Rawlsian maximin rule operates as a common cognitive anchor in distributive justice and risky decisions

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Distributive justice concerns the moral principles by which we seek to allocate resources fairly among diverse members of a society. Although the concept of fair allocation is one of the fundamental building blocks for societies, there is no clear consensus on how to achieve "socially just" allocations. Here, we examine neurocognitive commonalities of distributive judgments and risky decisions. We explore the hypothesis that people's allocation decisions for others are closely related to economic decisions for oneself at behavioral, cognitive, and neural levels, via a concern about the minimum, worst-off position. In a series of experiments using attention-monitoring and brain-imaging techniques, we investigated this "maximin" concern (maximizing the minimum possible payoff) via responses in two seemingly disparate tasks: third-party distribution of rewards for others, and choosing gambles for self. The experiments revealed three robust results: (*i*) participants' distributive choices closely matched their risk preferences—"Rawlsians," who maximized the worst-off position in distributions for others, avoided riskier gambles for themselves, whereas "utilitarians," who favored the largest-total distributions, preferred riskier but more profitable gambles; (*ii*) across such individual choice preferences, however, participants generally showed the greatest spontaneous attention to information about the worst possible outcomes in both tasks; and (*iii*) this robust concern about the minimum outcomes was correlated with activation of the right temporoparietal junction (RTPJ), the region associated with perspective taking. The results provide convergent evidence that social distribution for others is psychologically linked to risky decision making for self, drawing on common cognitive–neural processes with spontaneous perspective taking of the worst-off position.

distributive justice | risky decisions | maximin rule | perspective taking | right temporoparietal junction

The "Occupy Wall Street" protests in New York garnered worldwide attention, highlighting growing concerns about wealth inequality. A remarkable feature of the protests was that not only the financially disadvantaged but middle-class citizens, who were relatively wealthy in the current economy, also joined the movement. Traditional economic models that assume utility only for self-related outcomes (1, 2) fail to explain such a mass phenomenon.

However, there is one important psychological dimension that seems to characterize the wide civic involvement in the movement yet has been unaddressed in cognitive and social neuroscience—concern about the lowest, worst-off outcomes. Notice that, in the "Occupy" protests, people were not just concerned about the inequality (variance) of wealth distribution generally, but specifically advocated increasing the incomes of society's most disadvantaged. John Rawls, an eminent modern social philosopher, similarly argued that the benefit to the least well-off should be maximized according to the "maximin principle" (maximizing the minimum possible payoff) (3). Indeed, several behavioral studies suggest that such concerns about minimums may operate as a strong psychological anchor not only in social distributions for others but also in economic decisions for oneself. Research using behavioral games has shown that, when making distributive choices for others, people generally prefer to improve everyone's payoffs but are more concerned about raising the payoffs of the worse-off individuals than the better-off individuals (4–7). Similarly, in the risky-decision–making literature, parallel evidence is emerging that people often pay particular attention to their worst possible payoff as well as the expected mean when choosing among gambles (8, 9). Maximin strategies (those that maximize the minimum outcome) in risky choices are also used by some nonhuman animals during foraging (10), which likely reflects that real-world concerns about risk are often dominated by the rarest but most disastrous outcome (11). However, the neural circuitry that may underlie this common maximin concern remains unknown.

A recent and growing body of evidence suggests that social decisions for others may involve similar neural circuitry to that of economic decisions for oneself (12–18). Using functional magnetic resonance imaging (fMRI), Shenhav and Greene (13) showed that moral judgments about human life and death recruit "domain-general" valuation mechanisms to integrate probability

Significance

Distributive justice is a highly controversial issue across many societies. Compared with the accumulation of various normative ("ought") theories by philosophers over the centuries, our empirical ("is") understanding of people's distributive judgments remains insufficient. In a series of experiments, we show that the "maximin" concern (maximizing the minimum possible payoff) operates as a strong cognitive anchor in both distributive decisions for others and economic decisions for self, and that the right temporoparietal junction, associated with perspective taking, plays a key role in this linkage. Our approach illustrates how rigorous methods from behavioral, cognitive, and neural sciences can be combined to shed light on functional elements of distributive justice in our minds, and potential neural underpinnings shared by other nonsocial decisions.

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and magnitude; as in economic decisions under risk (15–18), in moral judgments the anterior insula (AI) was sensitive to probability (i.e., variability of losing/saving lives), whereas the putamen was responsive to magnitude (i.e., number of lives lost/saved). Likewise, Hsu et al. (14) showed that, when allocating resource to others as a third party, the AI was responsive to inequality in resources among the recipients (Gini coefficient), whereas the putamen was responsive to overall efficiency of allocation (the total amount allocated). These studies suggest that moral or distributive judgments for others may be linked to economic decisions for self, through a common neural circuitry that responds to the variance/inequality and magnitude/efficiency parameters of a decision task separately.

