



# Altruistic behaviors relieve physical pain

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**Engaging in altruistic behaviors is costly, but it contributes to the health and well-being of the performer of such behaviors. The present research offers a take on how this paradox can be understood. Across 2 pilot studies and 3 experiments, we showed a pain-relieving effect of performing altruistic behaviors. Acting altruistically relieved not only acutely induced physical pain among healthy adults but also chronic pain among cancer patients. Using functional MRI, we found that after individuals performed altruistic actions brain activity in the dorsal anterior cingulate cortex and bilateral insula in response to a painful shock was significantly reduced. This reduced pain-induced activation in the right insula was mediated by the neural activity in the ventral medial prefrontal cortex (VMPFC), while the activation of the VMPFC was positively correlated with the performer's experienced meaningfulness from his or her altruistic behavior. Our findings suggest that incurring personal costs to help others may buffer the performers from unpleasant conditions.**

altruistic behavior | physical pain | meaningfulness | functional MRI

**A**ltruism is highly valued and cherished by human society. From prehistoric to civilized times, altruistic behaviors facilitate human sharing and cooperation (1, 2) and enable group members to collectively survive various crises, such as food shortages and natural disasters (2). However, engaging in altruistic behaviors is costly for the performers themselves; it involves giving away one's own resources (time, money, food, etc.) and thus reduces the performers' fitness relative to selfish others (3, 4). Meanwhile, the literature has documented the positive impact of altruistic activities, such as volunteering and prosocial spending, on psychological well-being and health (5–8). How can these seemingly contradictory results be obtained? What are the mechanisms by which costly altruistic behaviors may benefit the performer? These questions become even more intriguing in the context of urgent life-threatening situations. Intuitively, altruism does not seem like an adaptive choice; people could instead maximize their chances of survival by hoarding resources for the self. However, empirical evidence shows that human altruistic tendencies are actually enhanced in times of crisis, such as immediately after a strong earthquake (9), and residents in devastated areas acted in a more prosocial manner than residents in less severe or nondevastated areas (10). The prevalence of altruism under life-threatening circumstances raises an important yet poorly understood question: What is happening within the individual at the time when he or she helps?

The current research offers a perspective that engagement in altruistic behaviors may affect the sensation of unpleasant stimuli, such as physical pain. Most physically threatening situations are accompanied by actual or potential tissue damage, which is often associated with the experience of pain (11). For example, ~300,000 people became injured and suffered pain following the 2010 Haiti earthquake (12). Would behaving altruistically lead the performer to feel more pain or less pain? One possibility is that altruistic behaviors may intensify painful feelings. Altruistic performers unilaterally deliver resources (time, money, effort, etc.) to improve others' welfare (13). In other words, altruistic actions are accompanied by objectively incurred losses. In previous research,

tangible losses, such as those involving losing money (14), an endowment (15), or a relationship (16), were usually found to be aversive and painful. This would lead to the prediction that engaging in altruistic behaviors would magnify the perception of pain.

In contrast, a competing view argues that the psychologically positive consequences and cognitive modulation of altruistic behavior may lead to the relief of pain. Although giving time, money, or social support incurs tangible loss, it also brings about intangible gains to the performers, such as enhanced positive affect, increased self-esteem, and less depression (17–22). In addition, people relate altruistic acts to the experience of meaning in life (21, 23, 24), that is, seeing one's life and existence as having value, purpose, and direction (23, 25–27). Since helpfulness is regarded as a virtue across human cultures (28), it may have been built into individuals' general orienting systems (29), which provide people with a mental schema with which to interpret the world. When individuals act altruistically, in accordance with their schema, they usually experience a sense of meaning (29). Previous findings have suggested that salient general orienting systems can affect the experience of physical stimuli in a positive way. For example, exposure to religious images enabled believers to detach themselves from the experience of pain (30), electric shocks that were accompanied with benevolent intentions from a partner hurt less (31), and painful stimulations accepted on behalf of a

## Significance

**For centuries, scientists have pondered why people would incur personal costs to help others and the implications for the performers themselves. While most previous studies have suggested that those who perform altruistic actions receive direct or indirect benefits that could compensate for their cost in the future, we offer another take on how this could be understood. We examine how altruistic behaviors may influence the performers' instant sensation in unpleasant situations, such as physical pain. We find consistent behavioral and neural evidence that in physically threatening situations acting altruistically can relieve painful feelings in human performers. These findings shed light on the psychological and biological mechanisms underlying human prosocial behavior and provide practical insights into pain management.**

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The authors declare no competing interest.

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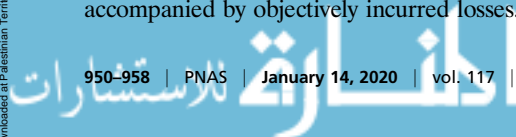
Data deposition: The data that support the findings of this study and the analysis code have been deposited on Open Science Framework, [https://osf.io/5xk73/?view\\_only=d9912f066d424773bd26c6961eca6890](https://osf.io/5xk73/?view_only=d9912f066d424773bd26c6961eca6890).

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romantic partner were perceived as less unpleasant (32). Moreover, recent evidence has shown that performing altruistic behavior alters the performers' sensory experience, for example leading the performers to perceive the ambient environment as warmer and a heavy carton as lighter (33, 34). Some research has documented causal effects of altruistic behaviors on the performers' biological processes, including reducing physiological responses to stress, regulating gene expression, and shaping cardiovascular health (5, 6, 8). In a similar vein, it is plausible that experienced meaningfulness, as an intangible benefit of performing altruistic behavior, may connect individuals to the general orienting system and help buffer them from unpleasant stimuli, such as through alleviating pain perception.

To test these 2 competing predictions regarding how altruistic behaviors may shape the sensory experience in physically threatening situations for performers, we began with 2 pilot studies that involved voluntary altruistic behaviors. Then, with random assignment of performing altruistic vs. control behaviors, we examined how these actions affected subsequent perception of acutely induced pain. We proceeded to investigate the neural mechanisms underlying the modification of pain by altruistic behavior using functional MRI (fMRI). Finally, we examined whether performing altruistic behaviors would affect the long-term pain experienced by cancer patients. If altruistic behavior modified the experience of pain in a particular manner (either intensifying or relieving), we should observe converging evidence of increased or reduced pain reported by participants. In addition, pain-related brain regions (including the insula, thalamus, somatosensory cortex, and anterior cingulate cortex) may also show significantly enhanced or reduced activation during painful stimulation; when combined with additional cortical features, the data would suggest how acting altruistically might modulate cortical activity in the pain-related brain regions as well as affect the subjective experience of pain.

