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Physical temperature effects on trust behavior: the role of insula

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Trust lies at the heart of person perception and interpersonal decision making. In two studies, we investigated physical temperature as one factor that can influence human trust behavior, and the insula as a possible neural substrate. Participants briefly touched either a cold or warm pack, and then played an economic trust game. Those primed with cold invested less with an anonymous partner, revealing lesser interpersonal trust, as compared to those who touched a warm pack. In Study 2, we examined neural activity during trust-related processes after a temperature manipulation using functional magnetic resonance imaging. The left-anterior insular region activated more strongly than baseline only when the trust decision was preceded by touching a cold pack, and not a warm pack. In addition, greater activation within bilateral insula was identified during the decision phase followed by a cold manipulation, contrasted to warm. These results suggest that the insula may be a key shared neural substrate that mediates the influence of temperature on trust processes.

Keywords: temperature; insula; trust; economic decision; priming

INTRODUCTION

Trust plays an essential role in person perception and interpersonal decision making. Moreover, human social inferences and behaviors can be affected by physical temperature (Williams and Bargh, 2008; Zhong and Leonardelli, 2008; IJzerman and Semin, 2009). For example, brief incidental contact with an iced (*vs* hot) cup of coffee leads people to subsequently perceive less interpersonal warmth in a hypothetical other and to behave less altruistically towards the known others in their life (Williams and Bargh, 2008). Moreover, feeling socially excluded leads people to judge their physical surroundings to be colder and express a preference for warmer products (Zhong and Leonardelli, 2008). Consistent with theories of embodied cognition, these investigations demonstrate that basic concepts derived from human interaction with the physical environment possess associative connections with higher order psychological concepts, such that activation of the former spreads to cause the activation of the latter (Barsalou, 1999; Niedenthal *et al.*, 2005; Williams *et al.*, 2009).

Judgments of interpersonal, metaphorical warmth occur spontaneously and automatically upon encountering others (Fiske *et al.*, 2007). People are able to reliably assess the trustworthiness of faces presented for only 100 ms, producing the same ratings as do other participants who are allowed to look at the faces for as long as they wished (Willis and Todorov, 2006). Indeed, spontaneous interpersonal warmth judgments can provide useful information regarding whom one should trust. Feelings of interpersonal warmth and coldness convey information regarding others' intentions toward a social perceiver, such that greater coldness connotes less prosocial intentions (Fiske *et al.*, 2007). To the extent that people sense metaphorical coldness (i.e. 'foe, not friend') in others, they should be and are less trusting of them.

A theoretical motivation for linking temperature to trust is clear, but empirical evidence for the relationship between judgments of physical temperature and interpersonal trustworthiness remains limited. In the present research, we examined the behavioral consequences of temperature priming by investigating the effect of exposure to cold or warm objects on the extent to which people reveal trust in others during an economic trust game. We also sought constraints on the neural mechanisms by which experiences with physically cold or warm objects prime concepts and behavioral tendencies associated with psychological coldness or warmth. Specifically, we examined the neural correlates of temperature priming effects on decision processes related to interpersonal trust, with a particular focus on the insula.

Areas of the insular cortex play a central role in processing of both thermal perception (Davis *et al.*, 1998, 2004; Gelnar *et al.*, 1999; Craig *et al.*, 2000; Sawamoto *et al.*, 2000; Brooks *et al.*, 2002; Maihöfner *et al.*, 2002; Moulton, 2005) and trust information (Winston *et al.*, 2002; Sanfey *et al.*, 2003; Preuschoff *et al.*, 2006, 2008; Rilling *et al.*, 2008; Rolls *et al.*, 2008; Todorov *et al.*, 2008). This dual role led Williams and Bargh (2008) to suggest that the insula may be one route through which physical experiences with cold

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(warmth) can activate or prime psychological coldness (warmth). Consistent with this hypothesis, growing evidence suggests that there is a posterior-to-anterior anatomical progression in which the posterior insula registers the primary physiological somatic sensations (Craig *et al.*, 2000; Brooks *et al.*, 2002; Olausson *et al.*, 2002, 2005), whereas the anterior insula provides the basis for subjective feelings and emotional awareness (Craig, 2002; 2009 for a review).