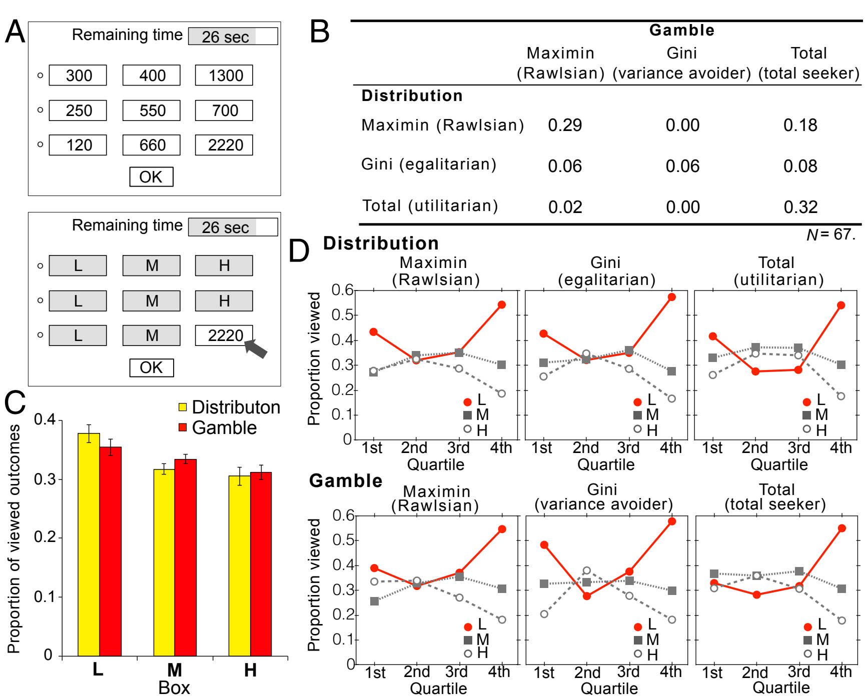
Here, we investigate the hypothesis that distributive judgments may also be linked to risky decisions psychologically via another parameter—spontaneous concern about the minimum, worst-off position. Although ecologically the minimum parameter is often correlated with the variance/inequality parameter, they are conceptually distinguishable from each other (3, 11, 19). We conjecture that perspective taking may be a key to understanding the potential linkage between distributive and risky decisions. Perspective taking here means mentally simulating a different standpoint (20–25)—how one would feel if placed in situations that differ physically or temporally ("other/future") from one's immediate environment ("myself/now"). Choosing a distribution as a third party often entails taking the perspectives of those affected by the decision (3, 19). Making risky financial decisions also requires mental simulations about one's potential future conditions (20–22). Recent neural evidence suggests that economic decisions involve taking the perspective of one's "future self" to evaluate possible outcomes at a distant time (26).

Of course, ideologies and choice preferences vary across individuals, ranging from "Rawlsian" [maximizing the minimum (3)] to "utilitarian" [overall maximizing (19, 27)] in distributions for others (4–7, 14), and from risk avoiding to risk seeking in economic decisions for self (8–11). However, we predict that, across tasks and individual differences, the minimum, worst-case scenario will tend to be a primary locus of perspective taking and function as a spontaneous cognitive anchor. We first test this thesis behaviorally using an attention-monitoring technique (28). Then we examine potential neural underpinnings of such a maximin bias using a brain-imaging technique with a focus on the right temporoparietal junction (RTPJ)—the brain region known to play a crucial role in perspective taking to infer others' experiences (20–25) and in shifting attention away from the here-and-now to imagine one's own experiences in different situations (20–22, 26, 29).

Experiment 1 (Behavioral Experiment)

Task. To investigate the connection between seemingly disparate decisions about distributions for others and gambles for self, we first conducted a behavioral experiment. Sixty-seven participants were provided three options in each trial (Fig. 1*A*, *Top*): one with the largest minimum (maximin), one with the smallest variance in terms of the Gini coefficient, and one with the largest total. We tracked participants' information search behavior during decision making using the Mouselab technique (28). On the screen, numerical outcome information was hidden behind boxes labeled "L," "M," or "H" (Fig. 1*A*, *Bottom*). When the mouse pointer was held over a box, its numerical information was displayed, and when the pointer was moved away, the information was hidden again, so that participants could only view one box at a time. Participants had to make choices within 30 s in each trial, during which they were free to view any boxes in any order. Participants made one set of 40 third-party distribution choices, from which one was randomly designated as a real reward allocation for three unknown others participating in a different ongoing experiment (14). Participants also made another set of 40 choices as gambles for themselves, with one choice randomly designated as the lottery from which one of the three outcomes would be randomly selected as their own real reward (*Materials and Methods*). The numerical structure of the choice options was identical across the two tasks (Table S1), task order was counterbalanced across participants, and presentation order of the 40 choice sets within each task was randomized.

Results. We first analyzed participants' behavioral choices. The maximin option was chosen more frequently in distributions [mean (M) = 16.4 of 40 choices] than in gambles (M = 14.4) [$F_{(1,66)} = 25.79$; $P < 0.0001$], indicating that the maximin concern is more pronounced in social distributions for others than in gambles for self.



	Gamble		
	Maximin (Rawlsian)	Gini (variance avoider)	Total (total seeker)
Distribution			
Maximin (Rawlsian)	0.29	0.00	0.18
Gini (egalitarian)	0.06	0.06	0.08
Total (utilitarian)	0.02	0.00	0.32

N = 67.

Fig. 1. Stimulus and results from the behavioral experiment. (*A*) A numerical example (in yen) of the three choice options (*Top*) and "Mouselab" interface (*Bottom*) displayed to participants. Numerical outcome information, initially hidden behind boxes labeled L, M, or H (low, medium, or high), was displayed only when participants held the pointer over a box. Column order was counterbalanced across participants (LMH or HML). Row order of the three options was randomized across participants and choice sets in each task. (*B*) Consistency of participants' types in the two tasks, displayed as proportion classified as each type by their most frequent choices [χ^2 (4) = 37.20; $P < 0.0001$]. Interpretive labels provided in parentheses. (*C*) Average proportion of L, M, or H views preceding choices. Participants viewed L boxes most frequently in both tasks [$F_{(2,264)} = 35.15$; $P < 0.0001$]. Error bars represent SEM. (*D*) Temporal changes in the average proportions of L, M, or H views when decision time used by each participant in each trial was divided into quartiles, as a function of task and participant type. The selective focus on minimums (shown in red) was largest in the final quartile of decision time in each trial [$F_{(2,80)} = 117.31$; $P < 0.0001$].

