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Social discounting and distance perceptions in costly altruism

Kruti M. Vekaria[1]*, Kristin M. Brethel-Haurwitz[2], Elise M. Cardinale[1], Sarah A. Stoycos[3] and Abigail A. Marsh[1]

Extraordinary acts of altruism towards strangers represent puzzling phenomena not easily explained by dominant biological models of altruism, such as kin selection and reciprocity[1–3]. These theories stipulate that genetically or socially close others should be the beneficiaries of costly generosity[4,5]. Extraordinary altruists exhibit increased empathic sensitivity and a fast, intuitive decision-making style[6,7], but no clear explanation yet exists for the most perplexing feature of these altruists, which is that they incur significant risks to benefit strangers[5]. Here, we considered two related proximal mechanisms—social discounting (valuational) and social distancing (perceptual)—that have been proposed to explain why costly help is preferentially given to close others. We hypothesized that variations in one or both mechanisms drive costly altruism towards distant others. We show that extraordinary altruists exhibit reduced social discounting, with altruists discounting the subjective value of outcomes for socially distant others less than controls. Group differences in social discounting were associated with self-reported other-oriented preferences and could not be accounted for by variation in social distancing. These results suggest a psychological mechanism by which costly helping behaviour towards genetically and socially close others might be extended to unrelated others.

Donation of a kidney to a stranger is painful, costly[8], non-normative[9], exceedingly rare[10] and meets the most exacting definitions of costly altruism. Established biological models of altruism, such as inclusive fitness, or shared genetic fitness of the altruist[3], and reciprocal altruism, according to which costly help may later be reciprocated by a beneficiary who usually shares social group membership with the altruist[2,4], cannot easily explain costly altruism towards strangers. We hypothesized that variations in social discounting may represent a proximal mechanism supporting this form of altruism. Social discounting is a robust phenomenon, with respondents across settings and cultures reliably willing to sacrifice more resources for socially close others relative to distant others[11,12]. Previous evidence does not directly link costly altruism towards strangers to reduced social discounting. However, participants who contribute more in a laboratory-based public goods game exhibit a shallower discount function[13], and, conversely, aggressive individuals exhibit a relatively steep social discounting function[14].

To test this hypothesis, we recruited and tested a sample of rare individuals who had donated a kidney to a stranger—a voluntary and extraordinarily costly act of altruism. We took this approach due to the notorious difficulty of evaluating proximal drivers of costly altruism in the laboratory. Ethical considerations prohibit human research participants from confronting genuinely costly or risky choices[15], and low-cost experimental and self-report measures of altruism are highly susceptible to social desirability and self-presentation biases[9,16]. Assessing social discounting and distancing in individuals who have engaged in a voluntary and costly act aimed at benefiting an anonymous, non-kin other—thereby satisfying the most stringent definitions of costly altruism and providing a valid ecological measure of it[17]—enables the relationship between these variables and costly altruism to be isolated[6]. This approach is analogous to the use of various extreme populations to illuminate basic psychological processes supporting, for example, memory, intelligence and face recognition[18–20].

We measured social discounting and distancing in 21 altruistic kidney donors and 39 controls, whose characteristics are described in Table 1. Participants completed a computerized social discounting task, during which they made nine dichotomous choices about keeping or forgoing resources to benefit each of seven target individuals who ranged in social distance from 1 (closest) to 100 (furthest)[21]. The rate at which generosity normally declines as relationships become less socially close follows a hyperbolic function, which was originally described by Jones and Rachlin[13,21]:

$$v = \frac{V}{1 + sN} \quad (1)$$

where V represents the undiscounted value of the reward, s represents the degree of discounting, N represents social distance and v represents the actual discounted value of the reward. As N increases, the resources individuals are willing to forgo (v) typically decreases hyperbolically.

Responses from 12 participants (1 altruist and 11 controls) could not be analysed due to choice inconsistencies within one or more blocks (for example, switching from generous to selfish and back to generous responding at a given distance, N). This pattern of choices precluded the identification of a single crossover point at that social distance. Analyses of the remaining participants' responses (Supplementary Methods) found that controls' discounting functions closely paralleled previous studies (Fig. 1a)[13,21]. The degree of discounting for controls was calculated to be $s = 0.034$ ($V =$ US\$78.11; goodness of fit of the model (R^2) $= 0.981$). For comparison, Jones and Rachlin[21] found $s = 0.051$ ($V =$ US\$83.00, $R^2 = 0.991$). In contrast, the degree of discounting for altruists was calculated to be $s = 0.009$ ($V =$ US\$79.87, $R^2 = 0.971$). Fitted hyperbolic parameters were also calculated for median values of v for each group, yielding model fits of $R^2 = 0.980$ for controls and $R^2 = 0.903$ for altruists.