## Results

To test how performing altruistic behaviors may affect physical pain perception, we first conducted 2 pilot studies (see details in *Methods*). Pilot Study 1 compared the pain perception of venipuncture between people who volunteered to donate blood for postearthquake medical usage and people who had blood drawn for regular physical tests on the same day. Participants reported the intensity of pain they experienced during the needling using the Wong-Baker Faces Pain Rating Scale (35). We found that blood donors (mean [ $M$ ] = 1.52,  $SD$  = 1.28) felt less pain than blood-test takers did [ $M$  = 2.36,  $SD$  = 1.14;  $t$  (64) = 2.85,  $P$  = 0.006,  $d$  = 0.69\*], although a much larger volume of blood (200/400 mL vs. 3 to 5 mL) was drawn by a larger needle (1.6 mm vs. 0.8 mm in diameter) among the blood donors than among the blood-test takers. The act of having blood drawn to benefit others vs. the self was found to alleviate the painful experience. This provides preliminary support for a pain-relieving effect of altruistic behavior.

In Pilot Study 2, we varied whether participants were offered an opportunity to perform an altruistic activity. Participants voluntarily revised a handbook for the children of migrant workers without pay (altruistic group), declined to engage in this optional revision activity (nonaltruistic group), or did the revision as a mandatory activity (control group). We used the cold pressor test (CPT) to induce pain (36). Participants put their nondominant hand in cold water (5 °C) and indicated pain intensity on a visual analog scale (VAS) every 15 s following a computerized reminder. We also recorded the length of time that participants kept their hand in cold water as an index of pain tolerance. In line with the prediction of analgesia by altruism, the altruistic group ( $M$  = 12.41,

$SD$  = 3.14) reported perceiving less pain than the nonaltruistic group ( $M$  = 14.18,  $SD$  = 1.90;  $b$  = 1.77,  $SE$  = 0.71,  $t$  = 2.48,  $P$  = 0.015) and the control group ( $M$  = 14.35,  $SD$  = 2.64;  $b$  = 1.94,  $SE$  = 0.71,  $t$  = 2.71,  $P$  = 0.008). The altruistic group ( $M$  = 91.59 s,  $SD$  = 57.54) also persisted in cold water for a longer time than the control group ( $M$  = 48.82 s,  $SD$  = 26.94;  $b$  = -30.66,  $SE$  = 11.90,  $t$  = -2.58,  $P$  = 0.012) and the nonaltruistic group ( $M$  = 60.93 s,  $SD$  = 34.70;  $b$  = -42.78,  $SE$  = 11.90,  $t$  = -3.60,  $P$  = 0.001). In addition, 10 out of 86 participants (11.6%) persisted for the maximum length of time of 3 min in the CPT; they were all in the altruistic group. These results suggest that people who had just performed altruistic behaviors perceived the same painful experience as less intense and were more tolerant of pain.

The pilot studies provided preliminary evidence for the hypothesis that altruistic behaviors relieve physical pain. One limitation is that participants were not randomly assigned to perform altruistic or nonaltruistic behaviors. Despite the pilot studies having the strength of reflecting real-life situations in which people freely decide whether to behave in an altruistic manner, this quality can lead to a selection bias—that is, people who do and do not engage in altruistic behaviors may differ in several ways (e.g., disposition and motivation) aside from the acts they perform. To address this concern, we proceeded by ensuring random assignment (Experiments 1 and 3) and by using a within-subjects design (Experiment 2).

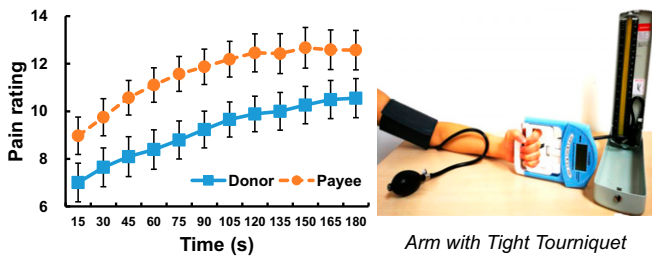
In Experiment 1, we used the tourniquet pain test (TPT) to induce acute pain in the laboratory (37). In this paradigm, a standard blood pressure cuff was applied on participants' non-dominant upper arm; participants were instructed to squeeze a spring exerciser in response to tape-recorded signals at a fixed rate while indicating their feelings of pain every 15 s on a VAS ("no pain" to "worst imaginable pain"). Each TPT lasted for 3 min. Participants took the first TPT as an assessment of their baseline level of pain. Then, they completed a 5-min survey on consumer decision making, which was introduced to them as irrelevant to the current study of pain. Participants were randomly assigned to either the altruistic group, in which they earned a donation of 10 yuan (~\$1.5) for victims in an earthquake-stricken area by completing this survey, or the control group, in which they were paid an extra 10 yuan as a reward. Finally, all participants completed a second TPT.

We found that the altruistic group ( $M$  = 5.63,  $SD$  = 1.95) and the control group ( $M$  = 5.67,  $SD$  = 1.35) did not differ in pain sensitivity ( $t < 1$ ). The altruistic group ( $M$  = 236.94,  $SD$  = 84.41) and the control group ( $M$  = 263.04,  $SD$  = 81.14) also did not differ in pain perception in the first TPT [ $t$  (38) = 1.00,  $P$  = 0.325]. To track their pain perception after performing the altruistic (vs. control) activity, we conducted repeated-measures analysis of variance on pain rating as the second TPT played out. This yielded main effects of group [ $F$ (1, 38) = 5.53,  $P$  = 0.024,  $\eta^2$  = 0.127] and time [ $F$ (11, 418) = 23.75,  $P$  < 0.001,  $\eta^2$  = 0.385]; the group  $\times$  time interaction was nonsignificant ( $F < 1$ ). Specifically, the altruistic group perceived less pain ( $M$  = 9.17,  $SD$  = 3.20) than the control group ( $M$  = 11.56,  $SD$  = 3.23) (Fig. 1), even as both groups perceived intensified pain during the entire TPT process. These results indicated analgesia induced by altruistic manipulations.

In Experiment 2, we examined the neural mechanisms underlying the pain modulation of altruistic behaviors using fMRI. Participants were informed that they would engage in 2 non-related experiments consecutively in the 3-T MRI scanning. One was about making decisions about monetary donations; the other was about their feelings of pain (Fig. 2). In each trial during the scanning, a pain stage was preceded by a donation stage. Participants were instructed to make 1 of 2 types of decisions in each donation stage: 1) for the altruistic condition, they decided whether to help young orphans through monetary donation at a cost of their own; 2) for the control condition, they judged whether 2 lines of figures had the same shape. After each decision, participants

\*For this and all of the studies, we presented all variables collected in *Methods* and reported results without covariates in the main text. Results with covariates are available in *SI Appendix*, which are essentially the same as the results without covariates.

### Tourniquet Pain



**Fig. 1.** Results from Experiment 1: Pain ratings as a function of group and time during the second 3-min TPT. Participants who had performed an extra activity to earn a monetary donation for earthquake victims (donor) before this test perceived significantly less physical pain than those who had been paid for themselves to perform this activity (payee). Error bars indicate 1 SE.

indicated how helpful their choice was to the orphans. The altruistic condition and control condition trials were presented in a pseudorandom order. In the pain stage, participants received an electric shock of high or low intensity on the dorsum of their right hand and indicated their feelings of pain on a 0-to-10 scale. Finally, participants answered several questions after the scanning session.