Choice concordance. Interestingly, however, individuals' choice preferences were highly consistent across the two tasks. In Fig. 1*B*, we classified participants into three "types" according to their most frequent choices in each task. Rawlsians, who chose maximin reward allocations for others most frequently, also favored maximin gambles most for themselves, whereas utilitarians, who favored the largest-total distributions, also preferred the largest-total gambles most. The infrequent "Gini" type (making up only 6% of participants), who preferred the least variable option most in gambling for themselves, were all classified as "egalitarians," choosing relatively equal social distributions most frequently [χ^2 (4) = 37.20; $P < 0.0001$]. To examine individual choice differences in a continuous (rather than discrete) manner, we also analyzed each participant's preferences using an economic model ["quasi-maximin model" (6)]. Applied to our three-outcome (π_1, π_2, π_3) cases, the model posits that the utility of option x for participant i is given by the following:

$$U_i(x) = \alpha_i \cdot \min[\pi_1,\pi_2,\pi_3] + (1-\alpha_i)\cdot(\pi_1+\pi_2+\pi_3), \qquad [1]$$

where $\alpha_i \in [0, 1]$ captures the individual weight reflecting the maximin principle. Setting $\alpha = 1$ in distributions corresponds to pure Rawlsian preferences, in which the welfare of the option is measured solely by the maximin principle, whereas setting $\alpha = 0$ in distributions corresponds to pure utilitarian preferences. For each participant, we estimated the maximin weight, α_i, for distributions ($\alpha_{\text{distribution}}$) and for gambles ($\alpha_{\text{gamble}}$) separately. As shown in Fig. S1, participants who favored the maximin distributions for others (higher $\alpha_{\text{distribution}}$) tended to prefer the maximin gambles for themselves (higher α_{gamble}) ($\rho = 0.54$; $P < 0.0001$). Also, mean α was greater in distributions ($M = 0.62$) than in gambles ($M = 0.44$) [$F_{(1,65)} = 14.39$; $P = 0.001$], corroborating the more frequent maximin choices in distributions than in gambles (for details, see *SI Materials and Methods*, *Economic model for maximin weight estimation*).

It could be argued that these behavioral consistencies were simply the result of the common stimulus features (i.e., the same display format and numeric structure) shared between the two tasks. However, responses on a separate risk attitude measure (30) in the postsession questionnaire, which had a totally different display format and numerical structure, revealed the same pattern (Fig. S2). Utilitarians, as classified according to their most frequent choices in distributions, were more risk seeking than the other two types (Rawlsians and egalitarians) [$F_{(2,56)} = 9.80$; $P < 0.001$], confirming the coherence between distributive and risk preferences.

Information search. More importantly, information search behavior preceding participants' choices was also remarkably similar between the two tasks. On average, participants viewed L (low) boxes most frequently in both tasks [$F_{(2,264)} = 35.15$; $P < 0.0001$] (Fig. 1*C*; see also Fig. S3). To examine the time course of information search behavior, we divided the decision time used by each participant in each trial into quartiles. Fig. 1*D* displays information search in each quartile as a function of task and participant type. The selective focus on minimums (shown in red) was largest in the final quartile of decision time in each trial, which persisted across participants [$F_{(2,80)} = 117.31$; $P < 0.0001$]. Confirming minimums just before the choice was dominant across tasks and participant types.

It should be noted that the third-party reward allocation implemented in this experiment involved zero monetary risk for participants themselves. However, participants' distributive preferences for others matched their own risk preferences, and most importantly, spontaneous focus on the worst cases characterized participants' thinking about both distributions for others and gambles for self. Taken together, these behavioral and cognitive similarities suggest that distributive judgment may be psychologically linked to risky decision making through spontaneous maximin concern.

Experiment 2 (fMRI Experiment)

Task. To examine our hypothesis that perspective taking (3, 19–26, 29)—the cognitive ability to adopt a different viewpoint beyond one's immediate situation (myself/now)—is a key to the behavioral–cognitive linkage between the two distinct decisions, we conducted an fMRI experiment. Similar to the behavioral experiment, 30 participants made 36 distribution decisions for unknown others as a third party and 36 gamble choices for themselves (Table S2). Participants had two options in each trial (*Materials and Methods*).

Region of Interest. Recent neural evidence suggests that the RTPJ plays a crucial role in adopting a different viewpoint and shifting attention away from one's own immediate environment to others (20–25) and to different times and locations (20–22, 26, 29). This region has also been implicated in empathy (31), moral reasoning (32, 33), and altruistic behavior (34, 35), for which perspective taking is required. Although previous studies on gambling have not addressed the role of perspective taking directly, they have also reported value-related activity in the intraparietal cortex, located near the TPJ (36, 37). Thus, we chose the RTPJ as the region of interest. Our behavioral experiment above revealed that participants generally directed spontaneous attention to the worst possible outcomes in both distributions for others and gambles for self. If, as we hypothesized, such selective attention reflects participants' perspective taking of the worst-case scenarios, we predict that the RTPJ will be activated to track how choice options compare in terms of the worst possible outcomes (i.e., the maximin criterion) while participants make decisions in both tasks.

Results. We first confirmed the behavioral-level coherence in participants' responses between distributions for others and gambles for self.

