Neuropsychologia 116 (2018) 34–43

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Neuroanatomical basis of concern-based altruism in virtual environment

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ARTICLE INFO

Keywords:
Empathy
Altruism
Prosocial
Morphometry
Empathic concern
Moral

ABSTRACT

Costly altruism entails helping others at a cost to the self and prior work shows that empathic concern (EC) for the well-being of distressed and vulnerable individuals is one of the primary motivators of such behavior. However, extant work has investigated costly altruism with paradigms that did not feature self-relevant and severe costs for the altruist and have solely focused on neurofunctional, and not neuroanatomical, correlates. In the current study, we used a contextually-rich virtual reality environment to study costly altruism and found that individuals who risked their own lives in the virtual world to try to save someone in danger had enlarged right anterior insula and exhibited greater empathic concern than those who did not. These findings add to the growing literature showing the role of caring motivation in promoting altruism and prosociality and its neural correlates in the right anterior insula.

1. Introduction

Humans are unique in terms of their ability to forge large-scale stable cooperation that lies at the heart of complex societal structures, and a considerable share in sustaining this endeavor goes to our prosocial and altruistic impulses. Prosocial behavior is any behavior that benefits others, while altruistic behavior is a subset of prosocial behaviors that improves welfare of the recipient and comes at a cost to the altruist (Batson, 2011; de Waal, 2008). Altruistic acts can be as simple as giving one's seat to an older person in a crowded bus or can be as extreme and extraordinary as entering a building on fire to rescue someone. A burgeoning body of work carried out across several academic disciplines using a multitude of approaches has shed light on biological, psychological, and neural underpinnings of different forms of altruism (e.g., Böckler et al., 2016; Marsh, 2016). In the current study, we focus specifically on the neural basis of what motivates possibly the most enigmatic variety of altruism: helping behaviors that come at a high cost to the self, also called extreme or costly altruism (FeldmanHall et al., 2015; Rand and Epstein, 2014), e.g. firefighters who rush into buildings on fire to rescue other people. Prior work has traced the roots of costly altruism to empathic concern (EC) (also labeled as sympathy or compassion), an other-oriented feeling of concern in response to another individual's state of distress or suffering, which relies on neural mechanisms involved in parental care and social attachment (FeldmanHall et al., 2015; Marsh, 2016; Morelli et al., 2014; Preston, 2013; Shaver et al., 2016; Swain et al., 2012; Zahn et al., 2009).

An important terminological distinction between empathy and EC is worth underlining. Empathy, in a narrow sense, entails our capacity to *represent* (cognitive component) and *feel* (affective component) what other people feel ("I feel anxious because you feel anxious"), while EC represents our ability to *care* about what other people feel ("I am concerned about you because you seem anxious") (de Vignemont and Singer, 2006). In line with extensive prior theoretical discussions highlighting this conceptual distinction (Batson, 2009; de Vignemont and Singer, 2006), recent empirical work demonstrates that empathy and EC are psychologically distinct and empirically distinguishable (Bloom, 2017; Jordan et al., 2016; Singer and Klimecki, 2014; Shdo et al. 2017). Furthermore, a large amount of evidence (See Supplementary Text S1 for more detailed discussion) supports the

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Abbreviations: AI, anterior insula; DBM, deformation-based morphometry; EC, empathic concern; IRI, interpersonal reactivity index; VR, virtual reality

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http://dx.doi.org/10.1016/j.neuropsychologia.2017.02.015
Received 13 December 2016; Received in revised form 9 February 2017; Accepted 21 February 2017

0028-3932/

claim that this general dispositional concern for the welfare of someone in distress (i.e., EC/compassion) is the primary contributor to our moral actions and thoughts, and not – as it has been proposed – the aversive arousal state stemming from empathy (Bach et al., 2016; Batson, 2011; Bekkers and Ottoni-Wilhelm, 2016; Bethlehem et al., 2016; Bierhoff et al., 1991; Bloom, 2016; Brethel-Haurwitz et al., 2016; Carlo et al., 2010; Cecchetto et al., 2017; Chopik et al., 2017; Crocetti et al., 2016; Decety and Yoder, 2015; Desteno, 2015; FeldmanHall et al., 2015; Gęsiarz and Crockett, 2015; Graham et al., 2011; Habashi et al., 2016; Hu et al., 2015; Hubbard et al., 2016; Jordan et al., 2016; Kawamichi et al., 2015; Maner et al., 2002; Nook et al., 2016; Paciello et al., 2013; Patil et al., 2016; Patil and Silani, 2014a, 2014b; Persson and Kajonius, 2016; Ru et al., 2017; Sassenrath et al., 2017; Shaver et al., 2016; Stocks et al., 2017; Wilhelm and Bekkers, 2010; Winczewski et al., 2016). In other words, an individual's willingness to help others in need at a cost to the self is driven not by an urge to minimize self-oriented distress stemming from witnessing someone in need, but by other-oriented caring motivation.

