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With you or against you: Social orientation dependent learning signals guide actions made for others

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ABSTRACT

In social environments, it is crucial that decision-makers take account of the impact of their actions not only for oneself, but also on other social agents. Previous work has identified neural signals in the striatum encoding value-based prediction errors for outcomes to oneself; also, recent work suggests that neural activity in prefrontal cortex may similarly encode value-based prediction errors related to outcomes to others. However, prior work also indicates that social valuations are not isomorphic, with social value orientations of decision-makers ranging on a cooperative to competitive continuum; this variation has not been examined within social learning environments. Here, we combine a computational model of learning with functional neuroimaging to examine how individual differences in orientation impact neural mechanisms underlying 'other-value' learning. Across four experimental conditions, reinforcement learning signals for other-value were identified in medial prefrontal cortex, and were distinct from self-value learning signals identified in striatum. Critically, the magnitude and direction of the other-value learning signal depended strongly on an individual's cooperative or competitive orientation toward others. These data indicate that social decisions are guided by a social orientation-dependent learning system that is computationally similar but anatomically distinct from self-value learning. The sensitivity of the medial prefrontal learning signal to social preferences suggests a mechanism linking such preferences to biases in social actions and highlights the importance of incorporating heterogeneous social predispositions in neurocomputational models of social behavior.

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Introduction

Navigating one's environment, whether it be foraging for food or interacting with social partners, requires evaluating available options and taking actions that are likely to benefit oneself. The application of formal learning models to the analysis of decision-related neural activity has begun to reveal the neural basis of computations underlying value-guided decision-making in humans (D'Ardenne et al., 2008; Daniel and Pollmann, 2014; Jocham et al., 2011). These data have shown that individuals learn the value associated with an action through experience by serially comparing expectations with outcomes (Krugel et al., 2009; Seymour et al., 2004; Sutton and Barto, 1998). Through this general process, humans dynamically learn how to value their actions and their environment, and dopaminergic signaling is believed to underlie these learning signals (Bayer and Glimcher, 2005; Delgado et al., 2008; den Ouden et al., 2010; Montague et al., 2006; Schultz et al., 1997).

This process becomes more complicated when making decisions that also impact others, whether friend, partner, adversary, or stranger. To successfully navigate such social transactions, it is crucial that decision-makers be able to assess (i) the value of the decision for oneself and (ii) the value of the decision to others, based upon one's own motivations toward oneself and the social partner. Previous studies have identified brain signals associated with outcomes delivered to oneself (Delgado et al., 2008; Galvan et al., 2005; Pessiglione et al., 2006; Ramnani et al., 2004) and outcomes delivered to others (Apps et al., 2013; Nicolle et al., 2012; O'Connell et al., 2013; Suzuki et al., 2012).

However, it is relatively less well understood how outcomes delivered to others are implemented in reinforcement learning environments.

Abbreviations: SVO, Social Value Orientation; mPFC, medial prefrontal cortex; PE_S, prediction error for outcomes (including negative rewards—e.g. −\$70) received for oneself (i.e. the decision maker); PE_O, prediction error for outcomes received by another person; Vs, value of outcome delivered to Self; Vo, value of rewards punishments delivered to Other.

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Behavioral research indicates that valuation of social outcomes, i.e. outcomes that involve other agents, depends on social preferences or motivations that can vary across individuals. For example, competitive types seek outcomes benefiting oneself at the expense of the social partner, while cooperative types seek outcomes benefiting both self and other (Fehr and Krajbich, 2014; Lurie, 1987; McClintock and Liebrand, 1988; Murphy and Ackermann, 2014). Studies of inequality aversion and guilt aversion have identified neural correlates of preferences over divisions of resources (Chang et al., 2011; Crockett et al., 2010; Fliessbach et al., 2007; Haruno and Frith, 2010; Tricomi et al., 2010), while measures of social value orientation have identified individual differences in neural correlates of these preferences (Haruno and Frith, 2010). However, the role of social preferences has not been taken into account in tasks that require learning the consequence of one's own action for social partners.

Here we examine the process by which decision-makers learn how actions map onto outcomes for others. In doing so, we first identify learning signals underlying value-based decision-making for others and differentiate these signals from value-based learning signals for oneself, replicating and extending previous research efforts; subsequently we show how these signals vary parametrically as a function of social value orientation. That is, in a large cohort of participants, we show that the direction and magnitude of learning signals based on the value of an outcome for a social partner vary with the cooperative or competitive orientation of the participant.

Materials and methods

Overview of procedures

Prior to scanning, the social value orientation (competitive, individualistic or cooperative) of participants was assessed through a parametric estimation by a sequential testing procedure (PEST; Luce, 2000). In this assessment, participants chose between allocations of an endowment between the participant and an anonymous social partner. Participants were then instructed that they would make a series of choices while in the MRI scanner (Fig. 1). Additionally, they were told that their payment and the payment of the anonymous social partner would be based on a random subset of their choices. Seventy-two participants underwent 3T fMRI as they performed six manipulations of an instrumental learning task. In each condition, participants chose between two square fractals that were probabilistically (80:20) related to gains or losses for the decision-maker and another, unknown to them, participant (for instance $70 for the participant and −$70 for the other participant). The manipulations varied in the magnitude and valence of value assigned to oneself and the value assigned to the social partner. The order in which blocks were presented was pseudorandomized across participants.

