Supplementary Information for "Neuroanatomical basis of concern-based altruism in virtual environment"

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Abbreviations: AI = anterior insula**,** DBM = deformation-based morphometry, EC = empathic concern**,** VR = virtual reality

Supplementary Text S1: Role of empathic concern in prosocialilty and altruism

A large amount of evidence is available in support of the claim that EC motivates the observer to relieve the target of his/her distress. Sympathetic concern for others promotes costly helping behavior in accordance with one's own sense of responsibility and is also associated with reduced moral disengagement and aggression (Carlo, Mestre, Samper, Tur, & Armenta, 2010; Paciello, Fida, Cerniglia, Tramontano, & Cole, 2013), probably via reappraising aversive arousal stemming from distress (Kawamichi et al., 2015; Lebowitz & Dovidio, 2015; Levy-Gigi & Shamay-Tsoory, 2017; Lockwood, Seara-Cardoso, & Viding, 2014). This relationship between EC and prosocial behavior holds across diverse cultures (across 63 countries; Chopik, O'Brien, & Konrath, 2016) and across states in US (Bach, Defever, Chopik, & Konrath,

2016). Real-life extraordinary altruists, individuals who have donated a kidney to a complete stranger, also score high only on self-report measures of EC (Brethel-Haurwitz, Stoycos, Cardinale, Huebner, & Marsh, 2016). EC also loads on the broader second-order general benevolence factor that represents an underlying dimension of personality tracking pure altruism (Hubbard, Harbaugh, Srivastava, Degras, & Mayr, 2016). This general other-regarding concern is also associated with higher donations to charitable causes (Tusche, Bockler, Kanske, Trautwein, & Singer, 2016) and more cooperative behavior that maximizes economic benefits for the group (Jordan, Amir, & Bloom, 2016). Situational EC response stemming from victim suffering is associated with anticipated recurring thoughts about victim's unpleasant situation (Stocks, López-Pérez, & Oceja, 2017). EC is also found to be strongly correlated with greater endorsement of harm moral foundation, which indexes our evolutionarily acquired concern for the protection of other people's physical integrity (Graham et al., 2011). In the same vein, individuals with higher self-reported EC are less likely to endorse personally harming others for the greater good in moral dilemmas (Patil, Melsbach, Hennig-Fast, & Silani, 2016; Patil & Silani, 2014b) and also condemn more harshly unintentionally caused harmful outcomes (Patil & Silani, 2014a). Individuals with higher EC prefer compensating victim over punishing perpetrator (Hu, Strang, & Weber, 2015) and profess higher other-oriented justice sensitivity for victims of harmful behavior (Decety & Yoder, 2015). Among the Big Five dimensions of personality, agreeableness is most closely associated with emotional reactions to victims in need of help, and subsequent decisions to help those individuals and EC act as a mediator between agreeableness and helping behavior (Habashi, Graziano, & Hoover, 2016). The relationship between EC and charitable giving is mediated by moral principle of care, i.e. internalized moral value that one should help those in need (Bekkers & Ottoni-Wilhelm, 2016; Wilhelm & Bekkers, 2010), but some studies also implicate nonaltruistic motivators (oneness and negative affect) as mediators of this link (Maner et al., 2002). Empathic accuracy (the cognitive ability to accurately infer another person's internal state) can lead to prosocial response only in the presence of caring motivation measured as EC (Winczewski, Bowen, & Collins, 2016). Thus, there is plenty of evidence to support the claim that a general other-oriented concern is a strong motivator for people to act in prosocial or altruistic manner (Batson, 2011).

On the other hand, empathy (as narrowly defined, see the main text) has been assessed with the personal distress (PD) subscale of IRI and represents a self-oriented aversive arousal state stemming from witnessing or imagining victim distress (Jordan et al., 2016). PD is associated with anticipated recurring thoughts about victim (Stocks et al., 2017), which can either not lead to any prosocial response or can even inhibit such a response (Jordan et al., 2016). This is also consistent with work showing that PD tends to be positively correlated with the tendency to disengage from morally demanding situations, which further reduces propensity to help (Paciello et al., 2013). Extraordinary altruists do not differ from controls on the self-report measures of PD (Brethel-Haurwitz et al., 2016). Additionally, PD does not predict altruistic choice of giving up one's monetary payoff to reduce painful shocks for others (FeldmanHall, Dalgleish, Evans, & Mobbs, 2015). The presence of bystanders during an emergency can reduce action preparation, as assessed by corticospinal excitability, in people with a disposition to experience high PD in demanding situations (Hortensius, Schutter, & de Gelder, 2016). But there is also some evidence that suggests that empathy can sometimes promote prosocial behavior (Hein, Lamm, Brodbeck, & Singer, 2011; Tomova et al., 2016), especially in situations where cost is low and helping can be an easy way to alleviate the empathic distress stemming from watching someone suffer (Batson, O'Quin, Fultz, Vanderplas, & Isen, 1983; Batson & Shaw, 1991; Graziano, Habashi, Sheese, & Tobin, 2007; Neuberg et al., 1997).

