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ABSTRACT

Gratitude arises when one is the target of an altruistic decision, particularly when this decision incurs cost to the agent. Here we examined how individuals evaluate others' altruistic decisions under risky (uncertainty with known probabilities) and ambiguous (uncertainty with unknown probabilities) costs and respond with gratitude and reciprocity. Participants played an interactive game in an fMRI scanner in which they would receive painful electric shocks. An anonymous co-player either intentionally (Human conditions) or unintentionally (Computer conditions) decided whether to help the participant reduce half of the pain by undertaking an amount of pain (i.e., cost) with varying level of uncertainty (Certain vs. Risky vs. Ambiguous). Participants could then transfer monetary points to the co-player knowing that the co-player was unaware of this transfer. Behaviorally, monetary allocation and gratitude rating increased as the uncertainty level of cost increased in Human conditions; these effects were reduced in Computer conditions. The effect of cost uncertainty on gratitude was mediated by the perceived kind intention behind the help. FMRI revealed both shared and differential neurocognitive substrates for evaluating the benefactor's altruistic decisions under risk and ambiguity: both were associated with fear- and anxiety-related processes, involving right lateral orbitofrontal cortex and anterior insula; ambiguity additionally recruited mentalizing- and conflict monitoring-related processes, involving dorsal medial prefrontal cortex and dorsal anterior cingulate cortex. These findings underscore the crucial role of social uncertainty perception in the generation of gratitude.

1. Introduction

Imagine that one day you are badly in need of money. One friend of yours knows that you need \$100 and decides to help you, while another friend decides to tide you over even before he knows the exact amount you need. Who would you be more grateful to? If we can benefit from the favors provided by both friends, why information about the factors influencing others' decision processes (e.g., knowled@onaboustlikite averilable catst, tainty of cost) should affect our feelings of gratitude and possibly reciprocal behaviors?

A large number of studies demonstrate that interpersonal gratitude,

as a moral indicator of benevolence and altruism (McCullough et al., 2001), could promote reciprocity and long-term relationships (Algoe et al., 2008; Bartlett and DeSteno, 2006; DeSteno et al., 2010; Tsang, 2006; Yu et al., 2017, 2018). Early research has demonstrated three major cognitive antecedents of gratitude, with the level of gratitude positively correlated with the perceived 1) benefactor's kind intention (i.e., the perceived care and benevolence from the help); 2) benefactor's exist, ScienceDirect

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1053-8119/© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/bynend/40/). benefactor's kind intention from these contextual factors, which enables individuals to recognize high-quality benefactors and build cooperative relationships (i.e., the find-remind-bind theory) (Algoe, 2012). Therefore, the perceived kind intention behind help may be a crucial factor that links other appraisals, such as benefactor's cost and self-benefit, to decisions under uncertainty. On the one hand, the simulation theory (Gallese and Goldman, 1998; Ondobaka et al., 2017) posits that in-

the cost faced by the co-player; otherwise, it would remain at Level 9. The participants' final monetary bonuses were the average amount of endowment the participants allocated to themselves over the randomly selected trials. The pain stimulation and monetary bonus for each participant were realized at the end of the whole experiment.

There were 6 possible combinations of Agent and Uncertainty level of the cost faced by the co-player during the Help trials, forming a 2 (Agent: Human vs. Computer) \times 3 (Uncertainty level of the cost faced by the co-player: Certain vs. **Risky**

follow the displayed information. To avoid this situation, we did not execute pain stimulation online for each trial; instead, the participant was told that after the experiment was completed, fi

multiple comparisons with the threshold of peak-level p<0.001 (uncorrected) and cluster-level p<0.05 (FWE-corrected). Statistical neu-

Human_Risky]. Similarly, if a term of psychological component was related to ambiguity-sensitive processing, the similarity between this term

although marginally significant for kind intention:

similar pattern was observed for gratitude ratings, although it did not reach statistical significance (Fig. S4B; $F_{2, 188} = 2.63$, p = 0.074). Moreover, although we did not find a significant Agent * Uncertainty level * gender interaction, we found a stronger main effect of Agent and a stronger main effect of Uncertainty level in intention ratings in females than in males (Fig. S4C; Agent * gender interaction: $F_{1, 93} = 4.80$, p =

demonstrate specificity, which is beyond the scope of the current study. Moreover, since the current study aimed to investigate how other's altruistic decisions under uncertainty influence individuals' gratitude, no post-hoc appraisals or emotion ratings were obtained for Nohelp conditions. Therefore, we were unable to build specific hypotheses for the neural analyses of Nohelp conditions based on behavioral observations. weigh the benefit of altruistic choice against the cost in various circumstances (Penner et al., 2004), in which the cost is usually uncertain. Although a number of studies have investigated how participants make altruistic decisions under uncertainty (e.g., Hu et al., 2017; Vives and Feldmanhall, 2018), it remains largely unknown as to how individuals perceive and respond to others' altruistic behaviors under different uncertain situations (e.g., ambiguity vs. risk). The current study contributes to the understanding of this issue by providing both behavioral and neuroimaging evidence in the context of interpersonal gratitude. Our results suggest that 1) perceived kind intention is a mediating factor for beneficiary's generation of gratitude when faced with other's help under uncertain cost; 2) there are both shared and differential neurocognitive processes of gratitude in response to benefactor's altruistic decisions in risky and ambiguous conditions.