Choice concordance. As in the behavioral experiment, participants' types according to their most frequent choices were consistent across the two tasks ($P = 0.004$ by Fisher's exact test) (Table S3). Fig. 2*A* shows scatterplots of the maximin weight, α_i, for distributions and for gambles, estimated by the economic model (Eq. **1**). The maximin weights were correlated across the two tasks ($\rho = 0.48$; $P = 0.007$), whereas mean α was greater in distributions ($M = 0.22$) than in gambles ($M = 0.10$) [$F_{(1,54)} = 5.63$; $P = 0.018$].

RTPJ activity. Having replicated the behavioral results, we then examined neural responses (*SI Materials and Methods*, *Image processing and statistical analysis*). As the quasi-maximin model (Eq. **1**) provided the best fit to the behavioral-choice data in the model selection (Table S4), we first analyzed how RTPJ activity responded to the maximin parameter. We regressed RTPJ activity during decision making to absolute difference in minimum (ΔMin) between the two options, that is, a parameter representing the superiority of one option to the other on the maximin criterion (see Fig. S4*A* for illustration). If participants' perspective taking focuses on the worst-off position, it is expected that RTPJ activity will track how the two options compare in terms of minimum outcomes. As expected (Fig. 2*B*, solid circle), RTPJ activation increased with ΔMin between the two choice options in both distributions ($T = 4.47$, $P_{\text{FWE}} = 0.001$ with the peak at $x = 42$, $y = -64$, $z = 25$) and gambles ($T = 3.14$, $P_{\text{FWE}} = 0.043$ with the peak at $x = 44$, $y = -66$, $z = 18$). To see that this RTPJ activity is dissociable from the other two task parameters (ΔTotal: the absolute difference in total; ΔGini: the absolute difference in Gini between the two choice options), we then included these parameters in the regression. As seen in Fig. 2*C*, the RTPJ responded to ΔMin only. Thus, as predicted, the RTPJ tracked the superiority of one choice option to the other by the maximin criterion in both tasks (see also Fig. S5 and Table S5).

Functional connectivity. To see how such RTPJ activity may be functionally connected to other brain regions, we next conducted a psychophysiological interaction (PPI) analysis. The quasi-maximin model (Eq. **1**) posits that the minimum outcome is linearly integrated into the option's utility by the maximin weight α.

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Given the involvement of RTPJ in tracking minimum outcomes, the economic model predicts that RTPJ activity will be linearly related to overall valuation of the choice option. Because previous studies found that caudate activity correlated with valuation of options in resource allocations for others (14, 38) (see also Table S6), we focused on the caudate in the PPI analysis (*SI Materials and Methods*, *Connectivity analysis*). As predicted, RTPJ activity was connected to activity of both left and right caudates while participants made decisions in both tasks (Fig. 2*B*, dotted oval). Furthermore, the mean RTPJ–caudate connectivity was stronger in distributions for others than in gambles for self ($T = 2.83$; $P < 0.007$) (Fig. 2*D*), corroborating the behavioral result that the mean α was greater in distributive choices ($M = 0.22$) than in gambling choices ($M = 0.10$; Fig. 2*A*).

Individual differences. So far, we have reported results from a group-level analysis, but it remains to be seen how individual choice differences may relate to the neural responses observed during decision making. Although behavioral data from the two experiments consistently showed that the maximin concern was generally more pronounced in distributions for others than in gambles for self, the degree of this elevation varied widely across participants (Fig. 2*A*). We thus examined neural correlates of these individual behavioral differences. For each participant, we calculated the degree of enhanced maximin concern in distributive choices over gambling choices ($\alpha_{\mathrm{distribution}} - \alpha_{\mathrm{gamble}}$). As the RTPJ–caudate connectivity was stronger in distributions than in gambles at the group level (Fig. 2*D*), we also calculated the differences in connectivity between the two tasks (contrast estimate$_{\mathrm{distribution}}$ − contrast estimate$_{\mathrm{gamble}}$) for each participant. Fig. 2*E* shows scatterplots of these two individual scores. The correlation was significant ($\rho = 0.39$; $P < 0.05$).

Abstract numeric comparison. Finally, it could be argued that the observed commonality of the RTPJ activation between the two tasks in the main fMRI experiment might simply result from the abstract numeric comparison per se, without necessarily being related to distributive or gambling contexts. Therefore, we conducted an additional fMRI experiment using a simple calculation task, in which a different set of participants ($n = 21$) compared two numeric options in terms of minimum, mean, or variance without any specific decisional context (for details of the procedure and results, see *SI Materials and Methods*, *Follow-Up fMRI Experiment* and Fig. S6). Brain activity during the abstract numeric tasks was situated in the superior temporal gyrus and the supramarginal gyrus. In contrast, the peak RTPJ coordinates in the main experiment were located in the angular gyrus, corresponding to the "canonical social TPJ," which was identified by a recent comprehensive metaanalysis (39) using the Neurosynth database (neurosynth.org) with more than 10,000 fMRI studies. The results confirmed that the RTPJ activity in the main fMRI experiment is clearly distinct from the brain activity involved in this abstract numeric comparison.

Taken together, these convergent results provide strong evidence for our prediction that the RTPJ, the region associated with perspective taking (20–26, 29), tracks the superiority of one choice option to another by the maximin criterion in both distributions for others and gambles for self.