Thus, although there is overwhelming evidence to support the association between empathic concern and altruistic behavior, the role of empathy or personal distress in motivating prosocial behavior remains to be thoroughly investigated (Bloom, 2016, 2017) and further inquiry will require more refined psychometric instruments (Jordan et al., 2016).

Supplementary Text S2: Presence in VR

A crucial point in experiments implementing virtual environments (VEs) is the subjective experience felt by the participant in the VR (Schubert, Friedmann, & Regenbrecht, 2001; Witmer & Singer, 1998). Indeed, the sense of presence may determine the way participants behave in the VR, resulting in a

confounding effect that should be taken into account. That is, this analysis should help dispel the alternative explanation that non-altruists behaved this way because they found the VR to be more realistic and engaging than altruists.

Questionnaire:

The findings reported in a previous study, where the current VR task was validated, seems to exclude this possibility (Zanon, Novembre, Zangrando, Chittaro, & Silani, 2014). Forty-three participants completed the iGroup Presence Questionnaire (IPQ: http://www.igroup.org/pq/ipq/index.php; Schubert, Friedmann, & Regenbrecht, 2001), a 14-item self-report scale, subdivided in 3 independent dimensions of the VR experience and a general item (listed along with one example item)-

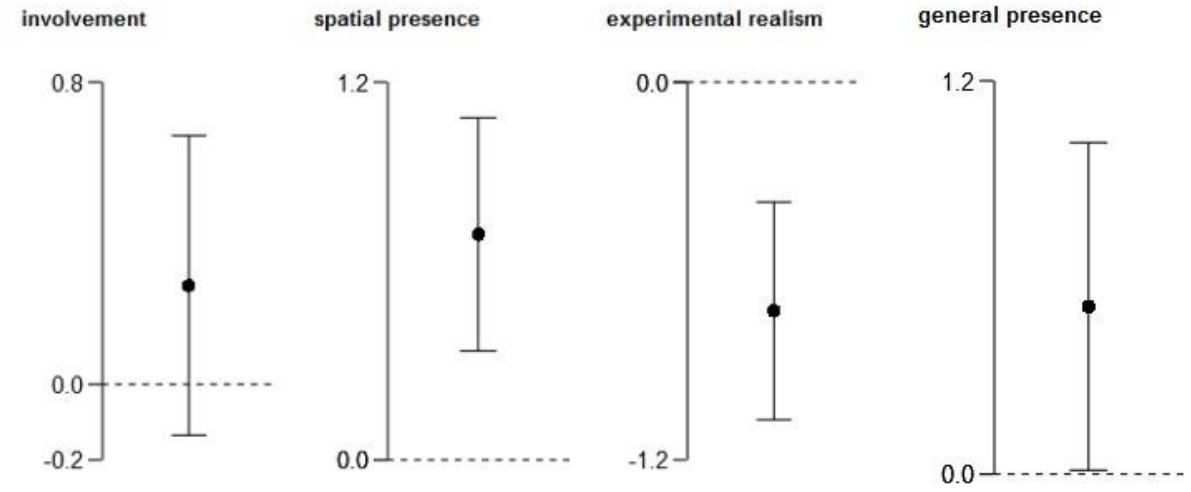
- *General presence* (1 item; *G*): "In the computer-generated world I had a sense of 'being there'": This is regarded as a necessary mediator that allows real emotions to be activated by a virtual environment.
- *Spatial presence* (5 items): "Somehow I felt that the virtual world surrounded me.": This indexes the degree of the sense of being physically present in VR.
- *Involvement* (4 items): "I was completely captivated by the virtual world.": This gauges the amount of attention focused on VR and the involvement experienced.
- *Experienced realism* (4 items): "How real did the virtual world seem to you?": This is the subjective rating of realism of a virtual environment.

All IPQ items are statements and respondents have to rate their degree of agreement on a 7-point Likert scale, ranging from -3 to +3.