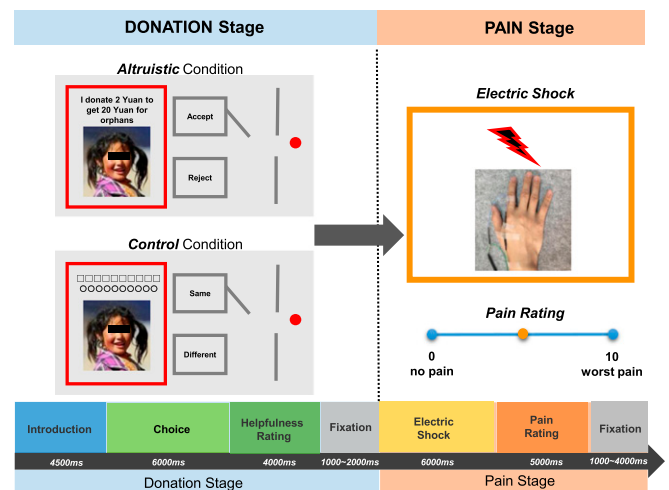
We first examined participants' responses in the donation stage. In most of the trials ( $M = 93.46\%$ ,  $SD = 16.05\%$ ) in the altruistic condition, participants decided to donate money. They also rated the decisions in the altruistic condition as more helpful to the orphans than those in the control condition [ $3.38 \pm 1.26$  vs.  $0.08 \pm 0.10$ ,  $t(30) = 14.63$ ,  $P < 0.001$ ]. These responses verified that our manipulation of altruistic vs. control behaviors was valid. We computed a pain score by subtracting the pain ratings of low-intensity shocks from the ratings of high-intensity shocks. A paired  $t$  test revealed that participants' pain scores were lower for the altruistic condition than for the control condition [ $5.11 \pm 1.58$  vs.  $5.35 \pm 1.49$ ,  $t(30) = -2.91$ ,  $P = 0.007$ ]. Participants perceived electric shocks as less painful after they performed an altruistic action (vs. a neutral action). This finding supports the notion of a pain-relieving effect of the precedent altruistic behaviors.

To identify pain-related brain regions activated by the application of the electric shock, we compared brain activities in the high- vs. low-intensity shocks in the pain stage. As expected, we found several brain regions including the left dorsal part of the anterior cingulate cortex (dACC), the bilateral insular cortex, and the bilateral frontal cortex were significantly activated ( $P < 0.050$  FDR- [false discovery rate] corrected; *SI Appendix, Table S10*) for physical pain. Next, we examined whether the brain activities in the pain-related cortical regions were differentiated by the behaviors in the precedent stage. To that end, we contrasted the brain activities during the pain stage for the altruistic vs. control condition. We observed that brain activities of the dACC, bilateral insular cortex, and right primary somatosensory cortex (SI) during the pain stage were significantly reduced in the altruistic condition compared to the control condition (Fig. 3A and *SI Appendix, Fig. S1 and Table S1*). This echoes the finding in Experiment 1 that pain-related experience was attenuated after performing altruistic behaviors. Moreover, the region of interest (ROI) analysis revealed that the decreased brain activation in the dACC and bilateral insular cortex were significantly correlated with participants' feelings of helpfulness in the donation stage (Fig. 3B). The more helpful participants considered their altruistic donation, the less their pain-related brain areas were activated during the electric shocks.

To further elucidate the neural mechanisms underlying the impact of altruistic behaviors on physical pain, we investigated brain activities in the donation stage and how they relate to brain

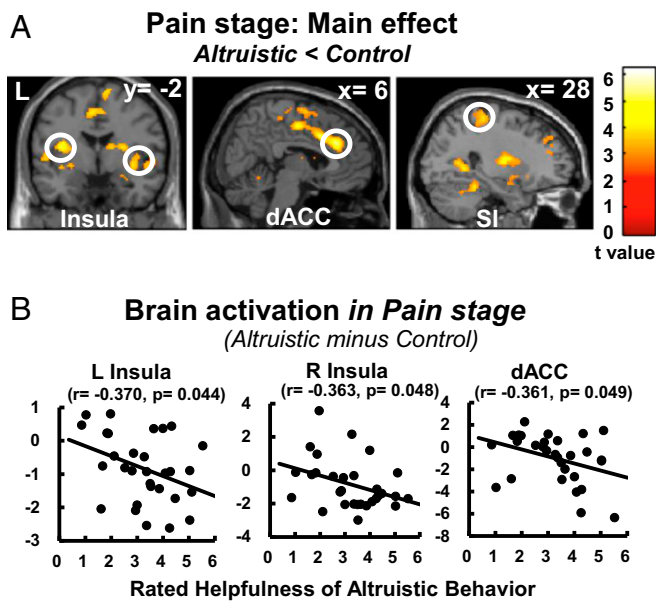
activities in the subsequent pain stage. Previous research on neural correlates of altruistic behaviors usually found involvement of the anterior insula (38), cingulate cortex (39), ventral medial prefrontal cortex (VMPFC) (40), and putamen (41, 42), while the putamen and ventral medial prefrontal cortex were considered to engage in reward processing (40, 42). In particular, the VMPFC was suggested as shared neural correlates of both personal and vicarious reward (43). The VMPFC has been found to be related to the subjective value of voluntary donations (44) and more engaged when individuals donated to people with evaluable identifiable information, such as orphans depicted by photographs vs. silhouettes (45). In this experiment, we found that during the donation stage the cingulate cortex, VMPFC, and right putamen showed increased cortical activity in altruistic decisions compared to shape judgments (Fig. 4A and *SI Appendix, Fig. S6*) at a loose threshold (*SI Appendix, Table S5*). Using an ROI analysis based on a 4-mm sphere centered at the peak voxel in these brain areas, we confirmed that the brain activities of the VMPFC and right putamen were significantly enhanced in making altruistic decisions (VMPFC:  $t = 3.19$ ,  $P = 0.003$ ; right putamen:  $t = 3.26$ ,  $P = 0.003$ ).