Despite this large amount of work implicating caregiving (EC) as the primary motive in costly altruism, the extant literature falls short on two counts. First, the costly altruistic behaviors have not been assessed using ecologically valid and contextually salient paradigms, and have relied on either decontextualized hypothetical vignettes or on more ecologically valid paradigms that did not feature high (harmful) cost for the altruists (cf. Grueter et al., 2016). For example, a number of lab-based experiments have studied altruism using economic games that typically feature salient and realistic paradigms (Fehr and Schmidt, 2006), but behavior in such games has been argued to be confounded with factors other than altruistic motives (e.g., Burton-Chellew et al., 2015) or found to be weakly correlated with real-life altruism (Brethel-Haurwitz et al., 2016; Winking and Mizer, 2013). Additionally, these paradigms investigate the moral domain of fairness rather than physical harm, which is what we wanted to focus on here. Second, studies focusing on the neural underpinnings of costly altruism have primarily examined the neurofunctional, but not the neuroanatomical, correlates of such behavior. To the best of our knowledge, only one prior study has addressed both of these concerns by showing that the individuals who had donated one of their kidneys to a complete stranger, an act of extraordinary altruism, had larger amygdala than controls (Marsh et al., 2014).

In the current study, both issues were addressed simultaneously by investigating the role of EC and the neuroanatomical basis of costly helping behavior in scenarios involving the highest cost possible: risking one's own life to save a stranger. Of course, it is ethically unacceptable to create lab situations that may put anybody's life in danger and, although text-based descriptions of dangerous situations can be safe and informative, participants' self-reports in the domain of morality can be notoriously unreliable for accurately predicting their actual behavior (FeldmanHall et al., 2012; Francis et al., 2016; Patil et al., 2014; Teper et al., 2015; Winking and Mizer, 2013). This is because such hypothetical settings are low in naturalistic intensity (i.e., the intensity of the sensory input or subjective processing) and evoke only a subset of mechanisms compared to more realistic choices (Camerer and Mobbs, 2017). To overcome these issues, we thus employed a virtual reality (VR) environment to simulate a life-threatening situation in which participants were faced with the decision of whether to save another participant at the risk of their own life. With this methodology, we were able to provide a contextually rich and more lifelike environment that we could control, and could thus- (*i*) study current altruistic behavior of participants rather than rely on their past behavior, (*ii*) focus on more typical individuals over those belonging to the high end of the distribution (cf. Marsh et al., 2014). VR thus helps overcome some of the limitations of the classical experimental paradigms in social neuroscience (Parsons, 2015; Rosenberg et al., 2013; Sanchez-Vives and Slater, 2005), especially in the fields of moral cognition and prosocialilty, that feature choices for which executing realistic consequences experimentally is impossible or unethical (Francis et al., 2016; Navarrete et al., 2012; Patil et al., 2014; Skulmowski et al., 2014; Zanon et al., 2014).

The purpose of this study was to assess whether there are any structural differences between brains of altruists versus non-altruists, classified as such based on their behavior in a VR task with high naturalistic intensity, providing a high degree of contextual information and ecological validity. We predicted that altruists would show enlargement of regions associated with EC, given the overwhelming evidence that puts such compassionate motivation at the heart of explaining costly altruism.

2. Methods and materials

2.1. Participants

Eighty participants (26 females) participated in the experiment and were financially compensated for time and travel expenses. The mean age of the sample was 23.71 years (SD =3.44; range =19–37). All participants gave written informed consent. The study was approved by the ethics committee of the hospital “Santa Maria della Misericordia” (Udine, Italy). Rule-out criteria for participation included non-native speakers of Italian, presence of a diagnosed psychiatric illness and/or history of psychiatric treatment, history of significant neurological illness or brain injury, and current usage of psychoactive drugs. All participants were screened for neurological conditions and MRI contraindications (first through pre-scanning telephone interviews and second before entering the scanner). All participants had normal structural brain MR scans. Part of the dataset (n =43) came from a previous study (Zanon et al., 2014), where participants performed the task while functional data was acquired.

2.2. Behavioral tasks

2.2.1. Empathic concern

All participants completed the EC subscale of the Italian-validated version of the Interpersonal Reactivity Inventory (IRI; Albiero et al., 2006; Davis, 1983). Participants reported agreement on 7 statements (e.g., “I often have tender, concerned feelings for people less fortunate than me.”, α=0.658) on a 5-point Likert scale (1: *never true for me*, 5: *always true for me*). This subscale measures the *other-oriented* tendency to experience feelings of warmth, compassion, and concern for other people. Although not of interest to our hypothesis, we also collected data for other subscales of the IRI (Full details provided in Supplementary Text S3).