Craig (2009) further suggested that there is a posterior-to-anterior progression of interoceptive information processing within the insula cortex, such that the initial bodily sensation registered in the posterior insula spreads over the anterior insula, which then provides a basis for one's emotional experience (Craig, 2002; Barrett *et al.*, 2004). For example, objective degrees of temperature intensity were linearly represented within the posterior insula, whereas participants' subjective ratings of these stimuli correlated with activation in the anterior insula (Craig *et al.*, 2000; Kong *et al.*, 2006). Additional studies also suggest the posterior-to-anterior gradient towards greater complexity of experience within the insula. For example, activation foci during subjective bodily experience (i.e. smelling a disgusting odor) were located anterior to those during a comparable empathetic feeling (i.e. seeing disgust expressed on another's face) (Hennenlotter *et al.*, 2005; Jabbi *et al.*, 2007). Similarly, empathetic pain felt for a loved one receiving painful simulation was associated with activation of the bilateral anterior insula but not with the posterior insula (Singer *et al.*, 2004).

The dual role of the insula in both physiological perception and emotional experience suggests that the insula may play a critical role in mediating the effects of physical temperature priming on subsequent social judgments, decisions and behavior. In this study, we hypothesized that physical coldness (warmth) would lead to lesser (greater) expressions of interpersonal trust, and that the effect of temperature priming on trust behaviors may be reflected in insular cortex activity. Specifically, we expected to find the thermal and trust processes corresponding activations in the posterior and anterior insular cortices, respectively; moreover, this pattern of activation should differ with the temperature (cold *vs* warm) that immediately precedes the trust decisions.

As a behavioral index of trust, we used people's responses during an economic trust game in which people make investments that involve entrusting a small amount of money to another player to invest on their behalf (the 'trust' game; Berg *et al.*, 1995; Delgado *et al.*, 2005). In Study 1, we examine the effect of touching physically cold or warm objects on people's decisions in the trust game, assessing the effect of temperature priming on social behavior. In Study 2, we used functional Magnetic Resonance Imaging (fMRI) to observe insula activation both when people are exposed to cold (*vs* warm) objects, and also while subsequently making decisions involving trust.

STUDY 1: EFFECTS OF TEMPERATURE ON TRUST BEHAVIOR

Participants touched either a cold or a warm pack, and then played an economic trust game. We predicted and found that experience of physical cold (*vs* warm) decreases the amount of money invested in subsequent trust decisions.

Methods

Participants

Thirty students (mean age = 19.7, s.d. = 2.6) provided written consent prior to participation according to the Declaration of Helsinki (BMJ 1991; 302: 1194), as approved by the Yale Institutional Review Board. All participants received either a course credit or cash ($5) as compensation.

Procedure

An experimenter briefly explained that this study would involve two separate tasks: a consumer product evaluation and an online game. Then participants played five practice trials of the trust game before the temperature manipulation.

Temperature manipulation. Participants were randomly assigned to either a cold or warm condition. The experimenter did not know the participants' test conditions until just before the temperature task. To further minimize the chances that participants would become aware of the experimental hypotheses, a cover story was used to distinguish the temperature priming from the subsequent trust game tasks. Participants were told that, 'We would like you to rate a specific consumer product. The product you will be rating is a therapeutic pack. Please hold the pack for 10 s and answer the following questions.'

We used temperature packs (260 × 370 × 10 mm, MD Prime Co., Korea) that were prepared to be 15°C (average) for the cold condition and 41°C (average) for the warm condition, respectively (following Davis *et al.*, 1998). The experimenter placed the pack on each participant's left palm; after 10 s, the participant completed a consumer questionnaire with the pack still resting on their palm. The questionnaire consisted of three items: (i) pleasantness of the pack (1 = very unpleasant; 7 = very pleasant); (ii) effectiveness of the pack (1 = very effective; 7 = not effective at all); and (iii) whether they would recommend it to their friends (yes/no).

Trust game. A version of a behavioral trust game (Berg *et al.*, 1995) was programmed using PsyScope software (Cohen *et al.*, 1993). Participants were informed that they would be playing a game with three online players connected from different study sites, and that there would be two types of players: 'investors' and 'trustees'. Investors were described as those who make an initial investment decision, and trustees as those who make a final reallocation decision back to the investor. Participants were told that they were 'randomly assigned' to the role of investor or trustee; however, all participants were in fact assigned to play the investor. Additionally, all of the trustee responses were computer generated; there were no human partners.