[1]Department of Psychology, Georgetown University, Washington DC 20057, USA. [2]Department of Psychology, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA. [3]Department of Psychology, University of Southern California, Los Angeles, California 90089, USA. *e-mail: kmv39@georgetown.edu

Table 1 | Participant demographic characteristics.

	Total sample			Social distance			Social discounting		
	Altruists ($n=21$)	Controls ($n=39$)	P	Altruists ($n=21$)	Controls ($n=36$)	P	Altruists ($n=20$)	Controls ($n=26$)	P
Sex (male/female (% male))	12/9 (57.14)	24/15 (61.54)	0.740	12/9 (57.14)	23/13 (61.54)	0.612	12/8 (60.0)	15/11 (57.70)	0.875
Race (white/non-white (% white))	20/1 (95.24)	31/8 (79.49)	0.103	20/1 (95.24)	31/5 (86.11)	0.279	19/1 (95.0)	22/4 (84.62)	0.262
Age (mean (s.d.))	44.95 (9.43)	43.85 (7.90)	0.631	44.95 (9.43)	44.11 (7.86)	0.719	45.20 (9.60)	44.92 (6.47)	0.908
IQ (mean (s.d.))	115.14 (11.82)	110.15 (14.22)	0.175	115.14 (11.82)	111.167 (14.29)	0.286	114.40 (11.60)	114.84 (13.49)	0.907
Education ≥ four-year degree (yes/no (% yes))	13/8 (61.90)	30/9 (76.92)	0.218	13/8 (61.90)	29/7 (80.56)	0.123	12/8 (57.14)	21/5 (80.77)	0.084
Household income ≥ US$60,000 (yes/no (% yes))	15/6 (71.43)	21/12* (63.63)	0.554	15/6 (71.43)	21/11 (65.63)	0.658	14/6 (70.0)	16/7 (69.57)	0.975

*Data on household income were not collected for three controls, and three controls opted not to disclose their household income.

For comparison with Jones and Rachlin[21], we also fit the parameters for both groups to the exponential equation:

$$v = V\mathrm{e}^{-sN} \quad (2)$$

This yielded a model fit for controls of $R^2=0.914$, and a model fit for altruists of $R^2=0.944$. The hyperbolic model yielded lower Akaike's information criterion (AIC_c) values[22], indicating a better model fit (Supplementary Table 1), so this model was used for subsequent analyses.

Results of a Mann–Whitney U-test indicated that altruists (median s value (Mdn_s) = 0.010) exhibit a lower degree of discounting than controls ($\mathrm{Mdn}_s=0.036$; statistical datum derived from Mann-Whitney U-test (U) = 135.50, $P=0.006$, effect size (r) = −0.41), as seen in Fig. 1a. Amount willing to forgo (v) is similar across groups for close others, but the average amount controls opt to forgo drops more steeply with increasing social distance compared with altruists. For example, altruists are willing to forgo approximately the same resources for a person at $n=100$ as controls forgo for a person at $n=20$. The two groups' baseline values for V, which represents the height of the discount function, did not differ significantly ($U=233.50$, $P=0.555$, $r=-0.08$).

Because discount rates (and the respective parameters in the model) are non-parametrically distributed, we calculated the area under the curve (AUC) for each group, which allows for a model-free approach to analysing discounting data that does not assume hyperbolicity in responding[23] and allows for parametric analyses to directly compare participant-level data. AUC was calculated for each participant by normalizing amount willing to forgo v as a percentage of maximum v, normalizing social distance N as a percentage of maximum N, connecting the crossover points by straight lines, then summing the trapezoids formed[24]. Following standardization, AUC can vary from 1.0 (no discounting) to 0 (complete discounting). Results indicated greater AUC for altruists ($\bar{x}=0.68$, s.d. = 0.33) than controls ($\bar{x}=0.42$, s.d. = 0.31; $t_{44}=2.71$, $P=0.009$, Cohen's d (d) = 0.80, as seen in Fig. 1b). Binary logistic regression demonstrated that AUC significantly predicted group membership (beta coefficient for AUC from the logistic regression model predicting group (b) = 2.46, model chi-square based on a likelihood ratio test (χ^2) = 5.99, $P=0.014$). The model had a Nagelkerke's R^2 of 0.183 and a 67.4% prediction success rate.