Discussion

Distributive justice is one of the most fundamental building blocks for organizing societies. However, compared with the accumulation of various normative theories by philosophers over the centuries (e.g., refs. 3, 19, 27, and 40), our empirical understanding of people's distributive judgments remains insufficient. In a series of experiments using attention-monitoring and brain-imaging techniques, we investigated the hypothesis that distributions for others may be psychologically linked to

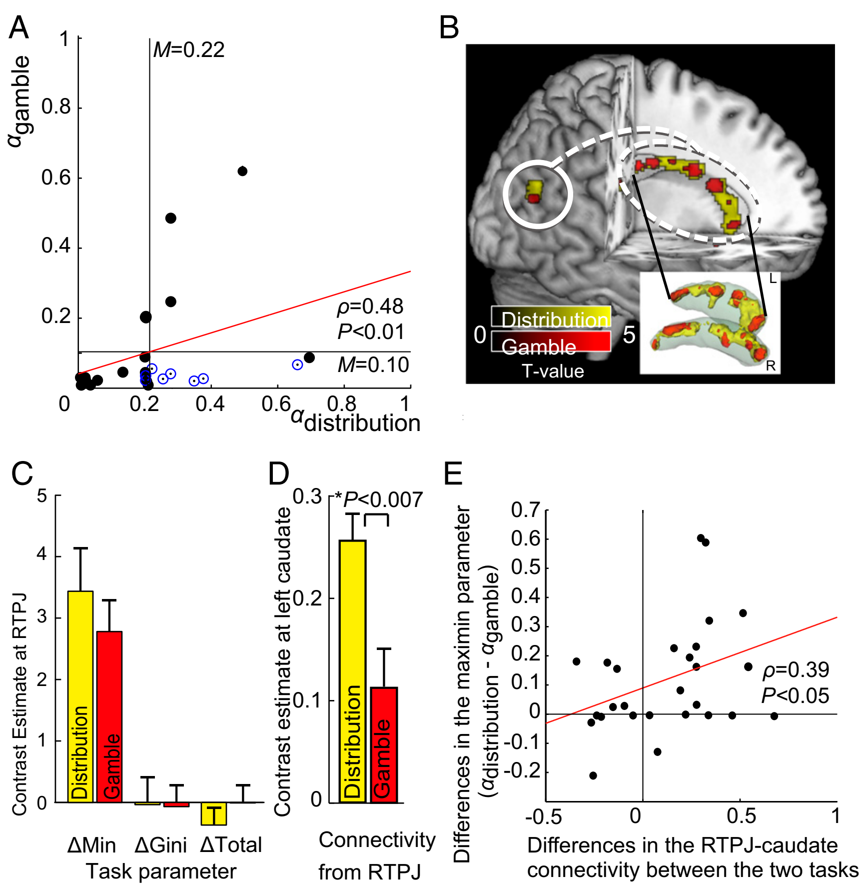

Fig. 2. Results from the fMRI experiment. (*A*) Concordance of individual maximin weights between distributions ($\alpha_{\mathrm{distribution}}$) and gambles ($\alpha_{\mathrm{gamble}}$). Points colored in blue correspond to the participants classified as Rawlsians in distributions for others but largest-total seekers in gambles for self according to their most frequent choices (Table S3). Spearman rank correlation between $\alpha_{\mathrm{distribution}}$ and α_{gamble} is significant even with these "switching" participants ($\rho = 0.48$; $P < 0.01$). (*B*) Activity of the right temporoparietal junction (RTPJ) during decision making. RTPJ activation was positively correlated with increase in absolute difference in minimum (ΔMin) between the two options (solid circle). Activation of the RTPJ was also functionally connected to activation of the caudate (dotted oval). (*C*) Dissociation between ΔMin and the other parameters (ΔTotal, ΔGini) in the RTPJ at peak coordinates [44 −64 21] identified by conjunction analysis between the two tasks ($T = 3.17$; $P_{\mathrm{FWE}} = 0.025$). Error bars represent SEM. (*D*) Stronger RTPJ–caudate connectivity in distributions for others than in gambles for self ($T = 2.83$; $P < 0.007$) at the peak caudate coordinates [−20 −27 27] identified by conjunction analysis between the two tasks. Error bars represent SEM. (*E*) Individual scores for elevated maximin concern in distributions over gambles, as indexed by differences in RTPJ–caudate connectivity (contrast estimate$_{\mathrm{distribution}}$ − contrast estimate$_{\mathrm{gamble}}$) and differences in maximin weight ($\alpha_{\mathrm{distribution}} - \alpha_{\mathrm{gamble}}$).

risky decisions for self through the spontaneous perspective taking of the minimum, worst-off position.

The results supported our hypothesis. At the behavioral level, choice preferences varied widely, with Rawlsians who endorsed the maximin principle making up only 47% of participants in distributive choices for others and 37% in gambling decisions for self (Fig. 1*B*). Interestingly, however, individuals' choices were highly concordant between the two seemingly distinct tasks—roughly summarizable as risk-averse Rawlsians vs. risk-seeking utilitarians—even though distribution for others as a third party involved no monetary risk for the decision-making participants. More importantly, the worst possible outcome served as a common cognitive anchor during decision making, attracting spontaneous attention across both tasks and participant types.

At the neural level, this common focus on the "floors" was reflected in the activity of the RTPJ, a brain region implicated in mental simulation of a standpoint physically or temporally distant (other/future) from one's immediate environment [myself/now (20–26, 29)]. The exact role of the RTPJ in social cognition is currently debated, including whether switching between the immediate and distant perspectives is a specialized or domain-general process (23, 29), and how multiple functions of the RTPJ are spatially organized in the region (39, 41). The RTPJ peak coordinates we identified in both tasks (Fig. 2*B*) were situated in the angular gyrus, corresponding to the canonical "social TPJ" (39), which is associated with theory of mind (23), empathy (31), moral reasoning (32, 33), and altruistic behavior (34, 35). As predicted, the RTPJ activity observed during decisions tracked how options compared according to the maximin criterion in both tasks. The RTPJ was responsive only to this maximin parameter, ΔMin, among the three task parameters. Furthermore, as the quasi-maximin model implied, RTPJ activity covaried with the activity of the caudates, the brain region associated with tracking marginal utilities of options in distributions for others (14, 38). Taken together, these convergent neural results suggest that participants spontaneously engaged in "what-if" thinking according to the maximin criterion in both tasks.