Participants played 15 trials of the trust game, with each trial consisting of a decision and an outcome phase. During the decision phase, participants decided how much money to invest with the trustee (possible responses ranged from \$0 to \$1.00 with \$0.10 increments). The money participants invested was then tripled in value, and this new value of invested money was displayed on the computer screen. After a delay of 4–6 s, the amount of money that the trustee ostensibly decided to give back was displayed on the screen. To prevent development of strategies against certain game players, participants were informed that their specific partners would vary randomly across each trial. Upon completion, participants were probed for suspicion of the actual hypotheses, and thanked for their participation.

Results

The primary dependent variable was the amount of money participants 'invested' with the trustees, averaged across the 15 trials. Responses did not differ as a function of gender, ethnicity, or age in any of the following analyses (all P's > 0.45).

As predicted, participants who touched cold packs ($M = \$0.46$, s.d. $= 0.18$) later invested on the average of 20 less cents in each trial than those who had touched warm packs ($M = \$0.66$, s.d. $= 0.16$), $F(1,28) = 10.52$, $P = 0.003$. None of the participants suspected an influence of temperature on their investments.

Cold packs ($M = 4.33$, s.d. $= 1.40$) were rated to be marginally less pleasant than warm packs ($M = 5.33$, s.d. $= 1.40$), $F(1,28) = 3.84$, $P = 0.06$, with the average pleasantness ratings falling between neutral and mildly pleasant for cold, and mildly pleasant and pleasant for warm packs. However, pleasantness ratings did not predict invested money, $r = 0.10$, $P = 0.61$. Instead, temperature predicted invested money independent of the pleasantness that it aroused. Analysis of covariance revealed that invested money still significantly differed by temperature manipulation after adjusting for pleasantness scores, $F(1,27) = 10.20$, $P = 0.004$.

Discussion

Recent physical temperature sensations should not, presumably, be a valid or relevant indication of the trustworthiness of others. Nonetheless, participants' recent experience with cold *vs* warm temperatures did predict the outcomes of their investment decisions in Study 1. This finding extends recent work demonstrating that brief experiences with cold or warm objects can influence people's social judgments and prosocial behavior without their awareness (Williams and Bargh, 2008), by showing the effects of temperature primes in the economic decision-making domain. Furthermore, this work provides compelling support for the view that physical temperature cues provide useful information regarding whether it is safe to trust others (cf. Fiske *et al.*, 2007).

However, the underlying mechanism of this physical-to-social-temperature effect remains unclear. Williams and Bargh (2008) suggested that the relationship between physical and psychological temperature might be due to a shared neural substrate (insula). Study 2 specifically examined the insula cortex as a candidate region that mediates the effect of temperature on trust processes.

STUDY 2: TEMPERATURE EFFECTS ON NEURAL ACTIVATION DURING TRUST-RELATED DECISIONS

In Study 2, we investigated the role of insula in the temperature-trust effect, using a modified version of Study 1 adapted for an fMRI scanning environment. Participants completed both cold and warm temperature tasks, each followed by a trust game. The two temperature conditions were randomized in order and separated by a distracter task. We identified the brain regions within the insular-opercular cortex that mediated the effect of temperature priming.

Methods

Participants

Twenty-three participants provided written consent according to the Declaration of Helsinki (BMJ 1991; 302: 1194) and received financial compensation for their participation (\$40). For the temperature task, data from 23 participants (mean age $= 22.7$, s.d. $= 4.6$) were analyzed. For the trust game results, the first seven participants were excluded due to changes in the design of the trust game (final $n = 16$, mean age $= 23.6$, s.d. $= 5.0$). All participants were right handed, and met the standard fMRI safety criteria, as approved by the Yale University Human Investigation Committee.

Procedure

Participants were informed that they would perform several unrelated tasks in the scanner. Study 2 used a within-subject design (Figure 1), having participants primed with both cold and warm packs, both followed by a trust game.

Temperature manipulation. An experimenter placed a cold (15°C) or warm (40°C) pack on the participants' left palm for 20 s, alternating with a neutral (room temperature) pack for 20 s, with a transition intervals (no pack) of 10 s. The order of the temperature conditions (cold, warm) was randomized across participants. An entire temperature run comprised an initial 6 s of resting followed by five blocks of a temperature-interval-neutral sequence, altogether lasting for 5 min and 6 s. A given scanning run included conditions that were either cold and neutral, or warm and neutral. Both were intended to influence brain activity during both the current and the next scanning run (trust game).