Given the parameters in the discounting equation, at least two explanations for observed group differences in social discounting are possible. The first is that acts of costly altruism towards strangers genuinely correspond to increased valuation (s) of distant others' welfare. Alternatively, decreased discounting may represent variation in the way altruists construe social distance (N). In the laboratory, decreasing psychological distance enhances generosity in economic games, charitable contributions and peer-to-peer prosocial lending[25–27]. It is therefore possible that costly altruism towards strangers reflects construals of strangers as unusually psychologically close, suggesting a form of perceptual bias.

To disambiguate between these alternatives, we evaluated perceptions of social distance using a computerized paradigm adapted from that developed by Yamakawa *et al.*[28]. Participants considered seven key Bogardus relationships[29] of varying social distance and then, using computer avatars, selected a physical distance to place between the self and each of these seven others. These relationships were: relative by blood, relative by marriage, close friend, next-door neighbour, co-worker, citizen of the United States and citizen of another country. Yamakawa *et al.* have shown that participants position close friends and family physically closer to the self, and more socially distant others at greater physical distances, when asked to plot the distance between the self and various others in terms of Euclidean space[26,28]. This reflects the common neurocomputational processes that support subjective perceptions of spatial and psychological distance[30].

To compare construals of social distance across groups, we estimated social distance for each of the seven Bogardus relationships[29] by calculating the length in pixels of the hypotenuse of the triangle formed by the self avatar position on the x,y plane and the second (relationship-labelled) avatar on the x,y plane using the Pythagorean equation:

$$a^2 + b^2 = c^2 \quad (3)$$

We then calculated a repeated measures analysis of variance to evaluate the main effects and interactions of relationship distance and group on the seven dependent variables (selected social distance for each relationship). We identified a main effect of relationship distance on social distance (F-test value comparing the ratio of variances (F)$_{6,330}=14.06$, $P<0.001$, partial eta squared (η_p^2) = 0.20). As expected, tests of within-subjects contrasts revealed a linear relationship between relationship distance and social distance ($F_{1,55}=41.39$, $P<0.001$, $\eta_p^2=0.43$), demonstrating that as the relationships in the task became more socially distant, participants selected greater physical distances in a linear fashion (Fig. 2). Neither a main effect of group ($F_{1,55}=0.05$, $P=0.82$, $\eta_p^2=0.001$) nor a group by relationship interaction ($F_{6,330}=0.47$, $P=0.83$, $\eta_p^2=0.01$) was observed. Results remained unchanged following exclusion of the 12 participants excluded from the discounting paradigm (Supplementary Methods).

Results were also similar when trials were grouped into categories of known others (relative by blood, relative by marriage, close friend, next-door neighbour and co-worker) versus strangers (citizen