Thus far, we have discussed the similarities of these two seemingly distinct decisions at the behavioral, cognitive, and neural levels. We also observed systematic differences between participants' responses to the two tasks, including greater maximin concern in distributions for others than in gambles for self, both at the behavioral level (more frequent maximin choices in Fig. 1*B* and Table S3, and greater α in Fig. 2*A* and Fig. S1), and at the neural level (stronger RTPJ–caudate connectivity in Fig. 2*D*). These robust differences indicate that the maximin concern is more central in distributive-justice judgments for others than in personal risky choices.

Importantly, the degree to which the maximin concern was accentuated in social distributions also varied substantially across individuals. For example, as seen in Fig. 1*B*, although most participants (67%) "remained" in the same types according to their most frequent choices across the two tasks, 18% of the participants "switched" categorically from the largest-total–seeking (i.e., risk-seeking) type when deciding on gambles for self to the Rawlsian type when choosing distributions for others (see Table S3, Fig. S1, and Fig. 2*A* for similar patterns). These consistent patterns prompted us to explore the neural correlates of such individual differences. As shown in Fig. 2*E*, the enhanced maximin concern in behavioral distribution choices ($\alpha_{\text{distribution}} - \alpha_{\text{gamble}}$) correlated with enhanced RTPJ–caudate connectivity in distributions. Participants who had elevated functional RTPJ–caudate connectivity in distributions over gambles also had elevated maximin preferences in distributive choices over gambling choices. We conjecture that the aforementioned "switchers" (the risk-seeking Rawlsians who made up 18% of the participants in Fig. 1*B*) may be willing to take risks in their personal choices but endorse the maximin principle as a "socially just" policy in the public arena. Notice that the opposite off-diagonal combination in Fig. 1*B* (i.e., risk-averse utilitarians) was quite rare, making up only 2% of the participants (and 0% in Table S3). Future research focusing more directly on the neural underpinnings of these ideological differences would seem to be important and promising.

Overall, our findings suggest that concern about misfortune, for oneself or others, operates as a strong cognitive anchor in our decision making, if not determining behavioral choices unilaterally. Indeed, among the three choice models applied to analyze the behavioral data (*SI Materials and Methods*, *Goodness-of-fit tests of three economic models for participants' behavioral choices*), the quasi-maximin model (6) (Eq. **1**) provided the best fit to participants' behavioral choices, outperforming the traditional constant relative risk aversion model (42) and the mean-variance model (11) in both distributions for others and gambles for self (Table S4). These results imply that the maximin parameter, which is often ecologically correlated with, yet conceptually distinguishable from, the variance/inequality parameter (3, 11, 19), merits a systematic investigation in cognitive and social neurosciences. Although still suggestive at this point, we believe that disentangling the behavioral and neural effects of the maximin concern from those of the variance/inequality concern will be essential in future research to shed light on the relative contributions of these task parameters in social as well as nonsocial decision making.

Of course, this robust maximin bias in people's choices bears no normative implication about how we should allocate resources—as Hume's famous dictum says, we cannot derive "ought" from "is" (40). Nevertheless, we conjecture that this consistent attention to the least fortunate position may serve as a reasonable starting point for designing distributive policies in modern societies (4–7, 14), seeking "common ground not where we think it ought to be, but where it actually is" [Greene (ref. 43, p. 291)]. Our approach also illustrates how cognitive, economic, and neural science methods may be systematically combined to illuminate the functional components of distributive justice in our minds and possibly the common neural underpinnings shared by other nonsocial decisions (12–18).

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Materials and Methods

Experiment 1 (Behavioral Experiment).

Participants. Sixty-seven student volunteers at Hokkaido University (Sapporo, Japan) (32 males; mean age, 18.8 ± 0.78 y) participated in the behavioral experiment. Informed consent was obtained from each participant using a consent form approved by the Institutional Review Board of the Center for Experimental Research in Social Sciences at Hokkaido University (No. 23-4).

Experimental procedure. Each participant was seated in a private cubicle with a computer. During the experiment, participants worked individually on the two decision tasks, with task order counterbalanced (Fig. 1*A*).

In the distribution task, participants were asked to choose one of three options as an allocation to three unknown others (identified anonymously as persons A, B, and C) who were participating in another experiment. Participants were asked to make 40 such distribution choices, from which one choice would be randomly designated as a real cash reward for the others; person A would receive the lowest outcome; B, the middle outcome; and C, the highest outcome. It was emphasized that participants and recipients would remain completely anonymous to each other.

In the gambling task, participants were asked to choose one of three lotteries for themselves. Each lottery option had three monetary outcomes with equal likelihood of 1/3. Participants were told that they would make 40 such lottery choices, from which one choice would be randomly selected at the end of the experiment; one of the three monetary outcomes in the chosen lottery would then be randomly picked to determine their own cash reward. No feedback was provided to participants about outcomes resulting from their distribution or lottery choices until the end of the experiment. For details, see *SI Materials and Methods*, *Experimental procedure*.