Given recent research suggesting that the VMPFC might be involved in representing the real-time experience of meaning (32, 46, 47), which is usually associated with altruistic behaviors (21, 23, 24, 48, 49), we were particularly interested in the engagement of the VMPFC here. We found that 1) the brain activity in the VMPFC (donation stage) significantly predicted participants' postscanning ratings of meaningfulness of their donation in general (VMPFC [10, 52, -6],  $r = 0.374$ ,  $P = 0.038$ ; Fig. 4D); 2) the brain activity in the VMPFC (donation stage) predicted the reduction in pain-related brain activities (altruistic vs. control condition) in the dACC and bilateral insula cortex in the pain stage (Fig. 4B; right insula:  $r = -0.354$ ,  $P = 0.050$ ; left insula:  $r = -0.381$ ,  $P = 0.034$ ; dACC:  $r = -0.375$ ,  $P = 0.038$ ); and 3) participants' postscanning ratings of the meaningfulness of their donation



**Fig. 2.** Illustration of procedures in Experiment 2. Each trial consists of a donation stage and a pain stage. In the donation stage, participants were asked to make 1 of 2 types of decisions when the red ball moved across the vertical bars: whether to donate money to orphans at a cost of their own (altruistic condition) or whether 2 lines of figures had the same shape (control condition). After making the choice, they were asked to rate how helpful their action was to the orphaned children on a 7-point scale (0 = not at all, 6 = very much). In the pain stage, participants received an electric stimulation on the dorsum of the right hand and rated their feelings on an 11-point slider (0 = no pain, 10 = worst pain). The slider started at the midpoint, permitting participants to move toward the more relevant endpoint. Black bars were added to render faces unrecognizable for display purposes only (participants saw unmodified stimuli).





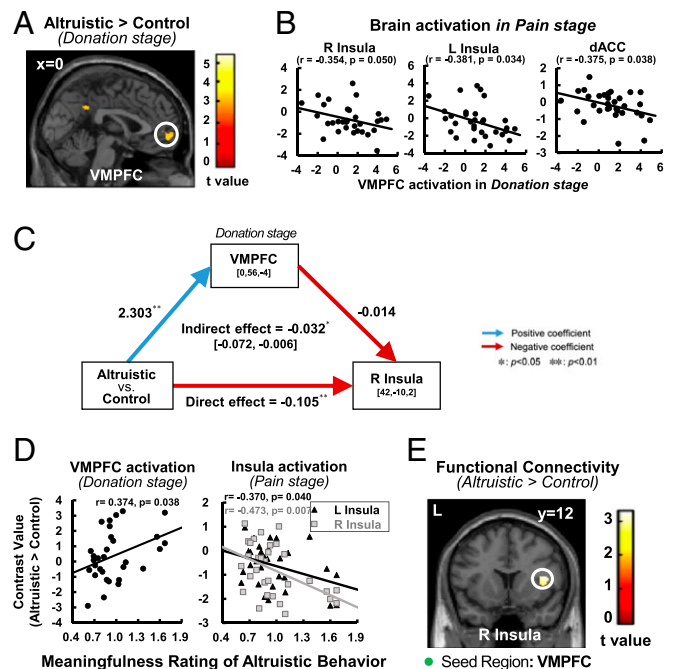
**Fig. 3.** fMRI results from Experiment 2. (A) During the painful electric shocks, brain activation of the classic pain-related cortical areas (i.e., bilateral insular cortex, dACC, and right SI) was significantly reduced in the altruistic compared to the control condition ( $P < 0.050$ , FDR-corrected; see also *SI Appendix, Table S1*). (B) ROI analysis revealed that participants' reduced brain activation in the bilateral insular cortex and dACC were significantly correlated with their perceived helpfulness of their donation to the orphans in the donation stage, showing that the more helpful people consider their altruistic behavior to others, the more their brain activation in pain-related areas for painful stimuli can be attenuated.

predicted the reduction in pain-related activities in the bilateral insula (Fig. 4D; right insula:  $r = -0.473$ ,  $P = 0.007$ ; left insula:  $r = -0.370$ ,  $P = 0.040$ ) in the pain stage. These results suggest that participants who experienced stronger meaning in performing altruistic behaviors showed more attenuated brain activities in pain-related cortical areas. To confirm the engagement of the VMPFC in modulating pain-related neural activity, we conducted a within-subjects mediation analysis using the MEMERO macro for SPSS (50). It revealed a significant indirect effect of condition (altruism vs. control) on the brain activity of the right insula in the pain stage (4-mm sphere around the peak center Montreal Neurological Institute (MNI) coordinate [42, -10, 2]) through the brain activation of the VMPFC in the donation stage (4-mm sphere around the peak center MNI [0, 56, -4]), 95% CI [-0.072, -0.006]; Fig. 4C). In addition, a whole-brain psychophysiological interaction (PPI) analysis (51) in the donation stage revealed an enhanced functional connectivity between the blood-oxygen-level-dependent (BOLD) time-series signals in the VMPFC (seed region) and right insular ( $P < 0.005$  uncorrected, Fig. 4E), suggesting a modulation effect prior to the electrical stimulation.

In the third and final experiment, we recruited cancer patients who were chronically bothered by physical pain to participate in a 7-d program. Patients who were matched on the clinical classification of cancer symptoms were randomly assigned to either the altruistic group or the control group. After the assessment of physical conditions and baseline pain level on the first day, all patients engaged in daily personal activities on the following 6 d and a group activity on the fourth day. In personal activities, patients were either asked to clean the public area for their wardmates (altruistic group) or for themselves (control group). In group activities, patients either prepared nutritional diet plans for the benefit of their wardmates and shared the plans in a group meeting (altruistic group) or attended a workshop on healthy

nutritional diets given by a nurse (control group). After each activity, participants indicated their pain perception on the Wong-Baker Faces Pain Rating Scale (35), which was the assessment tool used in the hospital and required by the clinical oncologist. Participants also reported on their emotions, feelings of fear, and stress.

The baseline pain for the altruistic ( $M = 3.75$ ,  $SD = 2.26$ ) and control groups ( $M = 3.53$ ,  $SD = 1.95$ ) did not differ ( $t < 1$ ). To compare how their pain perception varied over the 7-d period, we constructed a conditional growth model with group (+1 = altruistic, -1 = control) as a level-2 predictor and time point (coded from 0 to 7 in integer increments) as a level-1 predictor of pain rating. The model included a random slope and a random intercept of participants. We observed a negative effect of time points [ $B = -0.17$ ,  $SE = 0.02$ ,  $t(56.35) = -7.39$ ,  $P < 0.001$ ]. That is, participants experienced a decline in pain across time. Of key relevance, there was a significant group  $\times$  time points interaction [ $B = -0.07$ ,  $SE = 0.02$ ,  $t(56.35) = -3.28$ ,  $P = 0.002$ ]. The negative value of beta reflects that the decrease in pain perception was especially strong when the activities aimed to increase others' welfare [ $B = -0.24$ ,  $SE = 0.03$ ,  $t(56.88) = -7.52$ ,  $P < 0.001$ ]. However, when the activities were performed for oneself, the



**Fig. 4.** Donation-pain related fMRI results and mediation analysis in Experiment 2. (A) During the donation stage, donating money to orphans (altruistic condition) elicited greater brain activity in the VMPFC compared to shape judgment (control condition) ( $P = 0.003$ ; see also *SI Appendix, Table S5*). (B) Participants' brain activation of the VMPFC in the donation stage predicted the reduction in their brain activation (altruistic minus control condition) in pain-related brain areas (bilateral insula cortex and dACC) during the subsequent electric shock. (C) A within-subjects mediation analysis using a 10,000-sample bootstrap revealed a significant indirect effect of the altruistic vs. control condition on the brain activity of the right insula (pain stage) through brain activation of the VMPFC (donation stage). Path coefficients are unstandardized. (D) Participants' postscan rating on the meaningfulness of their donation behavior was positively related to their brain activity of the VMPFC in the donation stage and negatively related to their brain activation in the bilateral insula during the electric shock. (E) A whole-brain PPI analysis found an enhanced functional connectivity between the BOLD time-series signals in the VMPFC (seed region) and right insular (shown in  $P < 0.005$ , uncorrected) for the altruistic compared to the control condition during the donation stage.

pain-relieving effect was reduced by 62.5% [ $B = -0.09$ ,  $SE = 0.03$ ,  $t(55.82) = -2.92$ ,  $P = 0.005$ ] (*SI Appendix*, Fig. S13). A test of the difference between the slope values (52) confirmed that the slope values for the 2 groups were significantly different [ $t(62) = 4.92$ ,  $P < 0.001$ ].