4.1. Perceived kind intention as a mediating factor for the feeling of gratitude

Intention inference is crucial for social interactions (Falk et al., 2008; Falk and Fischbacher, 2006; Sanfey, 2007). According to theories of reciprocity (Fehr and Gächter, 1998; Fehr and Schmidt, 2006; Matthew Rabin, 1993), when an individual perceives the care and benevolence from another person, the utility of acting kindly towards this person increases. In studies of social psychology, individuals are more likely to trust and cooperate with those who engage in altruistic interactions under uncertainty than they do under certainty, as decisions under uncertainty are rarer than decisions under certainty (Hu et al., 2017; Vives and Feldmanhall, 2018) and reflect the concern about others' intention (Capraro and Kuilder, 2016; Jordan et al., 2016; Pérez-Escudero et al., 2016). Consistent with these studies, the current results provide novel evidence demonstrating that, the degree of beneficiary's gratitude varied as a function of the level of uncertaintynovelas a aversion in both risky and ambiguous situations when individuals make decision under uncertainty (

- Akitsuki, Y., Decety, J., 2009. Social context and perceived agency affects empathy for pain: an event-related fMRI investigation. Neuroimage 47, 722–734. https://doi.org/ 10.1016/j.neuroimage.2009.04.091.
- Algoe, S.B., 2012. Find, remind, and bind: the functions of gratitude in everyday relationships. Soc. Personal. Psychol. Compass 6, 455–469. https://doi.org/10.1111/ j.1751-9004.2012.00439.x.
- Algoe, S.B., Stanton, A.L., 2012. Gratitude when it is needed most: social functions of gratitude in women with metastatic breast cancer. Emotion 12, 163–168. https:// doi.org/10.1037/a0024024.
- Algoe, S.B., Haidt, J., Gable, S.L., 2008. Beyond reciprocity: gratitude and relationships in everyday life. Emotion 8, 425–429. https://doi.org/10.1037/1528-3542.8.3.425.
 Algoe, S.B., Fredrickson, B.L., Gable, S.L., 2013. The social functions of the emotion of
- gratitude via expression. Emotion 13, 605–609. https://doi.org/10.1037/a0032701. Ames, D.R., Flynn, F.J., Weber, E.U., 2004. It's the thought that counts: on perceiving how
- helpers decide to lend a hand. Pers. Soc. Psychol. Bull. 30, 461–474. https://doi.org/ 10.1177/0146167203261890. Barasch, A., Levine, E.E., Berman, J.Z., Small, D.A., 2014. Selfish or selfless? On the signal
- barasch, A., Levine, E.E., Bernan, J.Z., Sinan, D.A., 2014. Senish of seniess? On the signal value of emotion in altruistic behavior. J. Pers. Soc. Psychol. 107, 393–413. https:// doi.org/10.1037/a0037207.
- Barrett, L.F., Satpute, A.B., 2013. Large-scale brain networks in affective and social neuroscience : towards an integrative functional architecture of the brain. Curr. Opin. Neurobiol. 1–12. https://doi.org/10.1016/j.conb.2012.12.012.
- Bartlett, M.Y., DeSteno, D., 2006. Gratitude and prosocial behavior. Psychol. Sci. 17, 319–325. https://doi.org/10.1111/j.1467-9280.2006.01705.x.
- Bartra, O., McGuire, J.T., Kable, J.W., 2013. The valuation system: a coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. Neuroimage 76, 412–427. https://doi.org/10.1016/ j.neuroimage.2013.02.063.
- Belfi, A.M., Koscik, T.R., Tranel, D., 2015. Damage to the insula is associated with abnormal interpersonal trust. Neuropsychologia 71, 165–172. https://doi.org/ 10.1016/j.neuropsychologia.2015.04.003.
- Bell, S.B., DeWall, N., 2018. Does transcranial direct current stimulation to the prefrontal cortex affect social behavior? A meta-analysis. Soc. Cognit. Affect Neurosci. 13, 899–906. https://doi.org/10.1093/scan/nsy069.
- Bellucci, G., Chernyak, S.V., Goodyear, K., Eickhoff, S.B., Krueger, F., 2017. Neural signatures of trust in reciprocity: a coordinate-based meta-analysis. Hum. Brain Mapp. 38, 1233–1248. https://doi.org/10.1002/hbm.23451.
- Belmonte, M., Yurgelun-Todd, D., 2001. Permutation testing made practical for functional magnetic resonance image analysis. IEEE Trans. Med. Imag. 20 (3), 243–248. https:// doi.org/10.1109/42.918475.
- Blankenstein, N.E., Schreuders, E., Peper, J.S., Crone, E.A., van Duijvenvoorde, A.C.K., 2018. Individual differences in risk-taking tendencies modulate the neural processing of risky and ambiguous decision-making in adolescence. Neuroimage 172, 663–673. https://doi.org/10.1016/j.neuroimage.2018.01.085.
- Calhoun, V.D., Wager, T.D., Krishnan, A., Rosch, K.S., Seymour, K.E., Nebel, M.B., Mostofsky, S.H., Nyalakanai, P., Kiehl, K., 2017. The impact of T1 versus EPI spatial normalization templates for fMRI data analyses. Hum. Brain Mapp. 38, 5331–5342. https://doi.org/10.1002/hbm.23737.
- Camargo, A., Azuaje, F., Wang, H., Zheng, H., 2008. Permutation based statistical tests