Results:

On average, participants didn't find themselves to be completely involved in the VR, possibly because we did not use immersive VR with a head-mounted display. But the Bayes Factor[1] values show that the evidence was inconclusive, so there is possibility that we were underpowered to find this effect. Participants did exhibit a good degree of spatial and general presence. Even with our best efforts to create as realistic of an environment as possible, the participants' subjective realism ratings revealed that there was a lot of variation in how realistic different participants found the virtual environment to be. But most important issue for us was whether altruists and non-altruists differed from each other on any of these components of VR which could complicate our interpretation behind group differences.

Figure S1. Mean ratings for the entire group on subscales of IPQ. Error bars represent 95% confidence interval.



[1] When traditional null hypothesis testing results in a failure to reject the null hypothesis (H0), this can't be taken as evidence in support of the null hypothesis because p-values are unable to quantify support in favor of the H0 (Wagenmakers, 2007). Therefore, Bayes Factors (BF) were calculated for group comparisons to assess the relative likelihood of the null and alternative (H1) hypotheses (Jarosz & Wiley, 2014). A BF_{01} of greater than 1 implies that the data are more likely to occur under H0 than under H1. Similarly, a BF_{01} lower than 1 indicates that the data are more likely to occur under H1 than under H0. Thus, if we analyze data and find that $BF_{01} = 3$, this means that the data are 3 times more likely to have occurred under H0 than under H1. Based on prior guidelines (Etz & Vandekerckhove, 2016), BFs between 1 and 3, between 3 and 10, and larger than 10 are interpreted as ambiguous, moderate, and strong support, respectively.

Table S1. Results from one-sample *t*-test on subscales of IPQ

IPQ subscale	*t*	*df*	*p*	BF_{10}	Cohen's *d*	95% CI	
						Lower	Upper
involvement	1.331	42	0.190	0.375	0.203	-0.135	0.658
spatial presence	3.903	42	< .001	79.151	0.595	0.346	1.087
experimental realism	-4.243	42	< .001	204.11	-0.647	-1.072	-0.381
general presence	2.066	42	0.045	1.131	0.315	0.012	1.011

A multivariate analysis of variance (MANOVA) with group (altruistic, non-altruistic) as between-subject factor and IPQ subscale scores as the dependent variables showed no differences between participants who stopped and helped (or tried to help) the trapped humanoid and those who passed by, without helping on the three subscales and the general item of IPQ. Thus, it is unlikely that altruists were more willing to help (compared to non-altruists) the trapped humanoid in the virtual world because they didn't find the VR to be realistic enough and thus the situation wasn't threatening enough for them.

Table S2. Multivariate tests on self-reported questionnaires and the three scales evaluating the emotional state of the participants