## Discussion

The current research sought to understand how engaging in altruistic behaviors might promote the well-being of performers even as the act itself often incurs costs. We investigated how acting altruistically may affect the performers' sensation of threatening physical experiences, such as pain. Across 2 pilot studies and 3 experiments, we found convergent evidence in support of the notion that performing altruistic behaviors relieves physical pain. Such an effect was observed among various forms of altruistic behavior (i.e., donating blood for postearthquake usage, spending time editing a handbook for migrant children, working to earn donations for earthquake victims, making monetary donations to help orphaned children, and cleaning rooms for wardmates) and different types of pain (e.g., naturally existing in patients or temporarily induced in the laboratory). The present findings suggest that altruistic behaviors may play a fundamental role in one's physical experience in threatening situations.

Importantly, we investigated the neural mechanisms underlying this pain-attenuating effect of altruistic behavior. The results showed that after making an altruistic donation the brain activation of classic pain-related cortical areas such as the dACC and bilateral insula cortex was significantly reduced during electric shock compared to after making control judgments, while the decreased brain activation in the dACC and bilateral insular cortex was significantly correlated with the individual's feeling of helpfulness due to their donation to the orphans. This finding suggests that people who considered their altruistic behavior to be more helpful to the recipients showed less brain activation of pain experienced from the electric shocks.

Moreover, we found that donating money to others elicited greater brain activity in the VMPFC. This finding was consistent with a recent proposal that the VMPFC plays an essential role in "conceiving the meaning of a situation for one's physical and social well-being and future prospects" (ref. 46 and ref. 47, p. 147), considering that altruistic behavior was generally regarded as meaningful (21, 23, 24, 48, 49). Our results showed that the brain activation of the VMPFC after donation was positively associated with participants' self-report of the experience of meaningfulness for their altruistic behavior.

We observed that the meaningfulness that participants experienced during the performance of altruistic behavior predicted their reduced neural activation of the pain-related brain areas (including the left and right insula cortex) in response to electric shocks. Similarly, previous research found that the experience of meaning was positively linked to better health, including decreased mortality and extended longevity (53–55), better recovery from surgery (56), reduced risks of illness [e.g., stroke, myocardial infarction, and Alzheimer's disease (57–59)], reduced pain perception (60, 61), and enhanced pain tolerance (62). The experience of meaning is often viewed as a cornerstone of eudaimonic well-being (63, 64). It is generally agreed that meaningfulness is the essence of life, distinguishes human beings, and helps an individual navigate the world. When the experience of meaning is threatened, such as by exposure to certain words (e.g., "chaos," "trivial," or "empty"), people are often motivated to reestablish it, as evidenced by increased self-reported prosociality (49). Instead of regarding altruistic behavior as the cause of inevitable tangible loss that the performers incur to improve others' welfare, our results suggest that performing altruistically may boost the performers' experienced meaningfulness and help them to neutralize perceived unpleasantness (e.g., relieving the physical pain) in adverse situations.

In addition, our research found preliminary evidence that the neural mechanisms underlying such a pain-attenuating effect of experienced meaningfulness in adversity might be modulated by the brain activity of the ventral region of the medial prefrontal cortex. Although the VMPFC results were uncovered in a relatively loose threshold, the region we identified was consistent with previous findings of VMPFC during donation (32, 45). The results also suggested that participants with greater activation of the VMPFC during the altruistic donation showed more reduced brain activation in the pain-related regions (i.e., dACC and bilateral insular) during electric shock. In previous studies, the VMPFC was consistently found to be involved in the neural mechanism underlying the modulation of pain relief from manipulations, such as viewing pictures of attachment figures (65), taking placebos (66), or receiving pain on behalf of one's romantic partner (32). In our research, a within-subjects mediation analysis further revealed that the brain activation of the VMPFC for the altruistic performer during donation mediated the impact of the altruistic behavior on the neural activities of pain-related brain areas (i.e., right insular) during electric shock. In addition to the mediation effect of the VMPFC on the neural activities of pain-related brain areas in response to electric shocks, our results also showed an enhanced functional connectivity between the VMPFC and the right insular cortex during the altruistic donation, which suggested an immediate modulation of brain interaction between the VMPFC and the related cortical area during altruistic behavior even without the presence of painful stimuli. Considering that the donation procedure in our fMRI experiment involved dynamic features during the decision making, various decision-making stages for altruistic decision were included in this procedure. This might have influenced the observed brain activation of VMPFC. It would be interesting for future studies to investigate the temporal neural mechanism (especially for the involvement of VMPFC) underlying altruistic decision making by using more specific experimental designs and by employing brain imaging methods such as magnetoencephalography.

A recent study on prosocial acts and pain found that taking the pain for their romantic partner reduced pain-related neural responses and unpleasant feelings among females who were experiencing painful thermal stimulations (32). Additionally, the VMPFC showed increased activation when participants endured additional pain for the benefit of their romantic partner and was correlated with their willingness to do so, suggesting that the VMPFC played a key role in pain modulation and affective meaning. The results in the current research are consistent with these previous findings and further show that the analgesic effect of prosocial behavior is not limited to romantic couples but rather could exist in the general population. Relatedly, López-Solà et al. (67) found that social touch reduced pain and attenuated functional magnetic resonance imaging activity in the neurologic pain signature (NPS). It shows how supportive touch from a romantic partner could reduce pain for the receivers of the prosocial acts. Our research complemented it in revealing how performing altruistic behaviors may affect pain perception among the performers.

Although prior work has linked positive mood, which usually accompanies altruistic behavior (for a review of the warm glow of giving see ref. 68) to reduced pain (69), the present research suggests that the meaning that is experienced from performing altruistic behaviors plays an important role in analgesia in addition to positive mood. In Experiment 2, it was found that after the effect of experienced pleasantness in helping orphans was ruled out, participants' experienced meaning from their altruistic behavior still significantly predicted reduced pain-related neural activation in response to electric shocks ( $r_{\text{left insula}[-42,2,14]} = -0.356$ ,  $P = 0.050$ ;  $r_{\text{right insula}[40,16,10]} = -0.410$ ,  $P = 0.022$ ; see *SI Appendix* for details). Moreover, in Experiment 3, we found similar levels of positive emotions reported by cancer patients who

performed altruistic activities and by those who performed activities for their own benefit (see details in *SI Appendix*). These results suggest that the observed pain-relieving effect was unlikely driven by positive emotions alone and that meaningfulness from engaging in altruistic acts could uniquely contribute to the attenuation of pain.