After completing the two decision tasks, participants were asked to answer a short questionnaire to measure their risk attitudes (30). At the end of the experiment, participants received the randomly selected monetary outcome from their lottery choices plus a 200-yen (approximately US$2 at the time) show-up fee as compensation for their participation. They were then dismissed, after which the recipients were paid the allocated rewards from the distribution task. The data are available in Dataset S1.

Experiment 2 (fMRI Experiment).

Participants. Thirty healthy, right-handed student volunteers at Tamagawa University (Tokyo, Japan) (15 males; mean age, 20.9 ± 1.7 y) with no relevant medical history participated in this study. Informed consent was obtained from each participant using a consent form approved by the Institutional Review Board of the Brain Research Center at Tamagawa University (No. C25-9). All participants had normal or corrected-to-normal visual acuity. We had to exclude data from one participant due to abnormal brain structure, and another due to head movement in excess of the acquired voxel size.

Experimental procedure. The task setup was identical to that of the behavioral experiment except that we used two choice options instead of three to reduce the visual complexity of the stimuli (Fig. S4A). Participants made 36 choices of reward distributions (14) for three unknown others who were participating in another experiment, and another set of 36 choices as gambles for themselves. The numerical structure of the stimuli was identical between the two tasks (Table S2), the task order was counterbalanced across participants, and presentation order of the 36 choice sets within each task was randomized. For details, see *SI Materials and Methods*, *Experimental procedure*–*SI Materials and Methods*, *Task structure and task flow*. The behavioral data are available in Dataset S2.

Small-volume correction. We applied small-volume correction to focus on RTPJ within a 6-mm sphere centered at the mean coordinates ($x = 46$, $y = -63$, $z = 23$), which were calculated from previous studies examining RTPJ activity when taking another's perspective for altruistic helping (35, 44, 45) or shifting attention away from the here-and-now to imagine one's own experience at a different time (46–49). The mean coordinates were situated in the canonical social TPJ identified by a recent comprehensive metaanalysis (39).

Statistical analysis. Neural responses while participants made decisions in the two conditions (distributions for others and gambles for self) were modeled in a series of general linear models. We examined distinct neural correlates of the three parametric regressors, ΔMin, ΔTotal, and ΔGini, defined respectively as the absolute difference in minimum, total, and the Gini coefficient between the two choice options. To allow these parametric regressors to compete for variance, we turned off the orthogonalization option in SPM8 as recommended by Mumford et al. (50). For details, see *SI Materials and Methods*, *Image processing and statistical analysis*.

