterns for model components



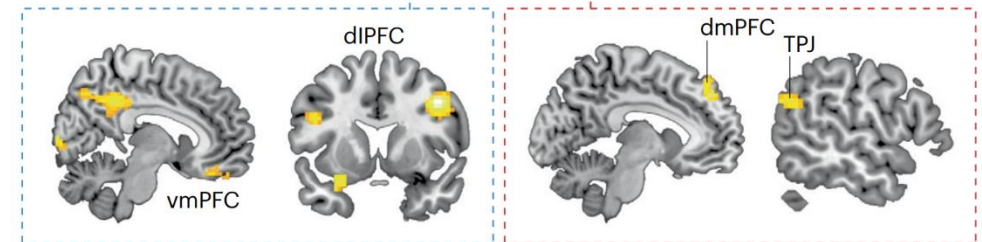
b Performance of the neural utility model



Neural utility model better than
Reciprocity brain pattern

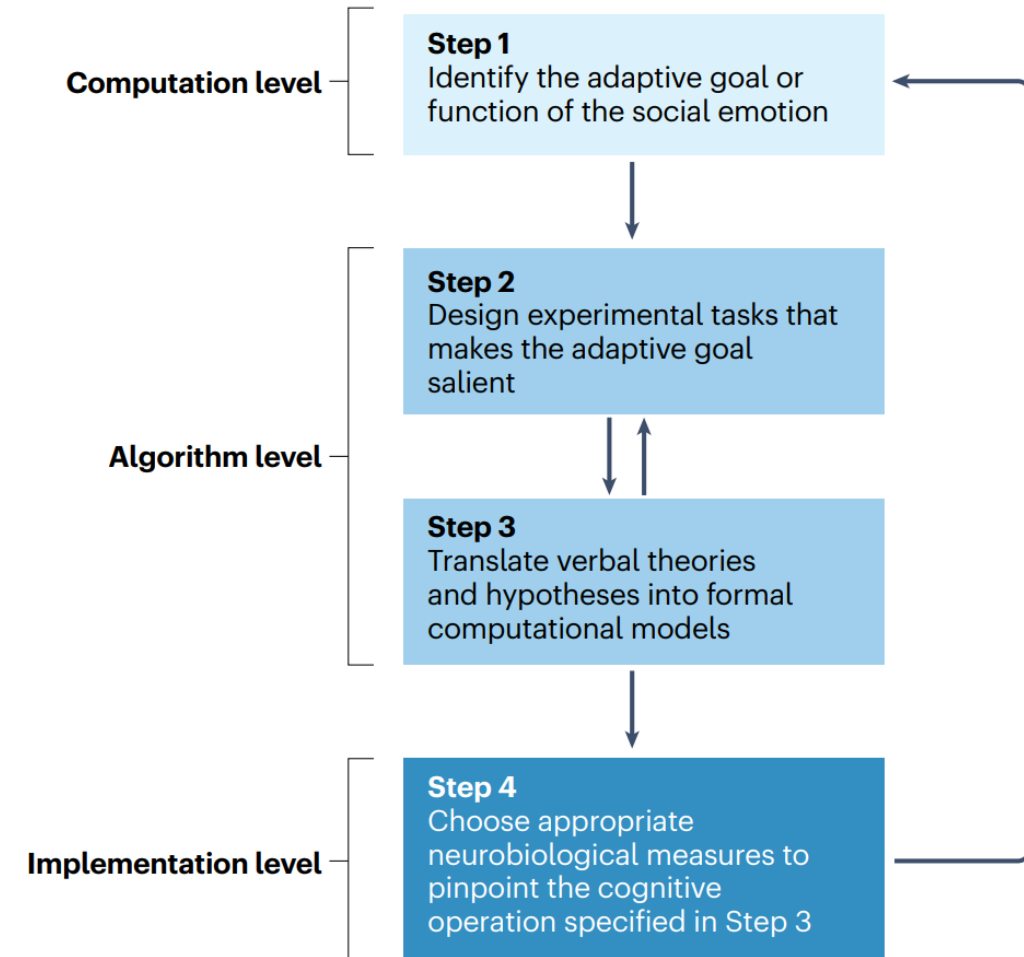
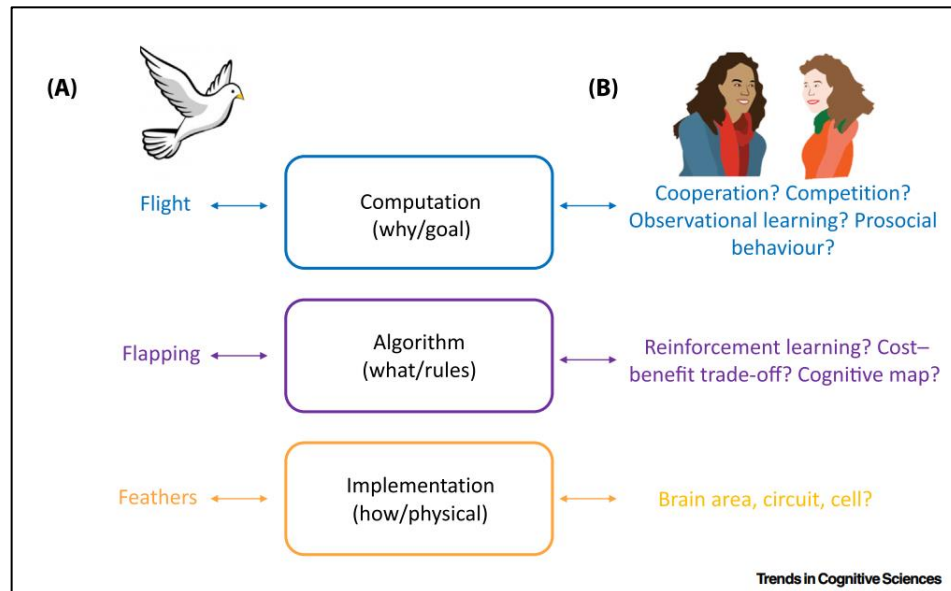


d
$$U(D_B) = \theta_B \times \pi_B + (1 - \theta_B) \times (\phi_B \times U_{\text{communal}} + (1 - \phi_B) \times U_{\text{obligation}})$$



Discussion

explore these hidden costs by developing and validating a conceptual model of indebtedness across three studies that combine a large-scale online questionnaire, an interpersonal game, computational modeling, and neuroimaging



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