Several other psychological mechanisms might also contribute to the observed analgesic effects of altruistic behavior. For example, previous research found that perceived controllability attenuates the neural and behavioral responses to pain (70–73). Considering that engaging in voluntary altruistic behaviors could enable people to gain personal control (74), this sense of control may translate into one's perceived controllability of nociceptive stimuli and attenuate pain-related responses. It is also possible that by performing altruistic behaviors people may shift their attention from personal distress toward beneficiaries' welfare, and such attentional diversion processes may also reduce pain perception (75). In addition, although a previous study found decreased pain perception in winning money compared to losing it (76), our study found that giving money away to help other people actually relieved pain. This finding suggested that the observed pain-attenuating effect achieved by altruistic behavior was unlikely to be solely associated with personal monetary rewards. Other types of rewards, such as vicarious rewards, in which the altruistic performer could share and enjoy the beneficiary's positive outcomes (77), might also be involved in pain reduction. It remains an interesting question to clarify how these potential psychological mechanisms interact and are related to the pain-alleviating effect of altruism. It is possible that stronger brain–behavior correlations might be observed if the influence of these potential psychological mechanisms were taken into consideration.

Our findings on the pain relief of altruistic behavior in the fMRI experiment cannot be explained by mere exposure to money (78), as the results from Experiment 1 showed that even though the participants in the control group received more money, they perceived more pain than the altruistic group. Although the present research indicated a pain-relieving effect of altruistic behavior both immediately and during a 1-wk program, future studies should clarify whether such an effect can be sustained even longer. Since the VMPFC and its surrounding regions are also related to endorphin release, which plays a critical role in the management of pain through their analgesic properties (79, 80), future research is needed to better understand the neurobiological mechanisms for how experienced meaning modulates pain perception. Although cortical areas such as the anterior cingulate cortex, thalamus, and insula have been consistently found showing response to nociceptive stimuli, previous works indicated that the activities of these pain-related brain areas are not unique to pain (81) and could also be found in individuals who are congenitally pain-free (82). It is possible that our finding of reduced brain activity in areas such as the dACC and insula during electrical stimulation is not specific to pain. Further investigation on the observed pain-attenuating effect of altruism could benefit from the use of recently developed brain measures for pain, such as the NPS (83) and stimulus intensity independent pain signature-1 (84), to identify precisely defined cortical patterns that are specific to pain. In addition, pain-inducing procedures in the laboratory inevitably expose participants to uncomfortable experiences, which limits the number of participants in the current studies out of concern for experimental ethics. Future pain research should seek to better address this issue, for example, by testing participants who suffer from persistent pain in the laboratory or by collecting secondary data from hospitals or other healthcare organizations. These approaches may help establish a higher level of ecological validity as well as provide larger sample sizes.

By demonstrating the analgesic effect of altruistic behaviors, this research also showed a possible method of addressing pain. Millions of people around the world are debilitated by pain

syndromes that impair the quality of their social and working lives. While the traditional medical approach seeks pain control through drugs and surgery (85), it also raises concerns of side effects and intensive costs, especially for people who chronically suffer from pain. Our findings, particularly those of cancer patients, suggest an alternative view, such that the act of altruism may supplement current behavioral therapies to treat pain and promote the welfare of a broad population.

Our research has revealed that in adverse situations, such as those that are physically threatening, acting altruistically can relieve unpleasant feelings, such as physical pain, in human performers of altruistic acts from both the behavioral and neural perspectives. Whereas most of the previous theories and research have emphasized the long-term and indirect benefits for altruistic individuals, the present research demonstrated that participants under conditions of pain benefited from altruistic acts instantly; these findings provided further evidence for the current theory on the immediate psychological gains of altruism implied by the lingering fragrance effect (33). The nondelayed gain that we found may be adaptive for survival, for it enables healthy as well as ill individuals to maintain positive physical feelings under conditions of bodily and emotional threat. The finding that the incurrence of a personal cost to help others may buffer performers of altruistic acts from unpleasant conditions contributes to a more comprehensive understanding of human altruism.

## Methods

All pilot studies and experiments were approved by the Committee for Protecting Human and Animal Subjects at Peking University. All participants provided informed consent before participation.

### Pilot Study 1.

**Participants and design.** This study was conducted for 2 consecutive days shortly after the 2013 Lushan earthquake (Ms7.0) that occurred in China. This earthquake caused severe damage to the stricken area and increased the need for voluntary blood donation. Sixty-six citizens (37 males, 29 females,  $M$  age = 35.64 y,  $SD$  = 10.96) in a city near the epicenter (~100 km away) participated in this study. Half of the participants (blood donors, 14 males,  $M$  age = 32.70,  $SD$  = 10.56) were recruited from either a voluntary blood donation station or a voluntary blood donation car, and the other half (blood-test takers, 23 males,  $M$  age = 38.58,  $SD$  = 10.71) were recruited during their check-up in a local hospital.

**Procedure.** Both blood donors and blood-test takers were invited by research assistants who waited at a rest area to complete a survey on their physiological feelings about having their blood drawn, in exchange for a small gift. Participants were required to recall the moment of needling and evaluate the degree of pain they felt by using the Wong–Baker Faces Pain Rating Scale (35), an easily understandable instrument widely applied to pain ratings in hospitals and many other healthcare settings (86). The scale consists of a horizontal axis ranging from 0 (no pain) to 10 (worst pain) and 6 facial expressions ranging from smiling to crying, illustrating a spectrum of pain intensity above the axis. Participants were also asked to provide their age and gender, to indicate previous experiences of blood donation/examination (0 = no, 1 = yes) and to indicate feelings of hunger and fear of needling (on 11-point scales, with higher scores representing hungrier and more fearful).

### Pilot Study 2.

**Participants and design.** One hundred five healthy participants were recruited as paid volunteers from the campus of a local university. Participants had no conditions of peripheral vascular abnormalities, hypo-/hypertension, chronic pain syndromes, injury or history of fracture, history of frostbite or Raynaud's syndrome, or any other condition that would render them ineligible to participate; none of the female participants were on their menstrual period. Nineteen participants were excluded from the data analyses because they failed to follow the instructions (i.e., either withdrew their hand several times from the cold water or placed only a finger in the water) or reported pain in other body areas. The final sample consisted of 86 participants (39 males, 47 females,  $M$  age = 23.14 y,  $SD$  = 2.86), with 40 in the altruistic group (20 males,  $M$  age = 23.09,  $SD$  = 2.83), 23 in the nonaltruistic group (9 males,  $M$  age = 22.83,  $SD$  = 3.37), and 23 in the control group (10 males,  $M$  age = 23.52,  $SD$  = 2.43).