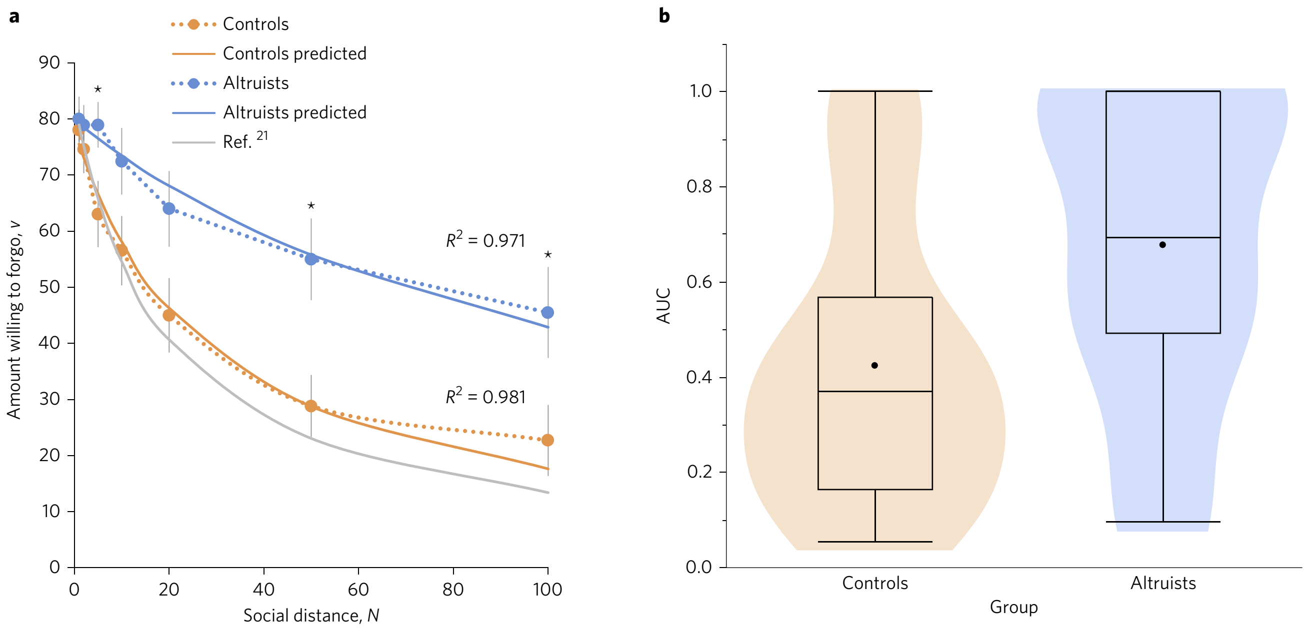

Figure 1 | Social discounting and AUC for altruists and controls. a, Social discounting curves (averages across participants, $n=46$) plotted as maximum amount willing to forgo (v) in dollars versus social distance (N) from 1 to 100. Results from a previous community sample[21] are included for comparison. Predicted curves demonstrate the best-fit hyperbolic functions for altruists and controls. Asterisks indicate distances ($N=5$, 50, 100) at which independent sample t-tests indicated that mean amounts willing to forgo were significantly different between groups ($P<0.05$). Error bars represent s.e.m. For 95% confidence interval information, see Supplementary Fig. 1 and Supplementary Table 2. **b**, AUC box–whisker contour plots for controls and altruists ($n=46$). The points represent mean values for each group. The boxes represent the third (top) and first (bottom) quartiles. The band represents the second quartile (median). The whiskers represent the range of data (minimum and maximum). The shaded areas represent the relative percentage (frequency) of subjects with corresponding AUC values. An independent sample t-test indicates that mean AUC is significantly different between groups ($P<0.05$).

of the United States and citizen of another country). Again, we identified a main effect of familiarity (known others versus strangers; $F_{1,55}=23.82$, $P<0.001$, $\eta_p^2=0.30$), but no main effect of group ($F_{1,55}=0.03$, $P=0.867$, $\eta_p^2=0.001$), or group by familiarity interaction ($F_{1,55}=1.35$, $P=0.250$, $\eta_p^2=0.02$), confirming that there were no differences in distance construals between altruists and controls.

Together, these results are consistent with altruists placing greater value on others' welfare despite normal social distance construals. This being the case, we investigated whether evaluations of social discounting account for group differences in self-report variables previously linked to other-orientedness, including facets of empathy[31] and psychopathy[32], to examine social discounting as a mechanism linking trait-level social preferences and costly altruism.

The first of two simultaneous linear regression analyses predicted AUC from the four subscales of the Interpersonal Reactivity Index[31] and found an association only with empathic concern ($b=0.03$, $t_{41}=2.41$, $P=0.020$). However, no bivariate simple linear relationship between AUC and empathic concern was identified ($b=0.02$, $t_{44}=1.96$, $P=0.057$). The second linear regression predicted AUC from the three Psychopathic Personality Inventory–Revised[32] factor scores and found only an association with coldheartedness, which is considered the inverse of empathic concern ($b=-0.02$, $t_{42}=-2.28$, $P=0.028$). Bivariate regression analysis found coldheartedness to be independently associated with AUC ($b=-0.02$, $t_{44}=-2.64$, $P=0.011$). Moreover, this factor also distinguished between groups (altruist: $\bar{x}=24.75$, s.d.$=4.97$; control: $\bar{x}=28.19$, s.d.$=5.32$; $t_{44}=2.18$, $P=0.035$, $d=0.67$).

A bootstrap-mediation analysis using the PROCESS[33] macro in SPSS version 23 found that AUC mediated the relationship between coldheartedness and group (controls = 0, altruists = 1; bias-corrected 95% confidence interval for indirect effect size −0.1505 to −0.0022; Fig. 3). Coldheartedness exerted an indirect effect of −0.047 (s.e.m.$=0.036$). The standardized total effect of coldheartedness on group (β) was −0.37 ($P=0.043$).

We hypothesized that we would observe similar effects of lower magnitude as a function of less costly forms of altruism, which are more likely to be multiply motivated. Accordingly, parallel analyses found positive but non-significant relationships between AUC and blood donation frequency[34], both when considering controls in isolation ($r_{26}=0.328$, $P=0.102$) and across groups ($r_{46}=0.23$, $P=0.119$). Blood donation frequency also positively corresponded to empathic concern ($r_{46}=0.34$, $P=0.022$), and was negatively but non-significantly related to coldheartedness ($r_{46}=-0.18$, $P=0.225$).