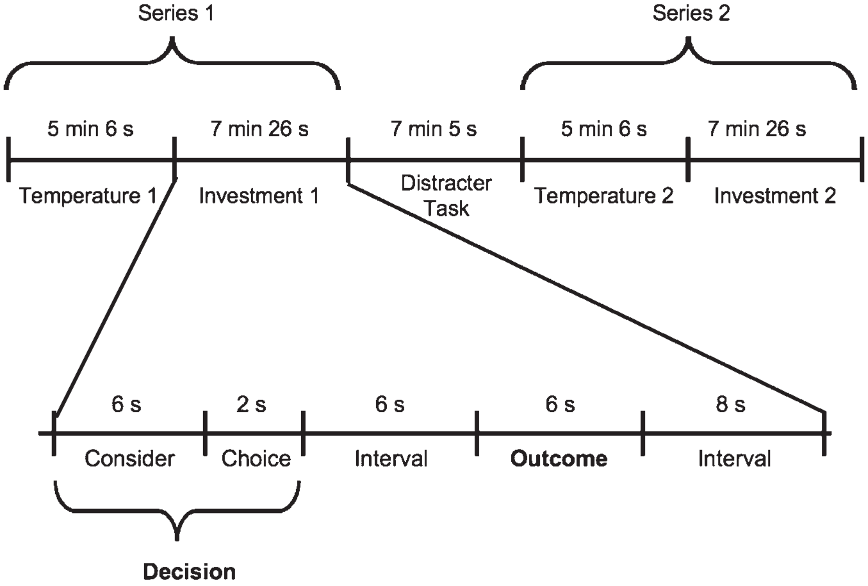

Fig. 1 Study 2 and the trust game timeline.

Trust game. After each temperature task, participants played a trust game that was modified to be compatible with the demands of the scanning environment. The decision phase consisted of a 6 s consideration phase in which participants decided how much to invest among four options ($0, 0.40, 0.65, 1.00) and a 2-s choice phase when the participants pressed the button of their choice (Figure 1). After a 6-s interval, a trustee's response was presented on the screen, followed by a fixation. There were 15 trials of the trust game, which lasted a total of 7 min and 26 s.

Immediately following the first trust game, a 3-back working memory task was introduced as a distracter task in order to attenuate any carry-over effects from the first series. Upon completion of the scanning, participants were probed for suspicions concerning the experimental hypotheses, thanked for their participation, and paid.

fMRI data acquisition and analysis. Imaging data were collected using a 3.0-T Siemens Trio scanner at the Yale Magnetic Resonance Research Center. Three structural images (plane localizer; T1-weighted MPRAGE, and T1 flash axial) and five functional runs were acquired (gradient-echo EPI sequence; TR = 2000 ms; TE = 25 ms; FOV = 240 cm, flip angle = 80°, matrix size = 64×64, slice thickness = 4 mm with no gap). The functional series lasted for 306, 446, 426, 306 and 446 s for the temperature task-1, trust game-1, working memory distracter task, temperature task-2 and trust game-2, respectively. Thirty-two contiguous oblique-axial slices parallel to the anterior commissure–posterior commissure (AC–PC) line were obtained. Stimuli were presented using a laptop running PsyScope (Cohen *et al.*, 1993). Participants viewed stimuli projected onto a screen through a mirror mounted on the head coil. Responses were made using a fiber-optic response buttons, using the fingers of the right hand.

The data were analyzed using FMRIB Software Library 4.1 (FSL, Analysis Group, FMRIB, Oxford, UK). The first three volumes (6 s) were discarded to allow for T1 equilibration. Preprocessing was done using the first-level FEAT default settings, including motion correction (MCFLIRT; Jenkinson *et al.*, 2002), brain extraction (BET; Smith, 2002), and spatial smoothing (5 mm FWHM). A high-pass filter of 100 s was used for temporal filtering. The mean functional image and the MPRAGE for each participant was then spatially normalized into standard stereotaxic space (MNI152 T1 2 mm: Montreal Neurological Institute, MNI), using 12-parameter affine transformation followed by nonlinear warping.

Results are reported as significant for $P < 0.05$ corrected for multiple comparisons using a Z threshold of 2.4 and minimum cluster-size constraints. All coordinates are reported in MNI space. Only clusters of at least 5 voxels in gray matter are reported.