2.2.2. Virtual reality task

Participants' altruistic behavior was assessed using a previously validated VR task (Zanon et al., 2014) reproducing a life-threatening situation that pits saving one's own life by evacuating a building on fire against risking it to rescue someone else in danger. The virtual experience was implemented using the C# programming language and NeoAxis (http://www.neoaxis.com), a game engine based on the Ogre rendering engine (http://www.ogre3d.org). VR has been shown to be effective in eliciting a high degree of sense of presence (Diemer et al., 2015; Schubert et al., 2001) and negative emotions (Chittaro, 2014; Diemer et al., 2015; Zanon et al., 2014). To increase sense of presence in the simulated experience, the scenario was experienced from a first-person perspective (Bergström et al., 2016), with the help of an MRI-compatible headphones for audio stimuli, and goggles for visual stimuli. Video samples are available at: https://osf.io/3hr3q/.

2.2.2.1. Instructions. Participants performed the task inside the scanner and were instructed via intercom. They were told that the objective of the task was to study strategies used by people while evacuating buildings in emergency situations. The experimenter also

Fig. 1. The virtual reality (VR) paradigm. (a)-(b) Screenshots of the initial familiarization phase session in which participants learned how to interact with objects in the VR environment (e.g., opening doors, lifting boxes, etc.). (c) During the initialization phase, the participant was placed in the VR environment in which the experimental task was going to take place. (d)-(e) In the experimental phase, the participant was supposed to exit a building on fire. The dangerousness of the situation was emphasized by visual cues, such as smoke in the corridors, reduced visibility, and sounds such as coughs. Additionally, the 'life energy' bar informed participants about the amount of life left and was always visible in the upper right corner of the screen. (f) At the end of the experimental phase, when there was little life left in the avatar, participants encountered an avatar trapped by a heavy cabinet and they could either stop to help and rescue this avatar (altruistic decision) or carry on without stopping and save their own life (non-altruistic decision).

prompted them to behave in the virtual environment as they would in a real-world situation and thus to evacuate the building as quickly as possible. Participants could move and act in the virtual environment by pressing four buttons on two MRI-compatible response pads: the right hand was used to move respectively leftward, forward, and rightward, whereas the left hand was used to interact with objects in the virtual environment.

2.2.2.2. Familiarization phase. To familiarize participants with response pad usage for navigating and interacting with objects in the virtual environment, this phase situated participants in a small building. Participants were instructed about how to interact with objects using action prompts (Fig. 1(a)) that appeared at the bottom of the screen (e.g., "spingi" (push), "apri" (open), etc.). At the end of this familiarization phase, participants were asked to lift and move away three virtual boxes placed in an empty room of the environment (Fig. 1(b)). To simulate the effort needed for successfully moving heavy boxes, the participant had to press repetitively the button on the response pad, until the object moved (41 button presses were required to completely move away the object).

2.2.2.3. Initialization phase. After the familiarization phase, the screen faded to black and was then replaced by a virtual meeting room in which participants could see three other avatars (Fig. 1(c)). Participants were told that these avatars were controlled in real time by other participants connected via intranet and performing the same task from computers located in another building. The movements of the avatars were actually pre-programmed and controlled by the computer application. Participants could explore the meeting room for about a minute, observe the behaviors of the other avatars, and could also go close to them. When approached, the avatars did not engage in any social interaction with the participant and continued their exploration of the meeting room.

2.2.2.4. Experimental phase. This phase started with a voice message on the public-address system of the virtual building as an emergency alarm sounded in the background. The message stated that fire had broken out and the building had to be immediately evacuated by all people by following the emergency signs. To increase the realism of the setting, the sound for the emergency alarm and the emergency signs followed Italian regulations for fire safety in the workplace. While participants were trying to evacuate the building by following the emergency signs, aversive visual and auditory feedback was provided by continuous emergency alarm sound and repeated announcement to evacuate the building. Furthermore, the participant heard the sound of her/his own avatar coughing due to smoke inhalation and the visual field was reduced when (s)he was in danger, to simulate tunnel vision phenomena that occur in high stress conditions. This type of feedback has been shown to be effective in creating an experience of risk and danger in VR (Chittaro, 2014; Chittaro and Zangrando, 2010). Participants could track how much ‘life energy’ was left in their avatar on a bar labeled as ‘life energy’. At the beginning of the evacuation, the bar was fully charged and shaded in green (Fig. 1(d–e)).