**Procedure.** Participants came to the laboratory one at a time. They were told that the aim of the study was to investigate people's pain perception and signed a consent form covering the safety issue and rights of withdrawal. They were instructed to first complete several questionnaires and then to complete a pain-related task in another room. Participants were randomly assigned (at a ratio of 2:1) to 2 groups that would or would not be informed of the altruistic purpose of a revision activity. We aimed for this ratio to obtain comparable numbers of participants across all conditions, given that the informed participants would be further divided depending on their decisions at a later time point (as described below).

The participants in the informed group learned about an opportunity to perform an altruistic act after they completed filler questionnaires. They were told that the student union at the Department of Psychology was currently running a public welfare project that involved editing a counseling handbook for children of migrant workers. Participants were asked whether they were willing to help revise this handbook, which would take 10 more minutes. Importantly, they were told that the revision was voluntary and would not affect their payment, so they could freely decide whether or not to perform it. Participants who chose to perform the revision activity (63.5% of the informed participants) were identified as the altruistic group, whereas the others who opted not to (36.5%) were categorized into the nonaltruistic group. For participants in the control group, the questionnaires contained an additional part—editing a counseling handbook. In other words, these participants performed the same revision activity as participants in the altruistic group, except without the knowledge that their efforts were to benefit migrant children; they performed the revision activity as part of the study requirement.

After that, participants were led to another room for the CPT (36). In this paradigm, participants first kept their nondominant hand in warm water (25 °C) for 2 min, after which they dried their hand and put the same hand in cold water (5 °C). With the hand fully immersed in the cold water, participants followed a computer reminder to indicate their feeling of pain every 15 s by drawing lines on a VAS. They were told not to withdraw their hand from the cold water unless the pain became intolerable. To avoid frostbite, the maximum length of time that they held their hand in the water was 3 min; after that, participants were to withdraw their hand and put it into warm water for recovery. Participants completed the CPT alone while being observed via real-time video by 2 research assistants in another room. The assistants recorded how long the hand was kept in the cold water. Their records were averaged to form an index of duration. After that, participants completed self-report measures of control variables, including attention to the hand under experiment (reflecting a lack of distraction), motivation to bear the pain, and pain sensitivity. Finally, they were debriefed and received their payment.

### Experiment 1.

**Participants and design.** Forty-nine healthy right-handed students were recruited from a local university as paid volunteers. Inclusion criteria were as follows: participants had no conditions of peripheral vascular abnormalities, hypo-/hypertension, chronic pain syndromes, injury or history of fracture, history of frostbite or Raynaud's syndrome, or any other condition that would render them ineligible to participate; none of the female participants were on their menstrual period. Participants were randomly assigned to either the altruistic group or the control group. Nine participants were excluded from the data analysis because 1 opted out of the experiment, 2 failed to follow the instructions, and the other 6 tolerated ischemia for less than 3 min. The final sample (40 in total, 25 males, 15 females,  $M$  age = 22.30 y,  $SD$  = 2.14) consisted of 19 participants in the altruistic group (11 males,  $M$  age = 22.26 y,  $SD$  = 2.18) and 21 participants in the control group (14 males,  $M$  age = 22.33 y,  $SD$  = 2.15).

**Procedure.** The experiment included 2 TPTs with a 5-min rest in the interval (37). In the TPT process, a standard blood pressure cuff was applied to the participants' nondominant upper arm. The pressure was raised to 200 mmHg and kept constant thereafter. After waiting for 60 s, participants squeezed a hand spring exerciser in response to tape-recorded sound signals at the rate of a 2-s grasp followed by a 2-s rest. Male participants gripped 12 pounds 20 times and females, 5 pounds 15 times. After the grasping stage, participants continued to wear the cuff and were instructed to indicate their feelings of pain every 15 s on a VAS scaled by the verbal descriptors "no pain" to "worst imaginable pain." They were required to mark the 18.6-cm VAS line at the position that represented their pain intensity, and its distance from the zero anchor (labeled "no pain") was recorded. The test lasted for 3 min, unless the participants could no longer tolerate the pain. Each participant who endured ischemia for the entire 3-min period had 12 records of distance, measured with millimeter accuracy.

The first TPT was aimed at assessing participants' baseline pain level.<sup>†</sup> Then, after a rest of 90 s, participants were invited to complete a 5-min survey about daily consumption preferences (e.g., choosing from different kinds of air cleaners), which was ostensibly designed to be irrelevant to the current study of pain. Here, the participants were randomly assigned to the altruistic or control group. The altruistic group were told that the research team was running a project to donate to victims in an earthquake-stricken area and that participants would be paid extra money for the donation once they completed the survey. The control group were told that they would be paid extra money as a reward for doing the survey because the research team had additional funding for collecting the survey data. After finishing the survey, participants in the altruistic group were instructed to put 10 yuan into a donation box, whereas those in the control group kept the money for themselves. Then, participants took a second TPT, which was the measure of pain perception as a dependent variable in this experiment. Participants also answered questions regarding altruistic disposition, attention to the hand under experiment, motivation to bear the pain, pain sensitivity, pain self-efficacy, and demographic information. As a manipulation check, participants in the altruistic group were asked the extent to which they agreed with the statement "In the period of this study, I helped other people" from 1 = totally disagree to 9 = totally agree. All of them believed they had helped others in the experiment ( $M$  = 7.74,  $SD$  = 1.37); their individual scores were no lower than the midpoint of the scale, and the average score was above the midpoint [ $t$  (18) = 8.72,  $P$  < 0.001]. Finally, participants were debriefed and thanked for their participation.

### Experiment 2.

**Participants and design.** Thirty-two students (18 females,  $M$  age = 22.25 y,  $SD$  = 3.60) recruited from a local university participated in this fMRI experiment as paid volunteers. We induced physical pain by electrical stimulation and adopted a 2 (condition: altruistic vs. control) by 2 (intensity of electrical stimulation: high vs. low) within-subjects design. One participant was excluded from the analyses because of excessive head movement (>3 mm) during the scanning. All participants were right-handed, were free of any neurological or psychiatric diseases, and had normal or corrected-to-normal vision.

**Materials.** Electrical stimulation was delivered with a Digitimer ds5 bipolar stimulator controlled by a Bits# Stimulus Processor. The electrical stimulation was sent through an MRI-compatible wire from an outside operating room into the MRI scanning room. Electrical stimulation was delivered onto the dorsal part of the participants' right hands. Each participant's pain threshold and electrical stimuli (low: rating of 1 vs. high: rating of 6 on a 0-to-10 scale) were identified 1 wk before the fMRI experiment in our laboratory (88, 89). **fMRI image acquisition.** All MRI data were acquired using the General Electric Signa VH/i 3.0T MRI scanner at the Center for MRI Research at our university. The BOLD signal was acquired using a whole-head gradient-echo echo-planar imaging sequence with the following parameters: time to repetition (TR) = 2,000 ms, time to echo (TE) = 30 ms,  $64 \times 64$  acquisition matrix, flip angle = 90, field of view (FOV) = 224 mm, slice thickness = 3.0 mm (voxel size  $3.5 \times 3.5 \times 4.2$  mm), no spacing. T1-weighted images were acquired using a 3D MP-RAGE sequence with the following parameters: TR = 2560 ms, TE = 3.39 ms, flip angle = 7, FOV = 256 mm, voxel size  $1 \times 1 \times 1$  mm.