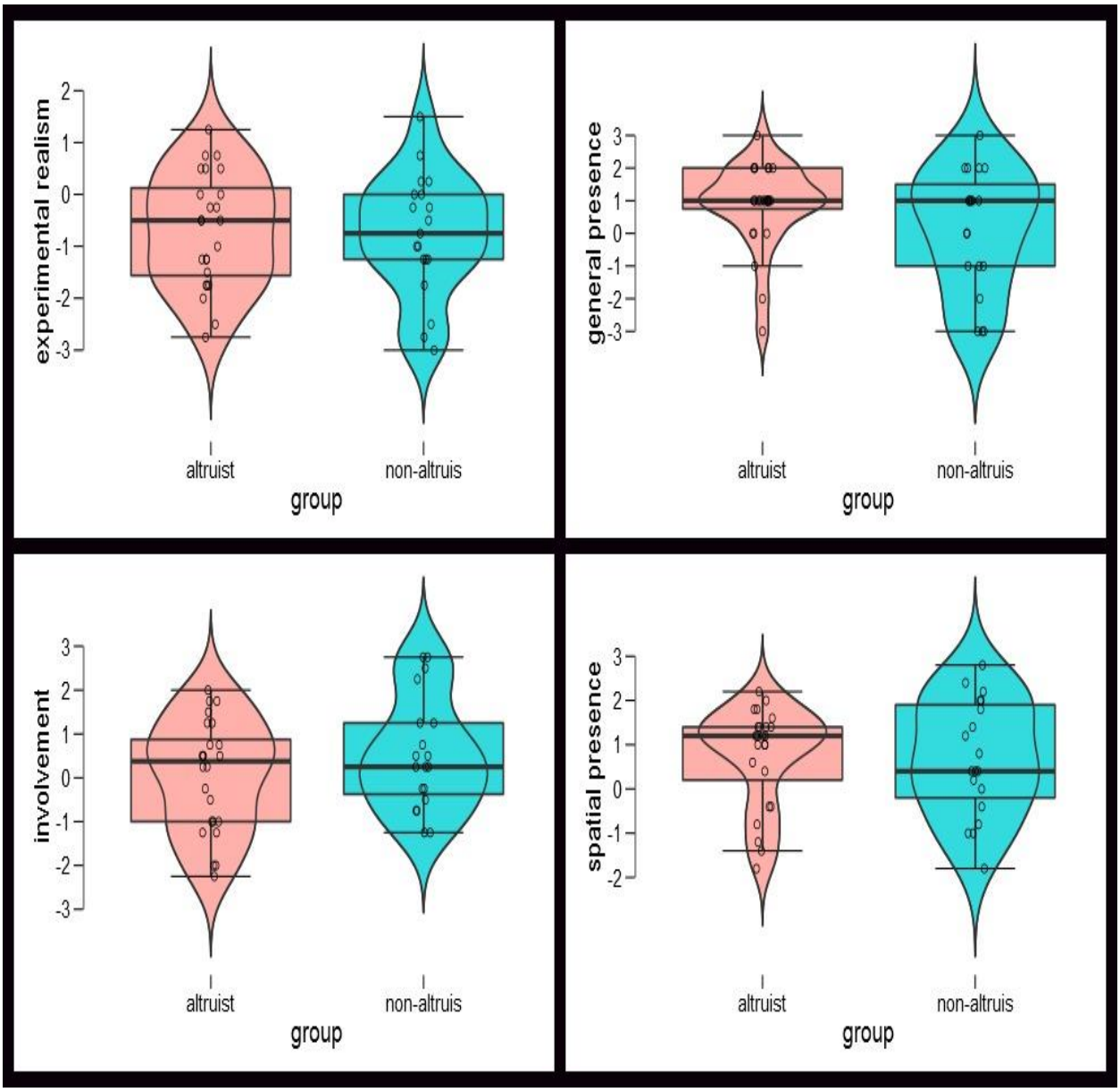
	Wilks λ	*F*	*df*	Error *df*	*p*	η_p^2
IPQ	0.834	1.889	4	38	0.132	0.166

Note: IPQ = Igroup Presence Questionnaire.

Table S3. Comparison of group scores (Mean (SE)) on the three subscales of the Igroup Presence Questionnaire (IPQ) and the general sense of presence item.

	Involvement	Spatial presence	Experienced realism	General sense of experience
Altruistic	0.04 (0.26)	0.74 (0.25)	-0.69 (0.23)	0.83 (0.33)
Non-altruistic	0.54 (0.29)	0.68 (0.28)	-0.78 (0.26)	0.11 (0.37)

Figure S2. Full distribution of scores for subscales of iGroup Presence Questionnare are shown using combination of box and violin plots (Allen, Erhardt, & Calhoun, 2012). Box plot within the violin plot contains thick black line for the median and the box indicates the interquartile range, while the added rotated kernel density plot shows the probability density of the data at different values.



The same results were obtained even in simple comparisons (both parametric and non-parametric) between altruists and non-altruists for each subscale of IPQ-

Table S4. Comparisons between altruists and non-altruists on the IPQ subscales.

IPQ Subscale	Test	statistic	*df*	*p*	Mean Difference	SE Difference	Cohen's *d*
involvement	Student's	-1.267	41	0.212	-0.498	0.394	-0.389
	Welch's	-1.265	38.53	0.213	-0.498	0.394	-0.389
spatial presence	Student's	0.154	41	0.879	0.057	0.381	0.047
	Welch's	0.151	35.58	0.881	0.057	0.381	0.047
experimental realism	Student's	0.255	41	0.800	0.089	0.352	0.078
	Welch's	0.253	37.48	0.802	0.089	0.352	0.078
general presence	Student's	1.481	41	0.146	0.728	0.511	0.455
	Welch's	1.424	31.39	0.164	0.728	0.511	0.455
Total	Student's	0.284	41	0.778	0.377	1.367	0.087
	Welch's	0.275	32.92	0.785	0.377	1.367	0.087

Supplementary Text S3: Analysis and results for the PT and PD subscales of IRI

For the sake of completeness, here we provide details for the analysis focusing on subscales of IRI apart from EC, which was the main focus of hypothesis-driven study.