Results

Temperature effects on neural activity

The key fMRI analyses for the temperature conditions were two group-level contrasts. First, brain areas that were more active during experience of cold and warm temperatures compared to neutral were identified. Within each run, neural responses to cold or warm temperature were contrasted with neutral temperature from that run. Both cold and warm evoked greater activation in right primary somatosensory cortex relative to neutral (Table 1, Figure 2). More importantly, cold (but not warm) temperature evoked greater activation than neutral in bilateral insula and bilateral central and parietal opercular cortex

Table 1 Brain regions that were sensitive to warm and cold temperatures: increased activity in response to warmth or coldness compared to neutral temperature (Z threshold = 2.4, $P < 0.05$)

Region of activation	Voxels	X	Y	Z	Z_{max}
Warm > Neutral					
R Primary somatosensory	1828	52	−16	54	4.82
Cold > Neutral					
Local maxima	3572				
R Insula/Central operculum		48	−18	14	4.28
R Primary somatosensory		40	−30	62	4.03
L Insula/Central operculum	567	−48	−22	14	3.64

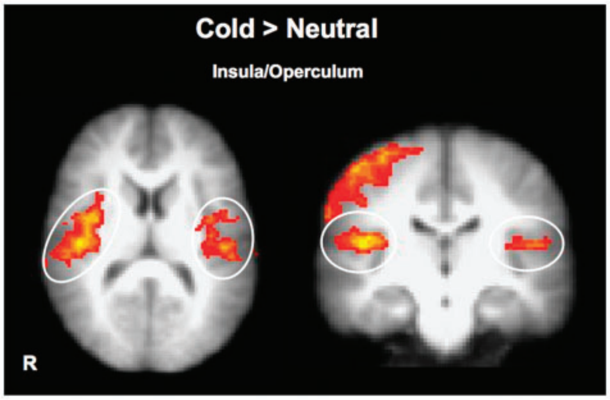

Fig. 2 Brain regions that showed greater activation during experience of cold than neutral temperature. Bilateral insular-opercular cortex showed uniquely greater activation than baseline.

Table 2 Brain regions that were sensitive to warm and cold temperatures: activity contrast between warmth and coldness (Z threshold = 2.4, $P < 0.05$)

Region of activation	Voxels	X	Y	Z	Z_{max}
Warm (-neutral) > Cold (-neutral)					
PCC	997	0	−34	22	4.17
Inferior medial frontal	519	0	56	−6	3.64
Cold (-neutral) > Warm (-neutral)					
R Primary somatosensory	983	38	−20	46	3.36
Temporal pole	422	42	−2	−18	4.59
R Insula/Central operculum	414	38	−14	18	3.65

PCC, posterior cingulate cortex.

(Figure 2). Such activation was absent in response to warm temperature relative to a neutral temperature baseline.

Second, we contrasted cold and warm conditions directly. Across two runs, regions that were more active in response to cold than neutral, and warmth than neutral were subtracted from each other. Consistent with previous findings (Davis *et al.*, 1998; Craig *et al.*, 2000; Maihöfner *et al.*, 2002), cold recruited greater activation near posterior insular-opercular regions than warmth (Table 2). Regions near bilateral insular-opercular cortex, temporal pole and right primary somatosesory were more active during cold perception, whereas warmth elicited greater activation in PCC and inferior medial frontal area (Figure 3).

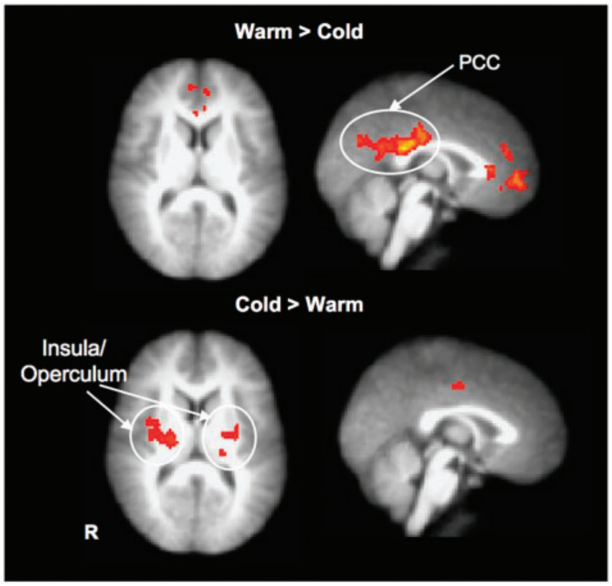

Fig. 3 Contrast between brain activations during warm and cold experiences.