**Procedure.** Participants completed 2 ostensibly unrelated experiments consecutively in the 3-T MRI scanning. In each of the 72 trials, participants first made a decision in the donation stage and then received an electric shock in the pain stage. The experimental paradigm of donation stage was adapted from a previous study on donation decision (90). It included 1 of 2 types of decisions: to decide whether to donate money to young orphans at a cost of their own (altruistic condition) or to judge whether 2 lines of figures had the same shape (control condition). After each decision, participants were asked to rate how helpful their choice was to the orphans from 0 (not at all) to 6 (very much). In the pain stage that followed, participants received an electric shock of high or low intensity on the dorsums of their right hands. They were asked to indicate their feelings of pain after each shock from 0 (no pain) to 10 (worst pain). The altruistic and control conditions were presented in a pseudorandom order, each appearing 36 times. In this way, we avoided

<sup>†</sup>The overall pain of the first TPT was calculated by the following equation (87).  $AUC_G$  refers to the area under the curve with respect to ground,  $m$  denotes the length of each line segment, and  $i$  denotes times of measurement:

$$AUC_G = \sum_{i=1}^{n-1} \frac{(m_{i+1}) + m_i}{2}$$

participants' undergoing the same type of trials or the same intensity of electric stimulation more than 3 times in a row (see *SI Appendix* for details). This approach minimized order effects and concerns about sensitization to pain. To ensure the genuineness of their altruistic decisions, participants were told that one random trial from the altruistic condition would be conducted in real time at the conclusion of the experiment. After exiting the scanner, participants answered questions regarding the donation (feelings of meaningfulness and pleasure) and their general characteristics, including personality and meaning in life (91). Finally, they were shown a randomly selected trial from the altruistic condition and were supervised to donate the exact amount of money in that trial to the orphan charity through an online platform. Through debriefing, we confirmed that the majority of the participants were not aware of the connection between the altruistic manipulation and the pain task.

**fMRI data analysis.** The fMRI data were analyzed using MATLAB and Statistical Parametric Mapping (SPM) software (<https://www.fil.ion.ucl.ac.uk/spm/software/spm12/>). For movement correction, each volume was aligned to match the sixth volume. The functional images were normalized using the standard ICBM space template and a  $2 \times 2 \times 2$ -mm voxel size and were smoothed with a Gaussian kernel (8 mm full width at half maximum) to optimize the signal-to-noise ratio, to compensate for interindividual variance in functional anatomy and to make the data conform more closely to the statistical models (92). The BOLD signal was modeled with gamma functions, convolved with a hemodynamic response function for the delay in blood flow change. The realignment parameters of motion correction were included as noninterested regressors in the estimation of the fMRI activity to exclude any possible influence from head movement. A one-sample *t* test was used for group analysis. Functional connectivity (PPI) analysis was assessed using PPI in SPM12. The PPI seed was created by placing a 6-mm sphere around the seed coordinates. Condition (altruistic vs. control) was used as the psychological variable in 2 separate PPIs (i.e., the interaction of the VMPFC time series and the psychological variables). Whole-brain voxelwise regression analyses were performed for each participant. Contrast images of the PPI interaction were statistically assessed with one-sample *t* tests. The ROI analyses were based on a 4-mm sphere in activated brain areas.

### Experiment 3.

**Participants and design.** Sixty-nine in-hospital cancer patients were recruited from Hebei General Hospital, China. The inclusion criteria of participants were as follows: 1) having clinical complaints of pain, 2) having over 3 mo of life expectancy remaining, 3) having the ability to perform required behaviors, and 4) participating voluntarily. Participants with matched cancer symptoms (i.e., with compatible TNM staging and Karnofsky Performance Status scores) were randomly assigned to 1 of 2 groups: altruistic vs. control. Five participants were excluded from the data analysis because 4 had data recording errors and 1 reported "unable to comprehend the questionnaires" on the first day. The final sample consisted of 64 participants (40 males, 22 females, 2 unidentified;  $M_{\text{age}} = 61.52$  y,  $SD = 13.29$ ), with 32 in each group

(altruistic: 21 males,  $M_{\text{age}} = 61.19$  y,  $SD = 13.69$ ; control: 19 males, 2 unidentified,  $M_{\text{age}} = 61.84$  y,  $SD = 13.08$ ).

**Procedure.** Participants were informed to take part in a 7-d study on their psychological states in the hospital and received a gift in return. On the first day, their pain perception, emotions, fear, and stress were assessed for baseline reference. Specifically, participants indicated their feelings of pain on the Wong-Baker Faces Pain Rating Scale; they reported emotions (unpleasant-pleasant, exhausted-energetic, nervous-relaxed) on scales that ranged from -3 to 3. They also rated fear ("how much do you fear the disease at the moment?") and stress ("how much pressure do you feel at the moment?") from 1 (not at all) to 7 (extremely). Participants also answered questions regarding previous medical treatment, pain sensitivity, and pain self-efficacy ( $\alpha = 0.803$ ) (93). Participants' demographic information (i.e., gender, age, height, and weight) and cancer symptoms (e.g., cancer type, TMN staging, and KPS score) were recorded by nurses in the hospital (*SI Appendix, Table S11*) and were similar between the groups ( $P > 0.489$ ).

On the second to seventh days, participants engaged in personal activities at a fixed time every morning and participated in a group activity on the afternoon of the fourth day. After each activity, they completed measures of pain perception, emotions, fear, and stress. In other words, each of these variables was measured 8 times. As personal activities, patients in the altruistic group were instructed to clean the public area for their wardmates, whereas those in the control group were instructed to clean their personal area. That is, all patients performed the exact same act but either did it for the good of others or for the good of themselves. The group activity took 1 of 2 forms: a share meeting on nutritional diet for the altruistic group and a lecture on healthy nutritional diet given by a nurse for the control group. All participants were asked to prepare 2 nutritional diet plans beforehand: The participants of the altruistic group were told that the purpose of their preparation was to benefit other wardmates, whereas the control group did the preparation as a mere prerequisite to attend the lecture. Thirteen participants (7 in the altruistic group, 6 in the control group) finished the activities on the first 5 d, and another participant had the day-4 questionnaire completed by a nurse due to worsened health condition. Empty records were defined as missing data in analyses.

**Data Availability.** The data that support the findings of this study and the analysis code have been deposited on Open Science Framework, [https://osf.io/5xk73/?view\\_only=d9912f066d424773bd26c961eca6890](https://osf.io/5xk73/?view_only=d9912f066d424773bd26c961eca6890) (94).

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