Measurement:

All participants completed Interpersonal Reactivity Inventory (IRI; Davis, 1983), a 28-item self-report questionnaire with four 7-item subscales, that was used to assess specific aspects of dispositional empathy. Participants reported agreement with statements on a 5-point Likert scale (1: *never true for me*, 5: *always true for me*). Apart from the EC, the other three subscales consisted of:

- fantasy scale (F), which measures the propensity to identify with fictional characters (e.g., "I really get involved with the feelings of the characters in a novel.", Cronbach's $\alpha = 0.788$);
- perspective taking (PT) scale, which measures the tendency to take the psychological point of view of others (e.g., "I try to understand my friends better by imagining how things look from their perspective.", $\alpha = 0.799$);

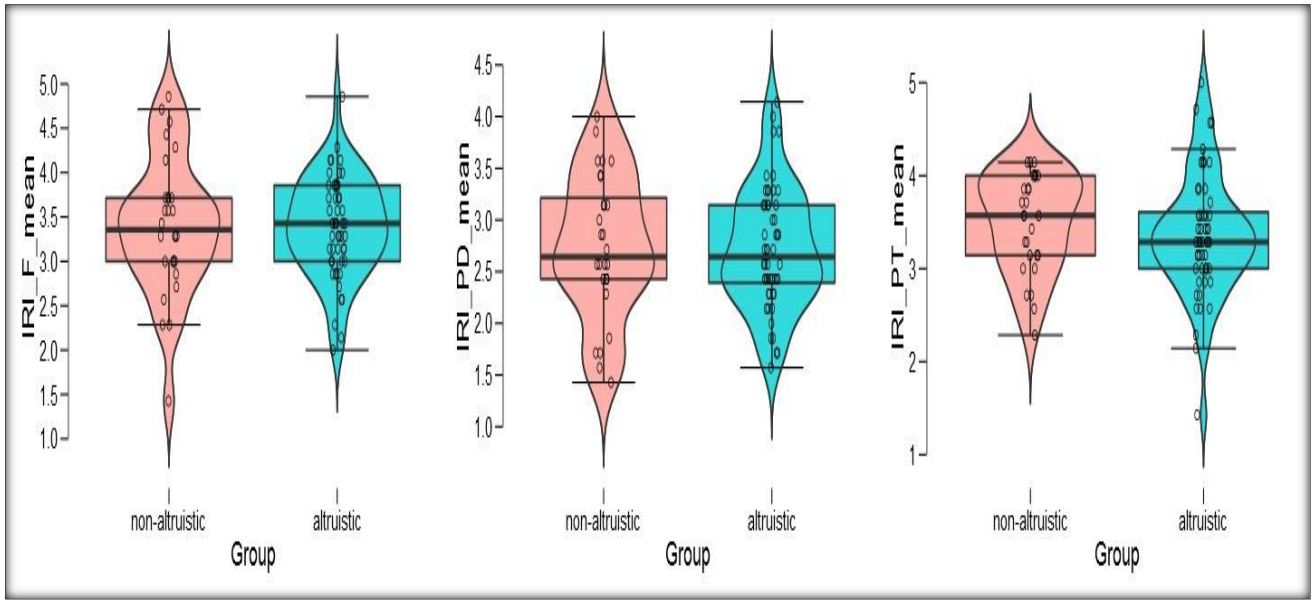
- personal distress (PD) scale, which measures the *self-oriented* tendency to feel personal unease and discomfort in reaction to the emotions of others (e.g., "I sometimes feel helpless when I am in the middle of a very emotional situation.", $\alpha = 0.843$).

Based on recent psychometric assessments of the IRI questionnaire (Baldner & McGinley, 2014), we decided *a priori* not to explore the fantasy subscale beyond descriptive statistics, as it does not map well onto the current theorizations of empathy (Decety & Cowell, 2014).

Behavioral analysis:

The altruists and non-altruists did not differ on self-reported PT (altruist: 3.495, non-altruist: 3.363; $t(67.08) = 0.972$, $p = 0.334$, $d = 0.213$) and PD (altruist:2.745, non-altruist: 2.723; $t(48.27) = 0.144$, $p = 0.886$, $d = 0.035$) (see the Figure S2).

Figure S3. Full distribution of scores for IRI subscale PT, F, and PD are shown using combination of box and violin plots (Allen et al., 2012). Box plot within the violin plot contains thick black line for the median and the box indicates the interquartile range, while the added rotated kernel density plot shows the probability density of the data at different values.