Close to the end of the path (i.e., the exit of the building), participants unexpectedly encountered an injured male avatar (cf. FeldmanHall et al., 2016) previously seen[2] in the meeting room but now lying on the floor, trapped under a heavy cabinet and asking for help. At this time, the participant's ‘life energy’ bar had already depleted and was shaded in red (Fig. 1(f)). Each participant was thus confronted with a dilemma between saving their own life by exiting the building without stopping or spending time at the possible cost of their own life to rescue the trapped avatar by removing the heavy cabinet. The amount of effort to move away the cabinet and free the avatar was set to 150 button presses. While the participants were trying to free the trapped avatar from under the cabinet, three aspects of the virtual environment conveyed the presence of danger: (*i*) a flashing red aura in the peripheral visual field, (*ii*) heartbeat sound at a progressively increasing frequency, played through the headphones, and (*iii*) red and almost finished ‘life energy’ bar. During debriefing, some participants also mentioned that the confined space of the MRI magnet bore, and the ensuing claustrophobic feeling, further amplified a sense of urgency and danger.

It is important to note that the gradient by which the ‘life energy’ bar decreased from the beginning of the evacuation was identical for each participant to make sure that they all had a very small amount of ‘life energy’ left when they encountered the trapped avatar. Furthermore, if a participant stopped to rescue the avatar, the bar kept decreasing, although the decrease was controlled in such a way that the participant could not “die” in the virtual experience. The purpose of the bar was to add to the sense of urgency, and to highlight the saliency of the threat to the participant's own avatar. The emergency experience ended when participants moved away from the point of encounter with the avatar and reached the emergency exit, with the scene fading away automatically.

Participants were divided into two groups based on the choice they made about helping the trapped avatar:

(i) *altruistic*, who stopped and either successfully helped the avatar, or started helping but then left before moving the cabinet away completely, without freeing the avatar;
(ii) *non-altruistic*, who passed by without stopping to help the trapped avatar.

Note that we included individuals who stopped to rescue the trapped person but could not in the altruistic group. This is because altruistic behavior is defined as helping others at a cost to the self and, to the degree that stopping to help someone in a burning building with little ‘life energy’ remaining is a cost to the self, these individuals did behave altruistically.[3]

2.2.2.5. Debriefing. At the end of the experiment, participants were informally debriefed, and were informed that the avatars were controlled by the computer application. None of them reported to have been suspicious about the fact that the avatars were computer controlled. We also asked them to report their subjective impression in an open-ended format, which revealed that the VR experience was indeed felt as very distressing. A subset of participants (n =43) also completed the iGroup Presence Questionnaire (IPQ: http://www.igroup.org/pq/ipq/index.php; Schubert et al., 2001) to assess the subjective experience felt by the participant in the VR (Schubert et al., 2001; Witmer and Singer, 1998) (Full details in Supplementary Text S2).

2.3. MRI data acquisition and preprocessing

2.3.1. Acquisition

High-resolution structural images were acquired as 190 T1-weighted transverse images with a 3D ultrafast gradient echo sequence on a 3 T Philips Achieva scanner at the Hospital ‘Santa Maria della Misericordia’ (Udine, Italy) equipped with an 8-channel SENSE head coil. The following parameters were used: voxel size =1×1×1 mm, TR/TE =8.2/3.7 ms, matrix size =240×240 mm, field of view =19 cm, flip angle =8°, no overcontiguous slices.

2.3.2. Preprocessing

Both preprocessing and statistical analyses were carried out using the Computational Anatomy Toolbox (CAT12: http://dbm.neuro.uni-jena.de/cat12/) for SPM12 running on MATLAB R2013a (MathWorks, Natick, Massachusetts, USA).

Bias field correction was applied to correct for MRI inhomogeneities, which are especially prevalent at high field strengths (≥3 T), noise was removed and intensities were normalized (Vovk et al., 2007). Each image was then simultaneously segmented[4] and normalized into six different tissues classes (grey matter (GM), white matter (WM), cerebrospinal fluid (CSF), bone, other soft tissues, and air/background) using the modified unified segmentation approach implemented in SPM12 (Malone et al., 2015). During normalization, the anatomy of

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[2] The victim was a stranger, just briefly seen at the beginning of the experience, because we wanted to avoid any unwanted effects that familiarity, liking, role-obligations, or other pre-existing attitudes might have on sympathetic responding (Batson, 2011).

[3] Indeed, the Carnegie Hero Fund Commission awards the Carnegie medal, one of the most prestigious recognitions for acts of heroism, to people who risk their lives to an extraordinary degree either to save or *attempt* to save the lives of others (http://www.carnegiehero.org/).