The present findings suggest that costly altruism towards strangers may reflect decreased social discounting, such that extraordinary altruists, relative to the average person, place more value on the welfare of more socially distant others despite comparable perceptions of these others as psychologically distant. The altruistic nature of the behaviours under consideration is reinforced by the fact that even controls' discounting function represents a departure from so-called 'rational choice', as mathematically, selfishness based entirely on distance would predict exponential decreases in helping as social distance increases[35]. Our findings indicate that extraordinary altruism reflects a particular sharp divergence from a self-interested pattern of choices. This suggests that the social discounting function may be a meaningful index of individual variation in ecologically valid generosity.

Discounting functions could successfully discriminate altruists from controls using both non-parametric comparisons and after converting these values to parametric values (AUC). The parameter V is often taken as a proxy for the level of generosity towards socially close individuals[36], further demonstrating that it is the steepness of the discounting curve (s), and not altruists' generally upwardly shifted discount function, that accounts for the observed group differences in discount functions. In addition, AUC accounted for the relationship

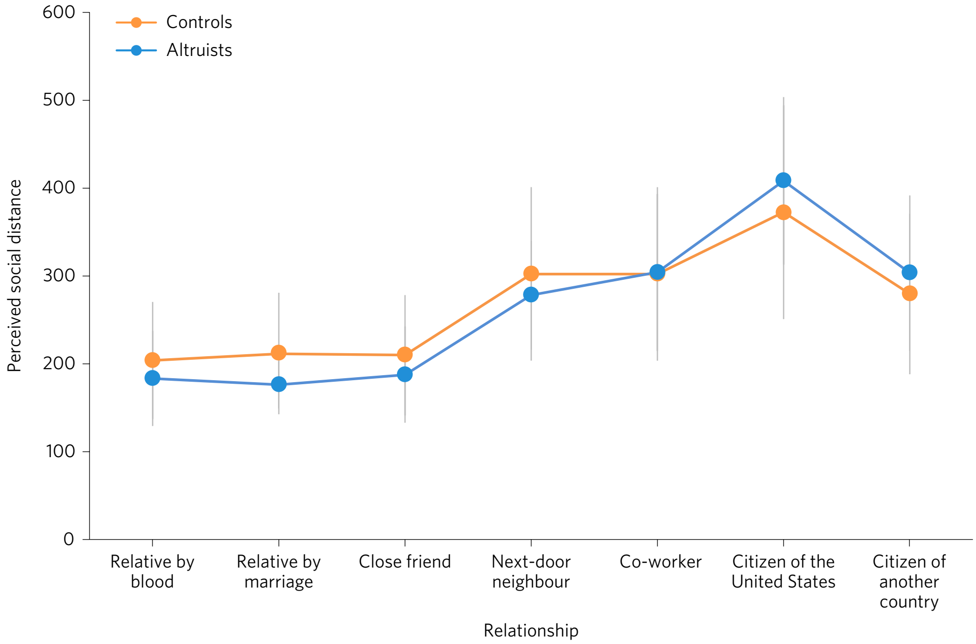

Figure 2 | Social distance perceptions for altruists and controls. Mean distances (in pixels) selected in the social distance task for each of seven Bogardus relationships for altruists and controls ($n = 57$). Error bars represent 95% confidence intervals. Repeated measures analysis of variance tests indicate that groups do not differ on social distance perceptions at any of the seven relationships.

between extraordinary altruism and low levels of coldheartedness, which indexes a lack of emotion, guilt or regard for others' feelings[32]. That AUC is associated with lower levels of personality-based group differences further supports the interpretation of our results, and suggests that this variable's relationship to altruism reflects not simply altruists' increased concern and regard for others' feelings, but the persistence of their other-regard across even large social distances.

We found that AUC is most closely associated with variation in costly altruism in particular. AUC and blood donation frequency were positively but not strongly correlated across groups and when examining only controls. This is consistent with the idea that low-cost altruism is often multiply motivated, reflecting other-oriented concern as well as the desire for social approval and to conform to social norms. Unlike blood donation, altruistic kidney donation is both descriptively and prescriptively non-normative[9] and not viewed as necessarily desirable[37], which may explain the stronger correspondence between this behaviour and measures that specifically index other-oriented concern. To an extent, this finding mitigates potential concerns that discounting patterns reflect socially desirable responding in altruists, who have been shown to not exhibit higher levels of norm-driven prosocial responding relative to controls[9].