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1. von Neumann J, Morgenstern O (1953) *Theory of Games and Economic Behavior* (Princeton Univ Press, Princeton).
2. Arrow KJ (1965) *Aspects of the Theory of Risk Bearing* (Yrjö Jahnssonin Säätiö, Helsinki).
3. Rawls J (1971) *A Theory of Justice* (Harvard Univ Press, Cambridge, MA).
4. Frohlich N, Oppenheimer JA (1992) *Choosing Justice* (Univ California Press, Berkeley, CA).
5. Engelmann D, Strobel M (2004) Inequality aversion, efficiency, and maximin preferences in simple distribution experiments. *Am Econ Rev* 94(4):857–869.
6. Charness G, Rabin M (2002) Understanding social preferences with simple tests. *Q J Econ* 117(3):817–869.
7. Norton MI, Ariely D (2011) Building a better America—one wealth quintile at a time. *Perspect Psychol Sci* 6(1):9–12.
8. Wang XT, Johnson JG (2012) A tri-reference point theory of decision making under risk. *J Exp Psychol Gen* 141(4):743–756.
9. Koop GJ, Johnson JG (2012) The use of multiple reference points in risky decision making. *J Behav Decis Making* 25(1):49–62.
10. McNamara JM, Houston AI (1992) Risk-sensitive foraging: A review of the theory. *Bull Math Biol* 54(2-3):355–378.
11. Markowitz HM (1952) Portfolio selection. *J Finance* 7(1):77–91.
12. Sul S, et al. (2015) Spatial gradient in value representation along the medial prefrontal cortex reflects individual differences in prosociality. *Proc Natl Acad Sci USA* 112(25):7851–7856.
13. Shenhav A, Greene JD (2010) Moral judgments recruit domain-general valuation mechanisms to integrate representations of probability and magnitude. *Neuron* 67(4):667–677.
14. Hsu M, Anen C, Quartz SR (2008) The right and the good: Distributive justice and neural encoding of equity and efficiency. *Science* 320(5879):1092–1095.
15. Kuhnen CM, Knutson B (2005) The neural basis of financial risk taking. *Neuron* 47(5): 763–770.
16. Platt ML, Huettel SA (2008) Risky business: The neuroeconomics of decision making under uncertainty. *Nat Neurosci* 11(4):398–403.
17. Preuschoff K, Bossaerts P, Quartz SR (2006) Neural differentiation of expected reward and risk in human subcortical structures. *Neuron* 51(3):381–390.
18. Tom SM, Fox CR, Trepel C, Poldrack RA (2007) The neural basis of loss aversion in decision-making under risk. *Science* 315(5811):515–518.
19. Harsanyi JC (1976) *Essays on Ethics, Social Behavior, and Scientific Explanation* (D. Reidel, Dordrecht, The Netherlands).
20. Buckner RL, Carroll DC (2007) Self-projection and the brain. *Trends Cogn Sci* 11(2):49–57.
21. Suddendorf T, Corballis MC (2007) The evolution of foresight: What is mental time travel, and is it unique to humans? *Behav Brain Sci* 30(3):299–313, discussion 313–351.
22. Mitchell JP (2009) Inferences about mental states. *Philos Trans R Soc Lond B Biol Sci* 364(1521):1309–1316.
23. Koster-Hale J, Saxe R (2013) Theory of mind: A neural prediction problem. *Neuron* 79(5):836–848.
24. Carter RM, Bowling DL, Reeck C, Huettel SA (2012) A distinct role of the temporal-parietal junction in predicting socially guided decisions. *Science* 337(6090):109–111.
25. Frith CD, Frith U (2007) Social cognition in humans. *Curr Biol* 17(16):R724–R732.
26. Irish M, Piguet O, Hodges JR (2012) Self-projection and the default network in frontotemporal dementia. *Nat Rev Neurol* 8(3):152–161.
27. Mill JS (1965) *Principles of Political Economy*, ed Ashley WJ (Kelley, New York).
28. Payne JW, Bettman JR, Johnson EJ (1993) *The Adaptive Decision Maker* (Cambridge Univ Press, Cambridge, UK).
29. Decety J, Lamm C (2007) The role of the right temporoparietal junction in social interaction: How low-level computational processes contribute to meta-cognition. *Neuroscientist* 13(6):580–593.
30. Eckel C, Grossman P (2002) Sex differences and statistical stereotyping in attitudes toward financial risk. *Evol Hum Behav* 23(4):281–295.
31. Zaki J, Ochsner KN (2012) The neuroscience of empathy: Progress, pitfalls and promise. *Nat Neurosci* 15(5):675–680.
32. Young L, Camprodon JA, Hauser M, Pascual-Leone A, Saxe R (2010) Disruption of the right temporoparietal junction with transcranial magnetic stimulation reduces the role of beliefs in moral judgments. *Proc Natl Acad Sci USA* 107(15):6753–6758.
33. Greene JD (2009) The cognitive neuroscience of moral judgment. *The Cognitive Neurosciences*, ed Gazzaniga M (MIT Press, Cambridge, MA), 4th Ed, pp 987–999.
34. Morishima Y, Schunk D, Bruhin A, Ruff CC, Fehr E (2012) Linking brain structure and activation in temporoparietal junction to explain the neurobiology of human altruism. *Neuron* 75(1):73–79.
35. Tankersley D, Stowe CJ, Huettel SA (2007) Altruism is associated with an increased neural response to agency. *Nat Neurosci* 10(2):150–151.
36. Huettel SA, Stowe CJ, Gordon EM, Warner BT, Platt ML (2006) Neural signatures of economic preferences for risk and ambiguity. *Neuron* 49(5):765–775.
37. Dorris MC, Glimcher PW (2004) Activity in posterior parietal cortex is correlated with the relative subjective desirability of action. *Neuron* 44(2):365–378.
38. Fehr E, Krajbich I (2014) Social preferences and the brain. *Neuroeconomics*, eds Glimcher PW, Fehr E (Academic, San Diego), 2nd Ed, pp 193–218.
39. Carter RM, Huettel SA (2013) A nexus model of the temporal-parietal junction. *Trends Cogn Sci* 17(7):328–336.
40. Hume D (2002) *A Treatise of Human Nature* (Oxford Univ Press, Oxford, UK).
41. Deen B, Koldewyn K, Kanwisher N, Saxe R (2015) Functional organization of social perception and cognition in the superior temporal sulcus. *Cereb Cortex* 25(11):4596–4609.
42. Wakker PP (2010) *Prospect Theory* (Cambridge Univ Press, Cambridge, UK).
43. Greene JG (2013) *Moral Tribes* (Atlantic Books, Ocean City, NJ).
44. Lamm C, Nusbaum HC, Meltzoff AN, Decety J (2007) What are you feeling? Using functional magnetic resonance imaging to assess the modulation of sensory and affective responses during empathy for pain. *PLoS One* 2(12):e1292.
45. Morey RA, et al. (2012) Neural systems for guilt from actions affecting self versus others. *Neuroimage* 60(1):683–692.
46. Hassabis D, Kumaran D, Maguire EA (2007) Using imagination to understand the neural basis of episodic memory. *J Neurosci* 27(52):14365–14374.
47. D'Argembeau A, et al. (2014) Brains creating stories of selves: The neural basis of autobiographical reasoning. *Soc Cogn Affect Neurosci* 9(5):646–652.
48. Abraham A, Schubotz RI, von Cramon DY (2008) Thinking about the future versus the past in personal and non-personal contexts. *Brain Res* 1233:106–119.
49. D'Argembeau A, Xue G, Lu ZL, Van der Linden M, Bechara A (2008) Neural correlates of envisioning emotional events in the near and far future. *Neuroimage* 40(1):398–407.
50. Mumford JA, Poline JB, Poldrack RA (2015) Orthogonalization of regressors in FMRI models. *PLoS One* 10(4):e0126255.
51. Deichmann R, Gottfried JA, Hutton C, Turner R (2003) Optimized EPI for fMRI studies of the orbitofrontal cortex. *Neuroimage* 19(2 Pt 1):430–441.
52. Akaike H (1974) A new look at the statistical model identification. *IEEE Trans Automat Contr* 19(6):716–723.
53. Ashburner J, Friston KJ (2005) Unified segmentation. *Neuroimage* 26(3):839–851.
54. Friston KJ, Holmes AP, Worsley KJ (1999) How many subjects constitute a study? *Neuroimage* 10(1):1–5.
55. Friston KJ, Frith CD, Frackowiak RS, Turner R (1995) Characterizing dynamic brain responses with fMRI: A multivariate approach. *Neuroimage* 2(2):166–172.
56. Hammers A, et al. (2003) Three-dimensional maximum probability atlas of the human brain, with particular reference to the temporal lobe. *Hum Brain Mapp* 19(4): 224–247.