[4] Note that the deformation-based analyses focus not on the registered voxels in segmented images, like in the voxel-based morphometry, but on the deformation fields used to register them to the template image (Mietchen and Gaser, 2009).

each subject was mapped to a common template in MNI stereotactic space (2×2×2 mm) by iteratively registering segmented images via a fast diffeomorphic registration algorithm (DARTEL; Ashburner, 2007) to CAT12's default template (IXI555_MNI152) (cf. Michael et al., 2016). Non-linear deformation fields, defined by a displacement vector at each voxel constituting the transformation required to map a voxel of the template to its corresponding position in the subject brain, were estimated for each individual image such that tissue probability maps for each tissue class were best aligned. The Jacobian matrices at each point of the deformation field contain information not only on local stretching but also on shearing and rotation and are reliable for indicating local brain shape and sensitive to the shape variations across groups (Davatzikos et al., 1996). The Jacobian determinant (JD) of this matrix[5] quantifies local shrinkage or enlargement caused by warping while registering images to the template: $JD > 1$ indicates tissue expansion, $JD < 1$ denote tissue contraction, $JD = 1$ indicates identical volumes, $JD < 0$ are indicative of folding, and $JD \rightarrow \infty$ denotes tearing (Wang et al., 2007). These JD images were smoothed with an isotropic Gaussian kernel with FWHM of 15 mm to improve delineation of patterns of shape difference.

Before carrying out statistical analysis, quality assurance review of the final images was performed using the CAT12 toolbox. Sample homogeneity was assessed using a number of measures (noise, bias, weighted overall image quality). Data from one participant was consistently found to be an outlier in the boxplot for all quality measures and was thus removed from the final analysis ($n = 79$; altruistic: $n = 51$, non-altruistic: $n = 28$).

2.4. Deformation-based morphometry (DBM) analysis

Because the JD value for each participant is derived with respect to the same template, all participants' brains can be compared with each other by employing a voxel-wise general linear model (GLM), regardless of their shapes. This property allows us to calculate point-wise statistics and create statistical parametric maps for the DBM analysis, which has been shown to be an unbiased and highly regional sensitive automated technique for volumetric assessments from MR images (Ashburner et al., 1998; Ashburner and Friston, 2004; Chung et al., 2001; Gaser, 2016; Gaser et al., 2001, 1999; Mietchen and Gaser, 2009). The DBM analysis can be either multivariate, such that the entire three-dimensional deformation field can be used to find global differences, or it can be univariate using the local JD as a derivative of the field. We utilized here the latter approach because- (*i*) we were interested in local volumetric differences between altruists and non-altruists (for which the local Jacobian is a superior option), and (*ii*) global DBM results are comparatively more difficult to interpret because they combine information about both directional displacement of structure and local size differences (for more, see Gaser et al., 2001).

2.4.1. Creating the mask for EC

Before investigating group differences between altruistic and non-altruistic individuals, we localized the regions that tracked interindividual variation in the self-reported EC scores. To this effect, we used a multiple regression model that included age, age-squared (to model quadratic effects of age), and gender as nuisance covariates (O'Brien et al., 2011). This analysis revealed the regions that showed positive association with trait EC (Supplementary Text S4), i.e. higher EC was associated enlargement of the respective areas. Although all identified regions ($p < 0.001$, $k > 10$, uncorrected) were included in the mask used for the second-level analysis, we *a priori* expected effects at the insular lobe (x=44, y=17, z=−10) in light of prior studies showing a positive association between self-reported EC scores and morphometric measures of insula (Banissy et al., 2012; Bernhardt et al., 2014b; Eres et al., 2015; Mutschler et al., 2013; Shdo et al. 2017; Valk et al., 2016; Yue et al., 2016).

2.4.2. Group comparison

The volume change maps (i.e., JD images) for subjects in each group were analyzed with a two-sample t-test, with age, age-squared, and gender included as nuisance covariates (O'Brien et al., 2011). Note that total intracranial volume (TIV) was not added as a covariate for DBM because the affine part of the deformation field is ignored when JD images are saved (http://www.neuro.uni-jena.de/cat12/CAT12-Manual.pdf).

Given recent criticism of parametric cluster-level inference (Eklund et al., 2016; Woo et al., 2014), significant clusters were formed by employing the threshold-free cluster enhancement (TFCE) method (as implemented in TFCE toolbox (r93): http://dbm.neuro.uni-jena.de/tfce/). The TFCE is a cluster-based thresholding method that circumvents the problem of choosing an arbitrary cluster forming threshold (e.g., $p < 0.001$ (uncorrected) and k=10) by taking a raw statistics image and producing an output image in which the voxel-wise values represent the amount of cluster-like local spatial support (Smith and Nichols, 2009). This also makes the TFCE inference fairly robust to non-stationarity in the data under varying smoothness levels, degrees of freedom, and signal to noise ratios (Li et al., 2016; Salimi-Khorshidi et al., 2011). The TFCE image is then turned into voxel-wise p-values via a permutation-based non-parametric testing (10000 permutations were used in the current study). All group comparisons are reported at $p < 0.05$ after Family-wise Error (FWE) correction (Roiser et al., 2016).