DBM analysis:

As with the EC subscale of IRI, for creating similar masks for PT and PD *separately*, we used multiple regression model, which included age, age^2 (to model quadratic effects of age), and gender as nuisance covariates in addition to the predictor of interest. These masks included voxels that tracked interindividual variation in self-reported EC in the positive direction, i.e. increased PT or PD associated with expanded regions.

The volume change maps for subjects in each group were analyzed with a two-sample *t*-test, with age, age^2, and gender included as nuisance covariates (O'Brien et al., 2011). The DBM was carried out at the whole-brain level using the PT or PD mask, i.e. by restricting analysis only to the voxels which were associated with variation in dispositional PT or PD, in order to avoid stringent threshold for multiple comparison. This analysis did not reveal any suprathreshold voxels, even at a more liberal threshold (p(uncorrected) < 0.001).

Supplementary Text S4: EC mask

The regression analysis revealed the regions that showed positive association with trait EC ($p < 0.001$, $k > 10$, Table 1), i.e. higher EC was associated enlargement of the following areas, and were included in the EC mask.

Table S5. Regions that showed enlargement with increasing levels of self-reported empathic concern.

Region Label	Extent (*k*)	*t* -value	MNI coordinates		
			x	*y*	*z*
L Middle Frontal Gyrus	14	4.698	-33	41	43
R Superior Medial Gyrus	22	4.613	4	35	55
L Superior Medial Gyrus	13	4.039	2	59	17
R Posterior-Medial Frontal	17	3.913	4	19	65
Cerebellar Vermis (4/5)	30	3.869	2	-60	3
Cerebellar Vermis (6)	17	3.812	4	-76	-10
R IFG (pars Opercularis)	10	3.542	52	9	23
R Insula Lobe	10	3.398	44	17	-10

Although all of these regions were included in the mask, we *a priori* expected effects at the insular lobe in the light of prior work. Previous morphometry studies have revealed a positive association between self-reported EC scores and various morphometry measures of insula-

(*i*) the grey matter volume of the AI (Banissy, Kanai, Walsh, & Rees, 2012; Eres, Decety, Louis, & Molenberghs, 2015; Mutschler, Reinbold, Wankerl, Seifritz, & Ball, 2013; Yue, Pan, & Huang, 2016),

(*ii*) increased insular-opercular cortical thickness (Valk et al., 2016),

(*iii*) higher structural covariance between dorsal AI and prefrontal-limbic regions (Bernhardt, Klimecki, Leiberg, & Singer, 2014).

Additionally, patients with insular damage due to glioma score less on self-report measures of EC than patients with non-insular glioma and healthy controls (Chen et al., 2016). Thus, although the second-level analysis was carried out on the entire mask, we a priori expected effect in the insular lobe.

Supplementary Text S5: Online survey

The online survey was conducted to test our hypothesis that the null effect we found with regards to the EC scores across two groups in the lab-based study was due to a combined effect of small sample size and a dichotomous measure (altruist versus non-altruist). In the online survey, we tested this hypothesis by recruiting a larger sample size and a continues Likert-scale.

Methods:

After the DBM study was completed, we also carried out an additional small-scale online survey using Google forms. This survey had two objectives, one of primary importance and another more ancillary:

1. Our primary objective behind this survey was to assess the validity of our claim that VR paradigm was more naturally realistic than its hypothetical analog. If this assertion is true, then we should see that participants' *judgments* about how they would behave in such scenarios would be misaligned with the *behavior* in VR (FeldmanHall et al., 2012; Francis et al., 2016; Patil, Cogoni, Zangrando, Chittaro, & Silani, 2014). Such judgment-behavior discrepancy would again speak to the advantage of using more lifelike situations to get more realistic responses from participants in situations involving harm, fatal risk, and danger that are ethically impossible to recreate in lab settings.

2. Our ancillary objective was to see if the relationship between EC and altruistic tendency, which has been observed numerous times in the past literature but not found in the DBM study with a dichotomous measure, was observed if Likert-type rating scale was used.

This survey was completed by 129 new volunteers (96 females, age = 26.03 ± 5.99). Participants read the following scenario-

> "Imagine to wake up to a loud noise, the ground shaking under your feet, and realize that there is an earthquake in progress. You immediately proceed to evacuate the building. You run down the stairway, constantly coughing from the dust you are inhaling, and reach the first floor and suddenly come across a man trapped under a heavy cabinet. This person can see you and is begging you for help. You are indeed strong enough to remove the cabinet and free this person. But you also recognize that stopping to help this man can potentially put your own life in danger, because the upper floors of the building are dangerously close to collapsing."