Participants

Ninety participants (mean age 27.37 years; 28 female) were recruited from a college and community sample. Ten participants were excluded following the social value orientation assessment described below, as the PEST (Luce, 2000) procedure did not produce reliable estimates across repeated measures. Seven additional subjects were excluded from neuroimaging analysis based on excessive movement during scanning. One subject was excluded as behavioral responses were not recorded for 40% of his/her trials. One condition [self −70/other −70; self +70/other +70] of a second subject was excluded for missing behavioral responses as well.

Social value orientation assessment (see Fig. SM1)

We employed a psychophysics-inspired non-learning choice task designed to assess social value orientation (SVO; (McClintock and Liebrand, 1988); (Kelly and Stahelski, 1970; Kuhlman and Marshello, 1975; Sattler and Kerr, 1991; Van Lange and Kuhlman, 1994)). During the PEST procedure, participants serially made preference choices between two allocations. Each allocation included a number of points for the participant and a number of points to another anonymous participant. The two allocations were represented by a pair of numbers placed

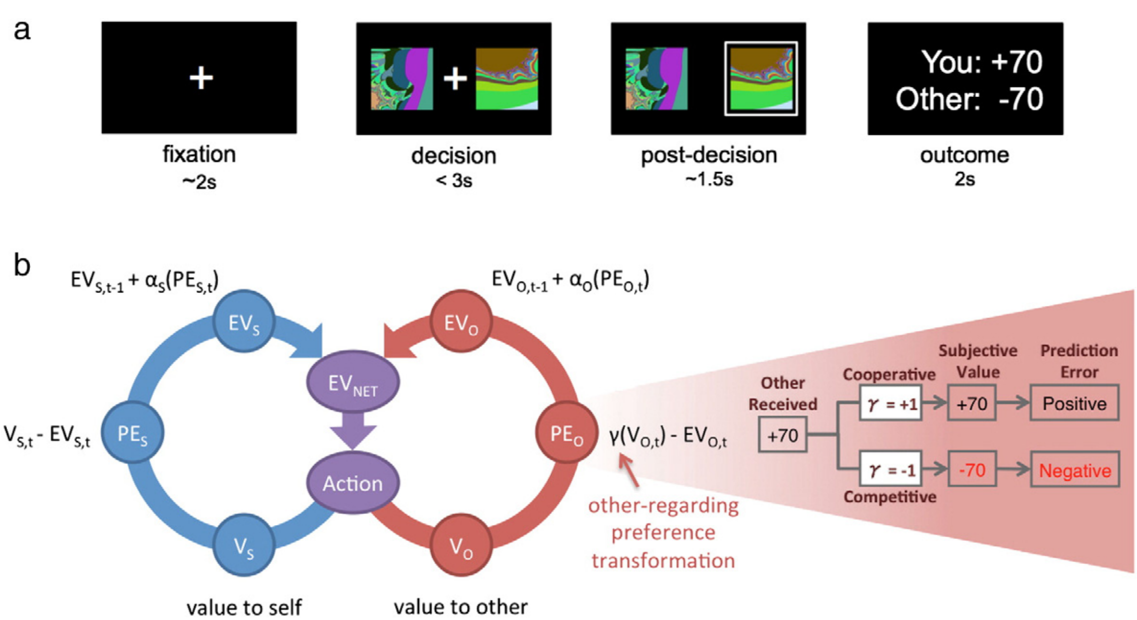

Fig. 1. Social value learning task and learning model. (a) Each trial began with a fixation cross (~2 s) indicating the onset of a new trial. Two unique fractal stimuli representing two decision options were displayed until a decision was submitted by keypress (limited to 3 s). The chosen stimulus was subsequently framed for ~1.5 s, after which the outcomes for the decision-maker and the social partner were revealed for 2 s. In each of six conditions, each participant made 30 choices between two options associated with probabilistic gain (or loss) for the decision-maker, as well as probabilistic gain (or loss) for a social partner. (b) Hybrid learning model of self-value and preference-dependent other-value. Choices produced an outcome for the actor and a different outcome for the social partner simultaneously. Following typical reinforcement learning algorithms, rewards received for self (blue circle) update the expected value (EV) of a choice at time t via prediction errors (PE) weighted by a learning rate (α). Rewards that are delivered to the social partner (red circle — 'other') are also updated by the same mechanism with the difference that the value is subjectively transformed (pink inset) according to social preferences, represented by the γ coefficient. For example, a competitive orientation will transform a positive outcome to a negative subjective value, thus producing a negative prediction error.