Additionally, past research has shown that the rate of Type-I error for group comparisons in morphometry studies is robust to choices of smoothing kernel, sample size, and modulation only for balanced designs (Scarpazza et al., 2015), but can inflate in highly unbalanced designs due to the violation of the assumption of normality (Scarpazza et al., 2013). Since we had unequal sample sizes[6] across groups, the recommended nonparametric whole-brain analysis (Scarpazza et al., 2016) was performed using the SnPM toolbox (SnPM13; http://warwick.ac.uk/snpm) to assess the robustness of our results (10000 permutations, no variance smoothing).

The DBM was carried out at the whole-brain level using the EC mask as an explicit mask, i.e. by restricting analysis only to the voxels which were associated with variation in dispositional EC, in order to avoid too stringent thresholds for multiple comparison (see Supplementary Text S4).

2.5. Data availability

Unthresholded DBM statistical maps of reported contrasts are available on Neurovault (Gorgolewski et al., 2015; Roiser et al., 2016) at the following address: http://neurovault.org/images/29237/.

All the behavioral data are available at: https://osf.io/3hr3q/.

3. Results

3.1. Behavioral results

According to their behavior after encountering the avatar trapped under the cabinet, participants were subdivided in two groups:

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[5] Note that the Jacobian matrix is a tensor and, thus, this method is also sometimes called more specifically as tensor-based morphometry (TBM) (Ashburner, 2009; Ashburner and Friston, 2004). However, we stick to the general term DBM, like in prior work (Chung et al., 2001; Gaser, 2016; Gaser et al., 2001), to refer to any method that uses deformation fields for morphometry analyses.

[6] Although it would have been ideal to have a fully balanced design, we would like to underscore that there was no way we could ascertain participants' behavior *a priori*, i.e. there was no way we could have known how many participants would behave in an altruistic manner. Also, note that the sample size for each group was greater than what is deemed as the absolute minimum sample size per cell ($n > 20$; Simmons et al., 2011).

1. *altruistic* group (participants who stopped to help, irrespective of whether they were successful or not): n =52 (16 females);
2. *non-altruistic* group (participants who did not stop to help): n =28 (10 females).

Therefore, there were more altruistic (65%) than non-altruistic (35%) participants in the sample (Z=2.571, p=0.010). The gender composition did not differ across groups ($\chi^2(1)$=0.203, p=0.652, ϕ =0.050).

Importantly, altruists did not differ from non-altruists on any aspect of experienced realism or sense of presence in the VR (MANOVA: $F(4,38)$=1.889, p=0.132; Wilk's Λ=0.834, $p\eta^2$=0.166; See Supplementary Text S2 for more details). Thus, it is unlikely that altruists were more willing to come to the rescue of (compared to non-altruists) the trapped humanoid in the virtual environment because they didn’t find the VR to be realistic enough.

Although altruists had numerically higher EC scores than non-altruists (altruist: 3.698, non-altruist: 3.556), this difference was not significant (Welch's t-test: $t(47.21)$=1.134, d =0.281, p=0.263), which could have been due to a dichotomous question with limited variation in the response (compared to continuous response scale). For this reason, we conducted an additional online survey with both dichotomous and continuous response scales and indeed found that higher EC scores were associated with increased (continuous) moral permissibility ratings for altruistic choice (Pearson's r =−0.208, p=0.018). Additionally, we also observed the expected judgment-behavior discrepancy (FeldmanHall et al., 2012; Francis et al., 2016; Patil et al., 2014; Teper et al., 2011, 2015; Winking and Mizer, 2013) – people were more altruistic while making judgments in hypothetical text-based scenarios (91%) than when they acted in VR scenarios (65%) ($\chi^2(1)$=85.465, $p < 0.001$, ϕ =0.318; all details provided in Supplementary Text S5).

3.2. *Morphometry results*

3.2.1. *Altruistic versus non-altruistic*

The DBM analysis did show an expected volumetric increase[7] in the altruistic group compared to the non-altruistic group, such that the right insular lobe was expanded in altruists as compared to non-altruists (Fig. 2): x=50, y=17, z=−10; TFCE =32.28, k=4, p=0.018 (FWE-corrected). A similar result was also obtained in the SnPM analysis[8]: x=50, y=17, z=−10; k=7, t=3.65, p=0.0131 (FWE-corrected at voxel-level). We used the NeuroSynth (http://neurosynth.org/locations/) database to assess the location-to-term association (Yarkoni et al., 2011) and found that the term anterior insula (AI) was significantly associated with these coordinates (Z =4.55, $p < 0.00001$, posterior probability =0.69).

No clusters of voxels survived correction for multiple comparisons under TFCE (p(FWE-corrected) < 0.05) when the same analysis was repeated without explicit mask.