Group differences in discounting emerged despite the fact that altruists and controls did not differ in their construals of social distance. This absence of group differences is notable given that helping as a result of perceptions of increased self-other overlap has been described as not sincerely altruistic[38]. Our results contradict the possibility that extraordinary altruism reflects aberrant perceptions of strangers as psychologically close (or, alternatively, of friends and family as psychologically distant). Instead, we found support for an altered subjective valuation hypothesis that is consistent with conceptions of genuinely altruistic motivation[38,39]. Absence of evidence for group differences in social distance does not automatically imply group differences in social valuation. However, the absence of alternative free parameters in the discounting equation, once group differences in construals of distance (N) and baseline generosity towards close others (V) have been ruled out (together with our efforts to rule out demographic variables that might drive discounting differences), leaves no clear alternative to genuine differences in how altruists and controls value the welfare of socially distant others.

Our interpretation of our findings is consistent with narratives collected from participant interviews following task completion. Controls frequently voiced sentiments consistent with strong social discounting, such as a 43-year-old female who stated: "I wouldn't put my health and well-being at risk for a stranger. For someone I love, it would be worth the risk. For a stranger, it would not." In contrast, one 53-year-old male altruist stated: "My favourite part is that people say, 'Oh I could never (donate to a stranger).' That's bullshit. That's absolutely bullshit, because I'll go through a series of questions: 'Would you give to your mother? Okay, so we've got that, so you would never do what I'd do, but you'd do it for your mom. How about your sister or your brother?' And I extend it: 'How about your best friend that's not related? How about your teacher or your boss?' So you start weighing what's priority."

Our results cannot, however, be used to conclusively determine which ultimate evolutionary mechanism may underlie costly altruism in strangers. Possible mechanisms include that such behaviour reflects a byproduct of cooperative breeding and alloparenting[40]; although most human alloparenting occurs between kin, alloparenting has been identified as the strongest predictor of altruism among unrelated adults across primate species[41]. Alternatively, it could reflect cultural changes that promote an expanding moral circle[42] or it could simply reflect the extreme of natural population variation in cooperative tendencies[43]. In the absence of direct tests of any of these mechanisms, any explanation of the ultimate mechanisms underlying observed variations in social discounting-linked altruism must remain speculative.

In addition, some limitations to our results should be considered. The use of a special population to isolate the construct of costly altruism limited our sample size, as altruistic kidney donors make up only 0.0006% of the adult population in the United States[10,44]. Relatedly, because all altruists had already donated before testing, our ability to draw causal or temporal conclusions is limited. The social discounting task we employed also used hypothetical instead of actual

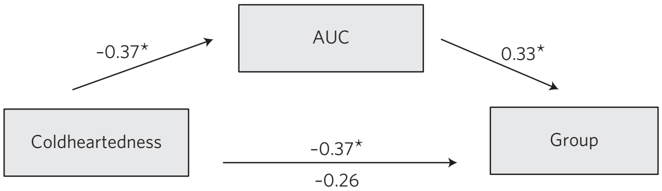

Figure 3 | Mediation model demonstrating that coldheartedness has an indirect effect on group through AUC. Coefficients represent standardized betas. For the association between coldheartedness and group the number above the arrow represents the total effect and below the arrow the direct effect. *$P < 0.05$.

rewards; however, previous social discounting work supports the validity of this approach[45,46]. Additionally, several control subjects were removed from analyses due to choice inconsistencies. These inconsistencies may reflect difficulties with the task instructions, as the average IQ of excluded controls ($\bar{x} = 101.63$, s.d. = 10.45) was significantly lower than that of those who remained in the analytic sample ($t_{24} = 3.21$, $P = 0.004$). Finally, the social discounting and social distance tasks were analogous, but mapped the seven social distances under consideration using two approaches: abstract numeric relationships[13,21,47] and specific individual relationships[28]. These approaches were selected to maximize consistency with related previous work and, thus, the interpretability of our findings. In future work, however, it could be informative to modify the social discounting task to enable information about which specific relationships were chosen for each increment to be incorporated into relevant analyses.

Despite these considerations, the results of the present study suggest a psychological mechanism by which costly helping behaviour towards genetically and socially close others might be extended to unrelated others, giving insight into the underpinnings of extraordinary altruism. These findings also add to a growing body of literature demonstrating that social discounting can meaningfully measure altruistic motivation, and provide evidence that increased subjective valuation for the welfare of distant others, rather than misperceptions of social distance, can predict real-world generosity.