Temperature effects on neural process during the trust game

The decision and outcome phases were modeled as different events in a general linear model. All 16 participants who completed the trust game later reported that they made the trust-related decisions during the decision phase of the game. The decision phase after each temperature condition was contrasted with the baseline intervals within each run using the FEAT higher level analysis.

Activation foci within the bilateral occipital poles (OC), anterior cingulate cortex (ACC), left thalamus and left dorsolateral prefrontal cortex (DLPFC) were identified during trust decision after both cold and warm pack manipulations (Table 3; Figure 4).

In accord with our *a priori* hypotheses about the insula, the left-anterior insula was significantly more active during the trust game for sessions preceded by a cold-temperature scan. Greater left-anterior insula activation during trust decision (relative to baseline) was identified only after exposure to cold temperature, and not warm, as revealed in whole-brain corrected comparisons.

Next, we directly contrasted the decision phases of trust game after the cold and warm manipulations. Decision phases after cold and warm temperatures were combined then contrasted. Results revealed greater activation in bilateral anterior insula and central operculum during the trust game followed by cold relative to warm temperature (Table 3; Figure 5). In addition, right VMPFC, right primary somatosensory cortex, right premotor cortex and right primary motor cortex were also more active during the decision

Table 3 Brain regions showing greater activation during decision phase of a trust game after temperature manipulation (Z threshold = 2.4, $P < 0.05$)

Region of activation	Voxels	X	Y	Z	Z_{max}
After warm > baseline					
Local maxima	15 656				
OC		−22	−90	20	5.49
ACC		6	10	42	5.32
L thalamus	588	−22	−28	−4	4.22
L DLPFC	413	−40	38	26	3.81
After cold > baseline					
OC	19 731	−8	−90	30	6.19
ACC	3373	6	12	40	5.28
L thalamus	738	−20	−32	−4	4.33
L DLPFC	661	−30	42	24	4.14
Premotor	615	34	−6	50	4.66
L insula/central operculum	527	−42	12	4	4.21
After cold > after warm					
R VMPFC	45	16	54	10	3.16
R primary somatosensory	35	32	−38	58	2.90
	27	16	−38	74	2.87
L insula	19	−32	10	−12	2.88
R premotor	16	22	−14	56	2.81
	10	8	−12	52	2.61
Central operculum	10	−48	−14	8	2.79
R primary motor	9	4	−36	58	2.81
R insula	6	30	18	−12	2.77

VMPFC, ventromedial prefrontal cortex.

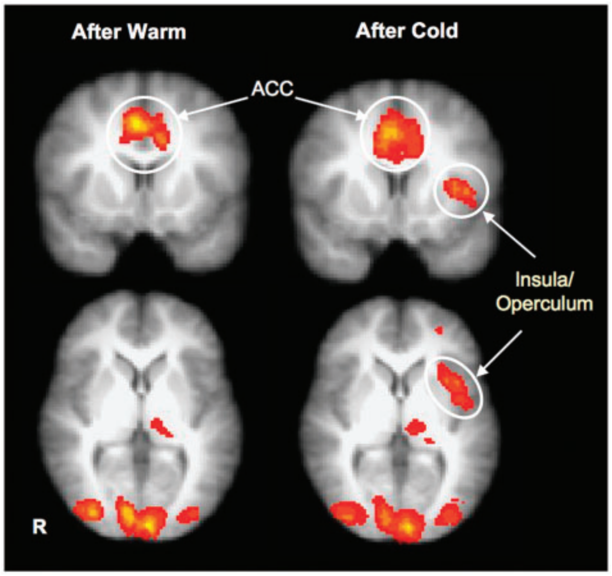

Fig. 4 Brain regions that recruited greater activation during the decision phase of trust game after the warmth and cold temperature manipulations. Left-anterior insula distinctively showed differentiated activations.

phase after the cold manipulation. On the other hand, no significantly greater activation was detected when decisions followed by warmth were contrasted to those followed by cold.