Note that the situation was modified (the cause that prompts the evacuation is an earthquake) to be emotionally more salient and ecologically more valid to our Italian participants in the wake of the devastating earthquake that hit Central Italy on 24 August 2016 (note that participants were not victims of that earthquake but had been exposed to the extensive media coverage that the disaster received in Italy). Participants then responded to two questions:

> [*a*] *behavior forecast*: Would you stop to help this man? (Yes/No)
>
> [*b*] *permissibility*: How morally permissible will it be for you to not stop to help this person in order to save your own life? (1: *not at all permissible*, 10: *completely permissible*).

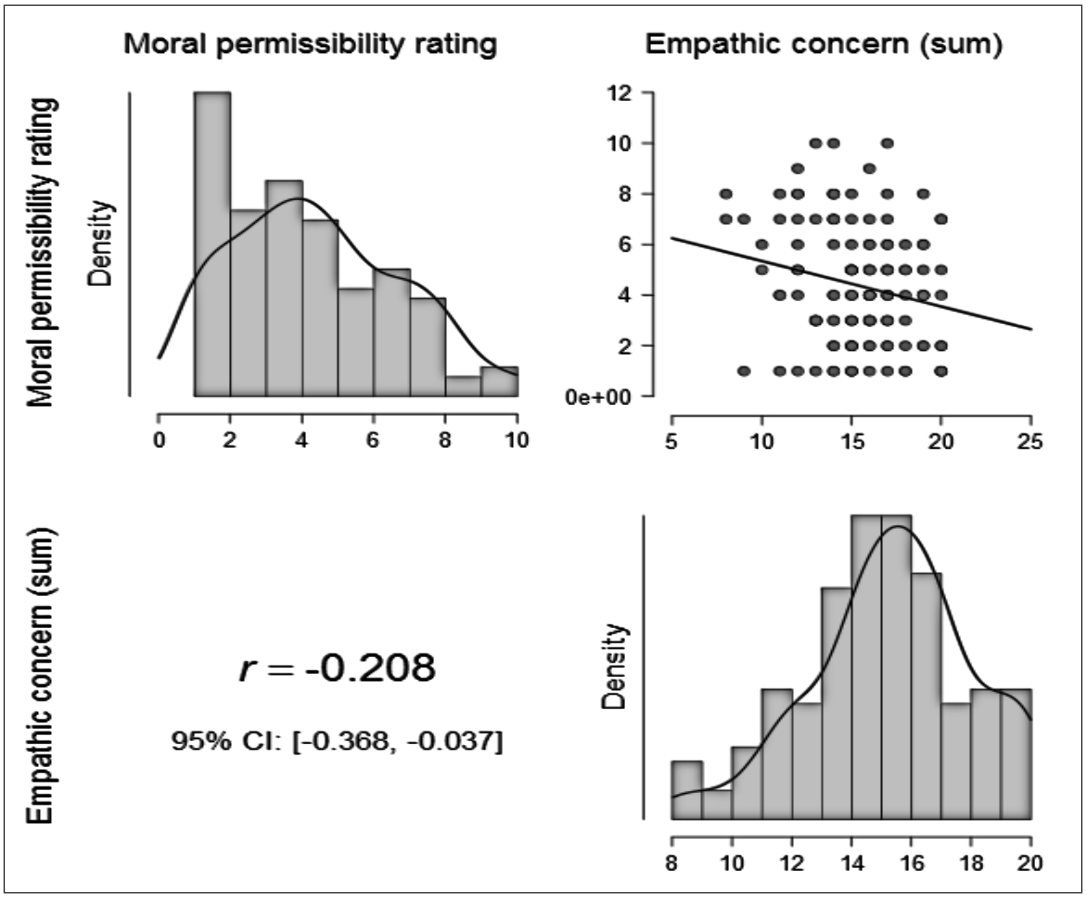
Next, participants completed four items from the abbreviated and Italian-validated version of the IRI (Ingoglia, Lo Coco, & Albiero, 2016) to index trait EC ($\alpha = 0.786$).

Results:

In the online text-based survey, most participants (117/129) said that they would stop to help the trapped person, while only a few said they would not (12/129) ($\chi^2(1) = 85.465$, $p < 0.001$). As in the DBM study, no difference in EC scores was observed between altruists and non-altruists (altruist: 3.863, non-altruist: 3.583; Welch's *t*-test: $t(13.23) = 1.335$, $d = 0.414$, $p = 0.204$).