Methods

Participants. Sixty healthy adults aged 23 to 56 years ($\bar{x} = 44.23$, s.d. = 8.40) completed behavioural testing as part of a larger study protocol[6]. The sample included 21 altruistic kidney donors (9 female), drawn from the approximately 1,482 such donors in existence at the time of recruitment, and 39 healthy matched controls (15 female). Sample size was constrained by the extreme rarity of altruistic kidney donors. Altruists were recruited from across North America via local and national transplant organizations, as well as online advertisements on donation-related web pages. Each altruist's kidney donation status was verified through an independent source (for example, a letter of confirmation from the transplant hospital). All altruists had donated a kidney to a stranger, 18 of which were non-directed donations in which the recipient was anonymous at the time of donation. The remaining three directed their donation to a specific individual unknown to them at the time of their decision to donate (for example, a stranger whose need for a kidney was advertised on Facebook). Using data obtained from the Organ Procurement and Transplantation Network[10], which is administered by the United Network of Organ Sharing under contract with the United States Department of Health and Human Services, we confirmed that altruists recruited for this study did not differ from the national population of altruistic donors in terms of sex ($\chi^2_{1, n=1,797} = 1.37$, $P = 0.242$) or race ($\chi^2_{1, n=1,797} = 0.165$, $P = 0.685$). Exact ages are not available for the national sample. Control participants were recruited from the Washington DC area via fliers and online advertisements. Exclusion criteria for all participants included current use of psychotropic medication, psychiatric diagnosis, history of head injury or neurological illness or IQ < 80. Controls were excluded if they had ever volunteered to donate an organ to any individual.

All participants completed a preliminary online screening, which assessed donation status, demographic information, and other exclusion and inclusion criteria. The online battery also included self-report questionnaires. Qualified participants then completed additional measures in the laboratory, including a screening for psychiatric symptoms and psychotropic medications, as well as the Kaufman Brief Intelligence Test[48]. Eligible participants ($n = 42$) completed a neuroimaging component of the study. Behavioural testing followed, including the social distance task and the social discounting task. Participants also completed a semi-structured interview about the altruistic kidney donation process. For altruists living outside of the Washington DC area, travel and up to two nights' lodging (up to US$700) were provided by the researchers. Each participant completed approximately 10 hours of testing, and was compensated US$170 for study participation. The majority of participants were tested at Georgetown University, but two kidney donors could not be tested on-site, so the researchers travelled to test them off-site. The protocol was approved by the Institutional Review Board at Georgetown University and all participants provided written informed consent before the study procedures took place.

Of the total sample of 60 participants, 56 participants completed both behavioural tasks. Fifty-nine participants completed the social discounting task. Data from 12 participants (1 altruist and 11 controls) were disqualified from hyperbolic estimation analyses due to response inconsistencies[21]. Data from 1 control participant were excluded from the social discounting task due to current use of psychotropic medication, leaving 20 altruists (8 female) and 26 controls (11 female) in the final analytic sample. Fifty-seven participants completed the social distance task. No participants were excluded from analyses on this task. In neither subset did altruists and controls differ in terms of age, sex, race, full scale IQ, education or household income (Table 1).

Due to the nature of the sample, there was no randomization for experimental group allocation and there was no blinding in this study.

Social discounting paradigm. We adapted the Jones and Rachlin[13,21] social discounting task for computer presentation. Participants were instructed to imagine a list of the 100 people closest to them, with the person at position 1 being their closest relative or friend (for instance, somebody they know well) and the person at position 100 being recognizable but no more than an acquaintance (for instance, they may not even know their name). The task consisted of seven blocks with nine trials each. Participants were prompted to imagine the seven possible individuals on the list ($N = 1, 2, 5, 10, 20, 50$ or 100) and make nine dichotomous choices about keeping and/or sharing hypothetical amounts of money with each.

For each trial, participants were asked to indicate if they preferred to keep a certain amount of money for themselves alone (option A: selfish choice) or to keep a certain amount of money for themselves and also share a certain amount of money with the *N*th person on their list (option B: generous choice). The selfish choice ranged from keeping US$155 to US$75 in the order of decreasing US$10 increments, and the generous choice always stayed the same: keeping US$75, and sharing US$75 with the *N*th person. Each block had the same format, and block order was randomized. Participants made their selections by pressing the A and B buttons on the keyboard.

The crossover point was calculated for each *N* by taking the mean of the dollar amounts where the switch between selfish and generous decisions was made. For example, if a participant chose the selfish option for all values from US$155 to US$105, then switched to the generous option at US$95, the crossover point was determined to be US$100. If the selfish option was chosen for all trials in the block, the crossover point was assumed at US$70, and if the generous option was chosen for all trials in the block the crossover point was assumed at US$160. Amount willing to forego *v* was calculated by taking the crossover point and subtracting US$75. Mean values and confidence intervals are shown in Supplementary Table 2. A visual representation of the discounting curves with the corresponding confidence intervals is available in Supplementary Fig. 1.