To better understand the specific region in relation to our hypothesis about the insula specifically, we defined it as an ROI (i.e. in the left-anterior insular-opercular cluster that was active during the decision phase of trust game after touching a cold pack, MNI coordinates: −34, 14, 6, 480 voxels, $P = 0.035$, $Z_{max} = 4.04$). Within the ROI, activation was greater during decision phase after cold ($M = 1.16$, s.d. = 0.84) than during the decision phase after warm ($M = 0.67$, s.d. = 0.68), $t(15) = 2.41$, $P < 0.05$. Prior experience of cold elicited greater engagement of the insular ROI in subsequent trust decisions, as compared to after warmth.

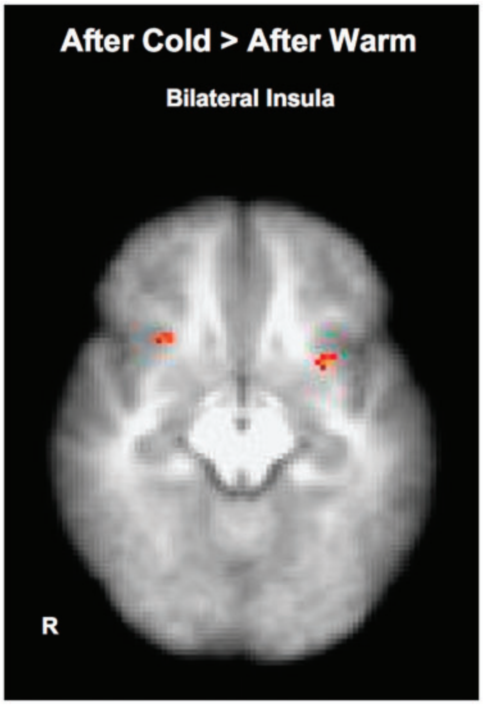

Fig. 5 Contrast between brain activations during the decision phases of trust game after cold and warm experiences.

The effect of temperature on the amount of invested money was not significant in Study 2, and participants invested nearly equal amount of money in warm ($M = 75$ cents, s.d. = 0.18) and cold ($M = 74$ cents, s.d. = 0.17) conditions, $t(15) = 0.20$, $P = 0.84$. In addition, there was a ceiling effect, such that in the majority (76%) of trust game trials, participants chose the 65 cents or 1 dollar options ($M = 75$ cents, s.d. = 0.18).

Discussion

Bilateral insular-opercular cortex showed greater association with cold temperature relative to neutral and warm temperatures. Of note, the left-anterior insular cortex was more active during trust decisions only after experience with cold but not warmth. This is largely consistent with previous findings on neural correlates of temperature and emotion experience. The operculum (the overlying cortical surface of insula) was also consistently identified as having major roles in temperature processing (Schmahmann and Leifer, 1992; Greenspan *et al.*, 1999; Bowsher *et al.*, 2004;

Bowsher, 2006). The insula and operculum are thought to function as a relay region where visceral sensations are translated into emotions and responsible for visceral awareness, having mostly aversive sensory inputs interpreted as negative affective states (Craig, 2002; Critchley *et al.*, 2002, 2004). Craig (2009) suggests that activation in the anterior insula often extends into the operculum, leading to a unified experience of emotions represented near the junction of the anterior insula and the operculum. In this light, we interpret the activation of posterior insular-opercular cortex during cold sensation as having spread into anterior insula during trust-related decisions, whereas such spreading effects did not occur (or occurred les strongly) in response to physical warmth.

Co-activation of regions near the insula and ACC during decision making is well-documented (Sanfey *et al.*, 2003; Delgado *et al.*, 2005; Kuhnen and Knutson, 2005; Knutson and Bossaerts, 2007; Tabibnia *et al.*, 2008). Notably, the insula's involvement in decision-making tasks suggests it has general role in initiating goal-oriented actions (Bechara, 2004, 2005; Grabenhorst *et al.*, 2008). Interestingly however, greater insula activity was absent during trust decision after experiences of warmth, and larger left-insula activations relative to baseline during trust decisions was present only after the experience of cold temperature. Our interpretation is that cold activates insula, and activation spreads into areas in anterior insula, influencing subsequent trust decisions.

Although the effect of temperature on the amount of invested money was not significant in Study 2, our ability to detect the effect (compared to Study 1) was decreased—not only because of the observed ceiling effect on responding, but by modifications to the investment task necessary to adapt it to the scanner environment. Specifically, the response box used in the scanner contained only four response options ($0, $0.40, $0.65 and $1.00), compared to 11 in Study 1. The differences in amount between these four options were greater than the magnitude of the behavioral effect of warmth on trust observed in Study 1 ($0.15) and so made it more difficult to detect a difference between conditions on the behavioral measure.