As expected, there was a significant correlation between EC and continuous moral permissibility ratings (Pearson's $r = -0.208$, $p = 0.018$; Spearman's $\rho = -0.176$, $p = 0.046$; see the correlation plot below), such that participants scoring high on EC found it less morally acceptable not to help the person in need to save their own life.

Figure S4. Correlation plot for permissibility ratings and scores on EC subscale of IRI, along with the density plot for the variables.



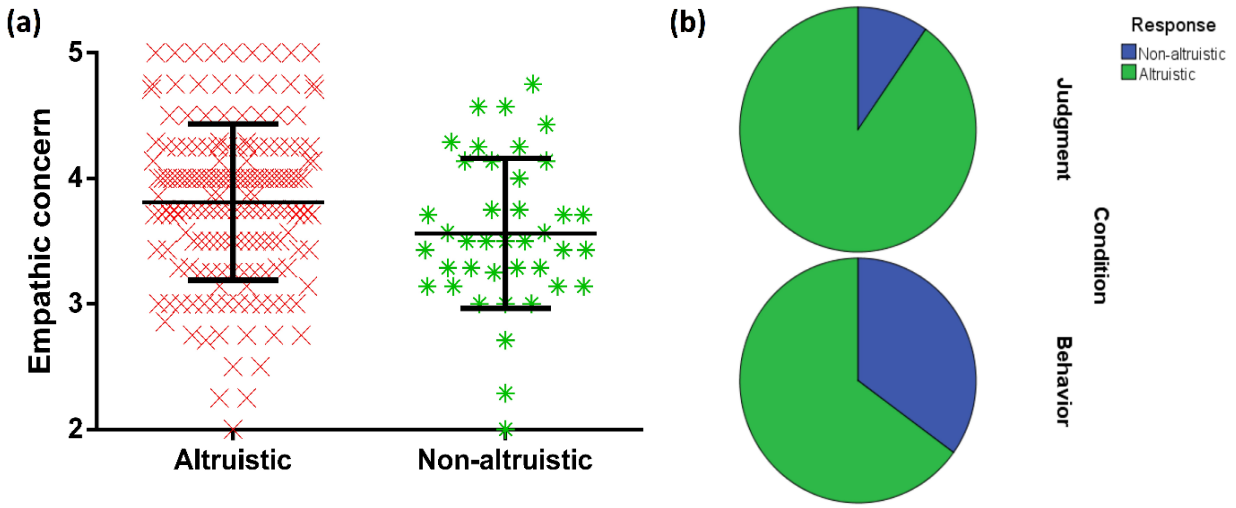
Combined data:

We also carried out exploratory analysis combining data from lab-based and online experiments to assess the oft-observed judgment-behavior discrepancy (Camerer & Mobbs, 2017; FeldmanHall et al., 2012; Francis et al., 2016; Patil et al., 2014; Teper, Tullett, Page-Gould, & Inzlicht, 2015) in the moral domain.

We combined EC data from both studies to see if altruists differed from non-altruists on EC scores (see the figure below). A linear mixed-effects model with fixed and random effects for the experiment (DBM study, online survey) and response (altruistic, non-altruistic) factors revealed a marginally significant effect for response (estimate = 0.1934, $F(1,209) = 2.914$, $p = 0.089$) with altruists (3.786) scoring higher than non-altruists (3.592), but no effect of experiment ($p = 0.13$).

Additionally, we also checked if participants exhibited judgment-behavior discrepancy (FeldmanHall et al., 2012; Francis et al., 2016; Patil et al., 2014; Teper et al., 2015), such that they judged that they would act in an altruistic manner more frequently than they actually did in the VR environment. Indeed, most participants (91%) predicted that they would act in an altruistic manner in the text-based online survey, but fewer (65%) exhibited this behavior in a contextually salient setting ($\chi^2(1) = 21.070$, $p < 0.001$, $\phi = 0.318$). Note that these two groups were from different studies with slightly different stimuli and this exploratory analysis was carried out only to demonstrate the previously observed judgment-behavior discrepancy.

Figure S5. (*a*) The scatterplot for the combined dataset from online and lab-based studies shows that participants who made altruistic choices also reported to have greater dispositional EC for others. Error bars represent the standard deviation. (*b*) The pie chart shows that the percentage of participants who chose the altruistic response in the text-based hypothetical scenario (judgment condition: 91%) was significantly higher than that of participants choosing to behave in an altruistic manner in a contextually salient virtual reality (VR) environment (behavior condition: 65%).



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