Parameter fits for all models were derived following previously validated methods for discounting calculations[24] using a hyperbolic discounting calculator implemented in Microsoft Excel, which was modifiable to solve for a variety of nonlinear equations. Allowing the parameters *V* and *s* (and *x* for the exponentiated model) to vary, expected values for *v* were calculated in a constrained least-squares residual model ($V \geq 0$, $s \geq 0$, $x \geq 0$, 100,000 iterations), which estimated values for *V* and *s* using mean (or median) values of *v* for each group. The R^2 and AIC values for each model were calculated by taking the sum square residuals from the solved best fit equation and determining the variance accounted for by the model[22].

Social distance construal paradigm. To assess construals of socially close and distant others, we designed a computerized task based on that constructed and validated by Yamakawa *et al.*[28]. As in the social discounting task, this task required that participants consider seven possible social relationships that varied in social closeness and then, using computer avatars, select a physical distance to place between the self and the other. Following Yamakawa *et al.*[28], participants were queried about seven specific relationships of interest, which were drawn from the Bogardus[29] scale of social distance. They included, in order of increasing relationship distance: (1) relative by blood; (2) relative by marriage; (3) close friend; (4) next-door neighbour; (5) co-worker; (6) citizen of the United States; (7) citizen of another country. Ten distractor relationships, of ambiguous social distances, were also included in the task (for example, 'A telemarketer' and 'Your town's mayor'). Thus, 17 trials, each presenting a distinct social label, were presented in random order.

In each trial, participants viewed a virtual stage depicted as a grid on which an avatar labelled 'YOU' was positioned. The starting position of the 'YOU' avatar varied randomly across trials among the upper left, upper right, bottom left and

bottom right portions of the stage. A sample trial is presented in Supplementary Fig. 2. Above the stage, a second avatar appeared, labelled as one of the 17 possible other people. Participants were instructed to first click on a white dot in the centre of the 'YOU' avatar. Next, they were asked to position the second labelled avatar anywhere they would like on the stage by clicking on that location on the stage. Each trial allowed unlimited time to respond, but only one response was allowed. After a location was selected, the next trial followed immediately. For all subjects, the social distance task immediately preceded the social discounting task. Both tasks were presented using SuperLab Version 4.0 on an Apple desktop computer. A MacBook laptop computer was used for participants tested off-site.

Self-report measures. Participants completed three self-report questionnaires assessing personality traits and social behaviours. The Interpersonal Reactivity Index[31] is a 28-item measure of empathy composed of four subscales: perspective taking, fantasy, empathic concern and personal distress. Each item is rated on a five-point scale. The Self Report Altruism scale[34] is a 20-item index of self-reported altruistic behaviours that assesses the frequency of everyday helping behaviours, including donating blood. Self Report Altruism scale responses reflect low-cost altruistic behaviours that are thought to be driven in part by norm conformity and self-presentation[9]. The frequency of each behaviour is rated on a five-point scale. The Psychopathic Personality Inventory–Revised[32] is a 154-item dimensional measure of personality tendencies and behaviours related to psychopathy (for example, callousness, manipulative behaviour and social deviance), which is designed to minimize self-enhancement bias in community or clinical samples. The scale is composed of three overarching factors: fearless dominance, which indexes low anxiety, social potency and assertiveness; self-centered impulsivity, which indexes impulsiveness, aggression and other antisocial behaviours; and coldheartedness, which indexes callousness and a lack of concern for others' welfare. Coldheartedness (items include: "It bothers me a lot when I see someone crying (reverse-scored)," and "When someone is hurt by something I say or do, that's their problem") is strongly and inversely related to empathic concern[32].

Code availability. The hyperbolic discounting calculator and AUC calculator are available at the Open Science Framework with identifier https://osf.io/79xtn/.

Data availability. The data presented in this manuscript are available at the Open Science Framework with identifier https://osf.io/79xtn/.

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Author contributions

A.A.M. developed the study concept. E.M.C. contributed to the study design. Testing and data collection were performed by K.M.B.-H., E.M.C., and S.A.S. K.M.V. performed the data analysis and interpretation under the supervision of A.A.M. K.M.V. and A.A.M. drafted the manuscript, and K.M.B.-H., E.M.C. and S.A.S. provided critical revisions. All authors approved the final version of the manuscript for submission.

Additional information

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Correspondence and requests for materials should be addressed to K.M.V.

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Competing interests

The authors declare no competing interests.