Nonetheless, Study 2 provides further support for a link between temperature and trust processing, as revealed in brain activity rather than in behavior. In particular, the insula showed greater response to cold temperature, and this differential activation was re-observed during decision phases of trust game, suggesting a plausible neural basis for a relationship between experienced temperature and interpersonal trust.

GENERAL DISCUSSION

Physical coldness led to decreased trust behavior, compared to warmth. Furthermore, trust-related decisions recruited regions that also activated differentially to cold temperatures. Specifically, insula was more active during cold temperature perception, and also active in trust decisions after having experienced cold. This differential brain activation during trust decisions as a function of prior experiences of different temperatures may explain how physical experiences with temperature can alter psychological states related to trust, as observed in several previous studies. Based on our data as well as those previous findings, our interpretation is that physical temperature experiences primed the insula, leading both to differences in behavioral responding (Study 1) and in patterns of neural activation (Study 2).

A deeper understanding of the mechanisms by which cold temperatures obstruct trusting behaviors can inform both cognitive science and practice. The present work represents an important step towards further elucidating the mechanisms by which physical environmental cues can influence people's judgments and decisions, by examining the neuropsychological consequences of exposure to cold *vs* warm temperatures. Furthermore, these studies provide initial evidence for the process by which conceptual scaffolding occurs (Williams *et al.*, 2009), by highlighting how an evolutionarily significant physical concept (temperature) is functionally linked on a neural level to the metaphorically related higher order psychosocial concept (trust). Similar to the way in which the processing of physical and psychological pain overlaps in specific areas of the brain (ACC; Eisenberger *et al.*, 2003), so too it appears that there is functional overlap in the processing of information related to physical and psychological warmth.

Considering practical implications, given the present findings and previous demonstrations of the effects of physical temperatures on psychological states (Zhong and Leonardelli, 2008; Ijzerman and Semin, 2009), it may be prudent to take physical temperature into account for cognitive and behavioral therapies treating psychopathological conditions, such as borderline personality disorder in which difficulties in expressing trust contribute to dysfunction (King-Casas *et al.*, 2008). For example, it may be possible that physical experience with cold temperatures can lead patients to be less receptive to attempts at behavioral change designed to increase their capacity for trusting others (perhaps via increasing insula activity normally associated with cold temperatures and the expectation of risk; Knutson and Bossaerts, 2007).

Risk perception literature provides possible explanations for the differential insula activity following temperature priming. Mounting evidence supports the association of insula and expected risk (Knutson and Bossaerts, 2007). Activation in insula increased proportionally to increasing risk (Dreher *et al.*, 2006; Preuschoff *et al.*, 2006, 2008), as well as in response to uncertainty in other financial and non-financial decision tasks (Critchley *et al.*, 2002; Grinband *et al.*, 2006; Huettel *et al.*, 2005). The absence of meaningful insula activity after experiencing warmth may reflect attenuated risk perception during subsequent trust decisions, which can lead to increased trust behavior. In addition, converging findings suggest that insula activations reflect negative anticipatory affective states that can lead to increased risk aversion (Kuhnen and Knutson, 2005; Paulus *et al.*, 2003). Differential insula activity may correspond to the effect of temperature on the shift of risk preference, where coldness (warmth) may prime individuals to be less risk-seeking (risk-aversive) during ensuing decision process. Exploring this possibility presents a potential avenue for future research on the neural correlates of temperature priming.

In sum, the present research demonstrates the behavioral and neuropsychological relation between experiences of physical temperature and decisions to trust another person. Neuroimaging techniques revealed a specific activation pattern in insula that supported both temperature perception as well as the subsequent trust decisions. These findings supplement recent investigations on the embodied nature of cognition, by further demonstrating that early formed concepts concerning physical experience (e.g. cold temperature) underpin the more abstract, analogous social and psychological concepts (e.g. cold personality) that develop later in experience (Mandler, 1992), and that these assumed associations are indeed instantiated at the neural level. Perhaps most importantly, by exploring the functional mechanism by which temperature priming occurs, this work offers new insights into the ease by which incidental features of the physical environment can influence human decision-making, person perception and interpersonal behavior.

Conflict of Interest

None declared.

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