# Interplay of social and self interests during learning in early adolescence

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## Abstract

Navigating social environments requires individuals to consider how their actions impact both themselves and others, and to dynamically adjust expectations and actions in ways that satisfy social goals. Yet, little is known about how self-interest and social interests interact to shape learning in early adolescence—a time of significant social development. Here, we studied how 13- and 14-year-olds learn from outcomes relevant to both themselves and others. Compared with self-regarding learning, learning from social outcomes was generally weaker but exhibited substantial individual differences. These variations were captured by an error-driven learning process incorporating individual-level social preferences, supported by a social preference-weighted prediction error encoded in frontoparietal network. These data suggest a neurocomputational mechanism by which early adolescents reconcile multiple, and sometimes competing, social motives during learning.

**Keywords:** learning; social preference; adolescence; fMRI

## Instruction

Social interactions lie at the heart of human life: even small acts—like holding an elevator door—affect not only ourselves but also those around us. To navigate this inherently social world effectively, individuals must learn how their actions influence both personal and social outcomes, requiring ongoing reconciliation of self-interest and social interests. However, how early adolescents—who undergo rapid social development—implement such learning remains unclear.

Early adolescence is a pivotal developmental stage marked by increasing complexity of social roles and independence in navigating one's social environments (Andrews et al., 2021). During this period, adolescents exhibit heightened sensitivity to rewards (Davidow et al., 2016), rapidly changing social preferences (Blake et al., 2015; Sutter et al., 2018), and still-developing executive control (Crone & Dahl, 2012), making social learning particularly challenging as adolescents balance potentially competing personal and social goals. Understanding how adolescents manage this challenge is thus essential to uncovering the neurocognitive mechanisms enabling cooperative societies.

Computationally, reinforcement learning (RL) models have provided quantitative, neurobiologically plausible frameworks for understanding how individuals associate actions with outcomes (Lee et al., 2012). Yet standard RL algorithms incompletely account for the simultaneous learning of rewards accruing to oneself and others, especially when individual-specific social preferences dynamically influence these processes. While prior research has extensively studied how social preferences shape decision-making (Fehr & Camerer, 2007), how these preferences affect ongoing learning, particularly during early adolescence, is unclear.

Here, we address this gap by extending the classic RL framework to incorporate well-established theories of social preference. Combining a carefully designed social learning task, computational modeling, and fMRI, we investigate the neurocomputational mechanisms—and individual differences therein—through which early adolescents learn action outcomes tied to both their own and others' rewards.

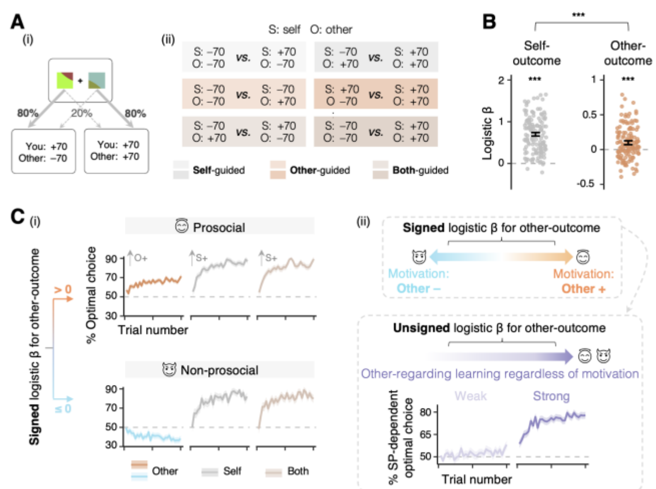


Figure 1: (**A**) Task design. (**B**) Mixed-effects logistic regression shows stronger learning from self-outcome than from other-outcome. (**C**) Individual differences in other-regarding learning. (i) Opposite learning curves between prosocial (β>0) and non-prosocial (β<0) groups in other-guided condition. (ii) Unsigned logistic β captures overall strength of other-regarding learning.

## Results

A total of 135 adolescents (ages 13–14), including 129 fMRI participants, completed a learning task with probabilistic rewards for both themselves and an anonymous social partner (Fig. 1A). On each trial, participants chose between two fractals, each predominantly linked to one of two reward allocations. The task comprised six allocation pairs, grouped into three conditions—*self-guided*, *other-guided*, and *both-guided*—depending on whether the self-outcome, other-outcome, or both were informative for learning.

**Behavioral results.** To assess adolescents' learning behavior, we performed a mixed-effects logistic regression examining how self- and other-outcomes influenced the likelihood of maintaining a choice. Both had significant positive effects ($P$s $\leq 4.8\times10^{-4}$), though the effect of self-outcome was stronger ($t_{134} = 14.20$, $P < 10^{-15}$; Fig. 1B), suggesting that adolescents prioritize self-interest over social interests during learning.

Interestingly, a considerable proportion of participants (36.3%) exhibited negative effects of other-outcome, implying a non-prosocial learning tendency—actively reducing rewards for others. Grouping participants by the sign of their logistic beta for other-outcome revealed opposite learning patterns specifically in the other-guided condition: prosocial learners (positive betas) increased optimal choices benefiting others, whereas non-prosocial learners (negative betas) decreased such choices over time (Fig. 1C, i). This led to the hypothesis that the unsigned logistic beta captures overall strength of other-regarding learning, regardless of its prosocial or non-prosocial direction. Supporting this, participants with larger unsigned betas showed stronger other-regarding learning (Fig. 1C, ii). These results indicate that while early adolescents engage in social learning, they differ in both its direction and strength, likely reflecting individual differences in social preferences.