3.2.2. *Non-altruistic versus Altruistic*

No suprathreshold voxels were found for this contrast, even at a more liberal threshold (p(uncorrected) < 0.001).

4. Discussion

The goal of our study was to investigate the neuroanatomical basis of costly altruism and the motivating role of EC in this phenomenon. Accordingly, we found that people who engaged in costly unreciprocated altruistic behavior, which entailed risking one's own life to save a stranger, had enlarged right AI compared to those who preferred to save themselves without helping. Importantly, this behavior was investigated using ecologically valid scenarios rich in contextual information (like situational cues, reward/punishment contingencies, etc.) instead of hypothetical moral scenarios with all non-essential contextual information stripped away. Additionally, EC was associated with increased moral permissibility of costly altruistic behavior and variation in the size of the insular cortex. Thus, we show that assisting vulnerable individuals at a great cost to the (virtual) self is motivated by the proximate mechanism of caring for others in need.

These findings are consistent with one of the key functional roles associated with the insular cortex, namely emotional processing related to social interactions (Lamm and Singer, 2010). In particular, the AI is one of the key neurobiological substrates of EC (or compassion or sympathy) for others (for a review, see Hastings et al., 2013). Compassion for both social and physical pain in others activates the AI (Immordino-Yang et al., 2009), and self-reports of compassion experience are correlated with increased activation in AI (Simon-Thomas et al., 2012). Furthermore, activation in the AI also correlates with trait, self-reported EC or compassion and is associated with subsequent helping behavior towards ingroup members (Hein et al., 2010; Hubbard et al., 2016) and prosocial behavior exhibited towards socially excluded individuals (Masten et al., 2011). Furthermore, the functional connectivity pattern between AI and other regions can be used to classify motivations (EC-based or reciprocity-based) behind altruistic behavior (Hein et al., 2016). In line with the hypothesis that early kinship-selective parental care lays the foundations for non-kin altruism by activating a common caregiving system (Marsh, 2016; Shaver et al., 2016), AI activation is also found to be correlated positively with mothers’ EC for their babies (Swain et al., 2012), and encodes trial-wise experienced EC for the needy individuals that predicts charitable giving to those in need (Tusche et al., 2016).

In addition to functional data supporting the role of AI in EC, previous morphometry studies have also revealed a positive association between self-reported EC scores and- (*i*) the grey matter volume of the AI (Banissy et al., 2012; Eres et al., 2015; Mutschler et al., 2013; Shdo et al. 2017; Yue et al., 2016), (*ii*) increased insular-opercular cortical thickness (Valk et al., 2016), and (*iii*) higher structural covariance between dorsal AI and prefrontal-limbic regions (Bernhardt et al., 2014a). Long-term meditation practitioners who have cultivated loving-kindness and compassion are found to have increased cortical thickness in insular cortices (Engen et al., 2017). Additionally, patients with insular damage due to glioma score lower on self-report measures of EC than patients with noninsular glioma and healthy controls (Chen et al., 2016). The current data are also in line with the prior work showing that individuals who exhibit cooperative behavior in economic games based on pay-it-forward reciprocity have larger grey matter volume in AI (Watanabe et al., 2014). Thus, both functional and anatomical MRI data converge to implicate the AI in tracking levels of caring motivation for suffering individuals.[9]

The current study thus extends prior morphometry work in the moral domain (Baez et al., 2016; Baumgartner et al., 2016; Marsh et al., 2014; Nash et al., 2017; Patil et al., 2017; Prehn et al., 2015) and behavioral work focusing on the role of EC in costly altruism (FeldmanHall et al., 2015) by assessing the neuroanatomical correlates

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[7] As seen in Fig. 2, the AI was consistently larger in the template brain (JD < 1) with respect to both groups ($p < 0.001$). But importantly the group difference is unaffected by this issue (Christian Gaser, personal correspondence).

[8] To address the possibility that this result was due to idiosyncrasies associated with our study-specific mask, we carried out an image-based small-volume correction with a meta-analytic functional map for empathy as an additional reliability check and observed the same result (Lamm et al., 2011): x=50, y=15, z=−6; k=74, $p < 0.0001$ (primary threshold), p=0.018 (FWE-corrected).

[9] But there are some studies that do not find any functional relationship between trial-to-trial compassion ratings and activity in AI (e.g., Kanske et al., 2015; Klimecki et al., 2014).