- Jenkins, A.C., Mitchell, J.P., 2010. Mentalizing under uncertainty: dissociated neural responses to ambiguous and unambiguous mental state inferences. Cerebr. Cortex 20, 404–410. https://doi.org/10.1093/cercor/bhp109.Jones, R.M., Somerville, L.H., Li, J., Ruberry, E.J., Libby, V., Glover, G., Voss, H.U.,
- Jones, R.M., Somerville, L.H., Li, J., Ruberry, E.J., Libby, V., Glover, G., Voss, H.U., Ballon, D.J., Casey, B.J., 2011. Behavioral and neural properties of social reinforcement learning. J. Neurosci. 31, 13039–13045. https://doi.org/10.1523/ JNEUROSCI.2972-11.2011.
- Jordan, J.J., Hoffman, M., Nowak, M.A., Rand, D.G., 2016. Uncalculating cooperation is used to signal trustworthiness. Proc. Natl. Acad. Sci. Unit. States Am. 113, 8658–8663. https://doi.org/10.1073/pnas.1601280113.
- Kable, J.W., Glimcher, P.W., 2009. The neurobiology of decision: consensus and
- controversy. Neuron 63, 733–745. https://doi.org/10.1016/j.neuron.2009.09.003.Kappes, A., Nussberger, A.M., Faber, N.S., Kahane, G., Savulescu, J., Crockett, M.J., 2018.Uncertainty about the impact of social decisions increases prosocial behaviour. Nat.Hum. Behav. 2, 573–580.

- Woo, C.W., Koban, L., Kross, E., Lindquist, M.A., Banich, M.T., Ruzic, L., Andrews-Hanna, J.R., Wager, T.D., 2014. Separate neural representations for physical pain and social rejection. Nat. Commun. 5, 1–12. https://doi.org/10.1038/ncomms6380.
- Wood, W., Eagly, A.H., 2012. Biosocial construction of sex differences and similarities in behavior. In: Advances in Experimental Social Psychology. Elsevier Inc., pp. 55–123. https://doi.org/10.1016/B978-0-12-394281-4.00002-7
- Wood, A.M., Maltby, J., Stewart, N., Linley, P.A., Joseph, S., 2008. A social-cognitive model of trait and state levels of gratitude. Emotion 8, 281–290. https://doi.org/ 10.1037/1528-3542.8.2.281.
- Xiang, T., Lohrenz, T., Montague, P.R., 2013. Computational substrates of norms and their violations during social exchange. J. Neurosci. 33, 1099–1108. https://doi.org/ 10.1523/JNEUROSCI.1642-12.2013.
- Yarkoni, T., Poldrack, R.A., Nichols, T.E., Van Essen, D.C., Wager, T.D., 2011. Large-scale automated synthesis of human functional neuroimaging data. Nat. Methods 8, 665–670. https://doi.org/10.1038/nmeth.1635.
- Yu, H., Cai, Q., Shen, B., Gao, X., Zhou, X., 2017. Neural substrates and social consequences of interpersonal gratitude: intention matters. Emotion 17, 589–601. https://doi.org/10.1037/emo0000258.
- Yu, H., Gao, X., Zhou, Y., Zhou, X., 2018. Decomposing gratitude: representation and integration of cognitive antecedents of gratitude in the brain. J. Neurosci. 38, 4886–4898. https://doi.org/10.1523/JNEUROSCI.2944-17.2018.
- Zahn, R., Moll, J., Paiva, M., Garrido, G., Krueger, F., Huey, E.D., Grafman, J., 2009. The neural basis of human social values: evidence from functional MRI. Cerebr. Cortex 19, 276–283. https://doi.org/10.1093/cercor/bhn080.
- Zhu, L., Mathewson, K.E., Hsu, M., 2012. Dissociable neural representations of reinforcement and belief prediction errors underlie strategic learning. Proc. Natl. Acad. Sci. U.S.A. 109, 1419–1424. https://doi.org/10.1073/pnas.1116783109.