To explore computational operations underlying these differences, we developed a social preference (SP)-weighted RL model, positing that adolescents' SPs modulate how they process rewards assigned to others. This model extends classic RL by introducing a parallel expected value for the other, updated by a separate other-prediction error (other-PE). Unlike self-PE following standard RL updates, other-PE is scaled by a factor ($\gamma$) combining multiple SP components—prosocial orientation, inequality sensitivity, and efficiency concern. Model comparisons against 12 alternatives confirmed that the proposed model best explained participants' choice behavior ($P$s $\leq 6.5\times10^{-4}$).

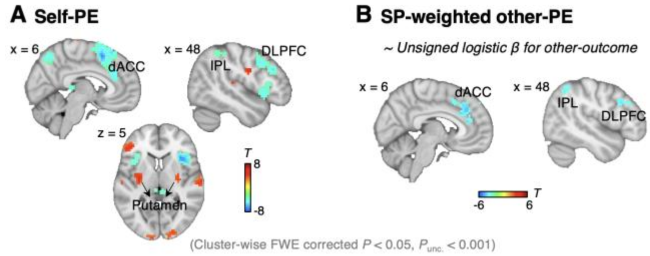


Figure 2: Neural encodings of self-PE (**A**) and other-PE (**B**) estimates derived from the model.

**Neural results.** We next tested whether fMRI activity reflected the model-derived PE estimates. At feedback, self-PE signals correlated positively with activity in the putamen, the area commonly associated with PE processing (Corlett et al., 2022), and negatively with activity in the dorsolateral prefrontal cortex (DLPFC), dorsal anterior cingulate cortex (dACC), and inferior parietal lobe (IPL)—regions overlapping with the frontoparietal network (FPN) that has been implicated in executive control (Zanto & Gazzaley, 2013) (Fig. 2A).

In contrast, SP-weighted other-PE estimates showed no significant correlation with brain activity among all subjects. However, a between-subject regression revealed that participants with stronger overall other-regarding learning (indexed by unsigned logistic beta for other-outcome) exhibited greater negative sensitivity to other-PE in FPN regions (Fig. 2B). More importantly, functional connectivity between these FPN regions and areas tracking inequality (amygdala) and efficiency signals (ventromedial prefrontal cortex) predicted individual differences in behavioral sensitivity to inequality and efficiency, respectively ($P$s $\leq 0.028$).

## Conclusions

These data suggest that early adolescents are capable of social learning, albeit with notable individual variability. This variability likely stems from differences in the development of FPN functioning, supporting the integration of social preferences into ongoing learning. Our findings thus offer a neurocomputational account of how early adolescents reconcile multiple social motives during learning, advancing our understanding of social behavior in uncertain environments at a critical developmental stage.

## Acknowledgements

This work is supported by the National Institutes of Health (DA051573 to PC & BC; AA029222 to PC; DA061024 to BC).

## References

Andrews, J. L., Ahmed, S. P., & Blakemore, S.-J. (2021). Navigating the Social Environment in Adolescence: The Role of Social Brain Development. *Biological Psychiatry*, *89*(2), 109–118. https://doi.org/10.1016/j.biopsych.2020.09.012

Blake, P. R., McAuliffe, K., Corbit, J., Callaghan, T. C., Barry, O., Bowie, A., Kleutsch, L., Kramer, K. L., Ross, E., Vongsachang, H., Wrangham, R., & Warneken, F. (2015). The ontogeny of fairness in seven societies. *Nature*, *528*(7581), 258–261.

Corlett, P. R., Mollick, J. A., & Kober, H. (2022). Meta-analysis of human prediction error for incentives, perception, cognition, and action. *Neuropsychopharmacology*, *47*(7), 1339–1349.

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature Reviews Neuroscience*, *13*(9), 636–650.

Davidow, J. Y., Foerde, K., Galván, A., & Shohamy, D. (2016). An Upside to Reward Sensitivity: The Hippocampus Supports Enhanced Reinforcement Learning in Adolescence. *Neuron*, *92*(1), 93–99.

Fehr, E., & Camerer, C. F. (2007). Social neuroeconomics: The neural circuitry of social preferences. *Trends in Cognitive Sciences*, *11*(10), 419–427.

Lee, D., Seo, H., & Jung, M. W. (2012). Neural Basis of Reinforcement Learning and Decision Making. *Annual Review of Neuroscience*, *35*(1), 287–308.

Sutter, M., Feri, F., Glätzle-Rützler, D., Kocher, M. G., Martinsson, P., & Nordblom, K. (2018). Social preferences in childhood and adolescence. A large-scale experiment to estimate primary and secondary motivations. *Journal of Economic Behavior & Organization*, *146*, 16–30.

Zanto, T. P., & Gazzaley, A. (2013). Fronto-parietal network: Flexible hub of cognitive control. *Trends in Cognitive Sciences*, *17*(12), 602–603.