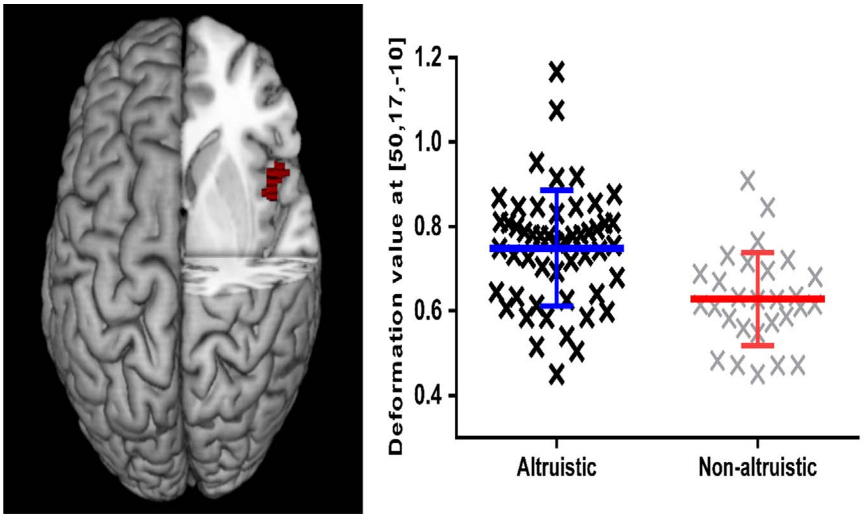

Fig. 2. On the left, result of the comparison between altruistic and non-altruistic participants at the whole-brain level are shown. Maps are thresholded at $p < 0.001$, k=0 uncorrected without any mask for illustrative purposes. On the right, the scatterplot of brain deformation differences extracted at the peak voxel [50, 17, −10] accounting for nuisance variables is depicted. Altruistic participants had a more expanded insular lobe compared to non-altruistic participants (t(66.262) =4.247, d =1.043, $p < 0.001$, 95% CI [0.0671, 0.1736], 5000 bootstrap samples). Volume change data presented in figures are non-independent and should *not* be used for effect size estimates (Vul and Pashler, 2017). They are included here only as a visual aid for interpretation of results. The error bars represent standard deviation.

of altruistic behavior in a more ecologically valid task. This provides further evidence that the insular cortex is a key neural substrate of EC for others in need, and its structural variation can differentiate altruists from non-altruists in costly helping contexts.

4.1. *Limitations and future scope*

The conclusions derived from the current study need to be qualified by the following limitations. First, we have studied here only one of the antecedents of prosocial behavior, namely EC. A number of other factors have also been shown to promote altruistic behaviors: socio-economic status (Grueter et al., 2016), subjective well-being (Brethel-Haurwitz and Marsh, 2014), variation in perceptual sensitivity to fear expressions (Marsh et al., 2014), enhanced impulse control skills (Steinbeis et al., 2012), reduced negative affect (Böckler et al., 2016), etc. It is possible that the neuroanatomical correlates associated with these various factors may vary from the ones implicated here. For example, Marsh and colleagues showed that altruistic kidney donors could be distinguished from controls based on the enhanced volume of their right amygdala and elevated responsiveness of this neural region to fearful facial expressions (Marsh et al., 2014). In the context of economic behavior, a parameter indexing fairness concerns that drive altruistic decisions to reduce advantageous inequality is found to be correlated with grey matter volume in the temporoparietal junction (TPJ), a region implicated in perspective-taking (Morishima et al., 2012). The cortical thickness of the left dorsolateral prefrontal cortex (dlPFC) predicts selfish (versus prosocial) economic behavior due to differences in impulsivity and strategic behavior (Steinbeis et al., 2012; but see Yamagishi et al., 2016). Thus, future studies can conduct a multimodal investigation including diverse measures (cf. Böckler et al., 2016; Peysakhovich et al., 2014) and see if they exhibit shared and/or differential structural correlates.

Second, although the task we used to assess costly altruism was contextually salient, it may still be an inadequate substitute for reality (as shown by poor realism ratings for the VR by participants; Supplementary Text S2). The helping behavior was always in the VR and it is unclear under what conditions the same individuals will also exhibit the same behavior in real life. Future studies can try to conduct structural MRI studies comparing real-life heroes that put their lives in danger to save others (e.g., Carnegie Medal winners) with controls to shed further light on this issue. Based on the current findings, we would predict that these individuals will score higher on EC and would have enlarged frontoinsular cortices.

5. Conclusion

In conclusion, we have shown that individuals who engage in costly altruistic acts involving putting their own life in danger to rescue someone else are motivated by other-oriented concern and have an enlarged AI, a neural region that underpins compassionate response towards others' suffering and facilitates helping behavior.

Conflict of interest statement

No potential conflict of interest was reported by the authors.

Acknowledgments

Authors gratefully acknowledge Kathryn Francis, Sebastian Korb, and Anne Böckler-Raettig for their insightful comments on the earlier version of the manuscript. Special thanks to Christian Gaser for helpful discussions on morphometry analyses. This work was supported by the Vienna Science and Technology Fund (WWTF; Project CS15-003) to GS.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuropsychologia.2017.02.015.

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