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Neural substrates of framing effects in social contexts: A meta-analytical approach

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ABSTRACT

We hypothesize that framing effects (risk-averse in the positive frame and risk-seeking in the negative frame) are likely to occur when ambiguous social contexts result in ambiguous or ambivalent risk preferences, leading the decision-maker to search for more subtle cues, such as verbal framing. In a functional magnetic resonance imaging (fMRI) study, we examined framing effects in both unambiguous homogeneous group and more ambiguous heterogeneous group contexts. We began by conducting a meta-analysis and identified three regions of interest: the right inferior frontal gyrus, the left anterior cingulate (ACC)/ventromedial prefrontal cortex (vmPFC), and the left amygdala. Our own fMRI data were collected while the participants made choices between a sure option and a gamble framed in terms of the number of lives to either save or die. The framing effect was evident in a heterogeneous context with a mixture of kin and strangers, but disappeared in a homogeneous group of either all kin-members or all strangers. The fMRI results revealed a greater activation in the *right middle/inferior frontal gyrus* under the negative than the positive framing, and less ACC/vmPFC deactivation under positive framing in the heterogamous/ambiguous context. The activation of the *amygdala* was correlated with greater risk-seeking preference in homogeneous kinship contexts.

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Introduction

In their seminal work, Kahneman and Tversky (1979, 1981) demonstrated that verbal framing (phrasing) of equivalent decision outcomes in either a positive or a negative light causes individuals to have different choice preferences. Such impact of naming on thinking is referred to as the framing effect. Since then, multidisciplinary research on framing effects has gleaned converging evidence that different ways of framing, phrasing, or presenting virtually identical choice options systematically affect risk preference (risky choice framing), evaluation of experience (attribute framing), and persuasiveness of arguments (goal framing) (Chong & Druckman, 2007; Druckman, 2001; Kühberger, 1998; Levin, Schneider, & Gaeth, 1998). Framing effects epitomize the power of linguistic subtlety in regulating decision-making, oftentimes without awareness of the decision-maker. Beyond phenomenology, different theories of framing effects have been proposed (e.g., Dunegan, 1993; Kahneman & Tversky, 1979; McElroy & Seta, 2003, 2004; Reyna & Brainerd, 1991, 1995, 2011; Wang, 2008; Wang, Rao, & Zheng, *in press*).

To better understand the underlying mechanisms of framing effects, functional magnetic resonance imaging (fMRI) has become a unique testing tool. First, many hypothetical mechanisms and *post hoc* explanations based on behavioral effects can be tested or verified in fMRI studies. Second, neuroimaging studies often shed light on puzzling or conflicting findings from behavioral studies of framing effects. Third, meta-analyses of extant neuroimaging studies can reveal convergent brain regions that underpin framing effects and offer valid guidance for future studies. Although neuroimaging studies of framing effects are fewer compared to a myriad of behavioral studies of framing effects, a body of such neuroimaging research is ready for a synthetic meta-analysis.

In this study, we examine framing effects in social contexts and the neural substrates implicated in the appearance and disappearance of the framing effects. We began with a meta-analysis of fMRI studies of framing effects to identify unique brain regions that underpin framing effects. We then focused on the identified brain regions from the meta-analysis to test the predictions derived from the ambiguity–ambivalence hypothesis of framing effects (Wang, 2008; Zheng, Wang, &

Zhu, 2010). In particular, we investigated social context-dependent framing effects and how social group composition (homogeneous vs. heterogeneous groups) and kinship affect the occurrence of framing effects.

A meta-analysis of neuroimaging studies of framing effects

To identify regions of interest (ROIs) for fMRI analysis, we first conducted a meta-analysis of extant fMRI studies of framing effects. We carried out a literature search using the keywords “framing effect” and “MRI” to identify relevant studies included in the PubMed and PsycINFO databases; the search was conducted in August 2015, and no time span was specified for date of publication. Our inclusion criteria were: (1) fMRI studies of risky choice framing; (2) the studies presented coordinate-based analyses of the data; (3) all or most of the brain was imaged; and (4) participants were asked to choose in different valence frames. The six studies obtained from this search are summarized in Table 1. The choice tasks involved life–death, monetary, and other types of problems. The behavioral framing effects were all significant.

We then conducted a meta-analysis by entering the coordinates of 29 foci that were reported in the fMRI studies of framing effects to get their topographic

convergences. Any convergent brain loci identified from the meta-analysis would be used as ROIs in the subsequent fMRI study of framing effects. For this purpose, we adopted a widely used technique for coordinate-based meta-analyses of neuroimaging data, called activation likelihood estimation (ALE). ALE assesses the overlap between foci based on modeling them as probability distributions centered at their respective coordinates. ALE maps are then obtained by computing the union of activation probabilities for each voxel. To differentiate true convergence of foci from random clustering (i.e., noise), a permutation test is applied to determine statistical significance. To obtain an ALE null distribution, the same foci identified for the meta-analysis are randomly redistributed throughout the brain (see Eickhoff et al. 2009; Turkeltaub, Eden, Jones, & Zeffiro, 2002). In other words, ALE meta-analysis determines if the clustering is significantly higher than expected under the null distribution of a random spatial association of results from the considered experiments.

Our analysis was implemented using GingerALE Version 2.1.1 (available at <http://brainmap.org/ale>). The meta-analysis was performed using the Montreal Neurological Institute (MNI) stereotactic coordinates derived from the studies listed in Table 1. No assumptions were made concerning the distribution or spatial

Table 1. Functional MRI studies of framing effects.

Study	Behavioral framing effects inside the scanner	Main neural correlates	<i>n</i>	Foci
De Martino et al. (2006)	Used monetary problems. The percentage of risk-seeking choices was 43% in the positive frame and 62% in the negative frame	The framing effect was associated with amygdala activity; but reduced by ACC , OMPFC , and right OFC activities.	20	6
Gonzalez, Dana, Koshino, and Just (2005)	Used life–death, monetary, and other problems. The percentage of risk-seeking choices was 33% in the positive frame and 59% in the negative frame	Higher activation in positive–gamble choices than in positive–certain choices in the right DLPFC , posterior precentral sulcus , and multiple areas in the parietal cortex .	15	7
Guitart-Masip, Talmi, and Dolan (2010)	Used monetary problems with visually conditioned stimuli as valence frames. The percentage of risk-seeking choices (in the last session) was 40% in the positive frame and 50% in the negative frame	The framing effect was associated with activation of the left amygdala , right caudate , and right insula .	24	3
Roiser et al. (2009)	Used monetary problems. Framing susceptible and insusceptible participants differed in the size of the alleles at 5-HTTLPR. The percentage of risk-seeking choices was 43% in the positive frame and 57% in the negative frame	Framing effects-prone individuals had higher activation in the left amygdala whereas insusceptibility to framing was associated with ACC activation.	30	4
Zheng et al. (2010)	Used life–death problems. The percentage of risk-seeking choices was 52% in the positive frame and 65% in the negative frame	The framing effect was correlated with activation in the right IFG . The disappearance of the framing effect in a small group context was associated with activation in the right insula and an area in the right parietal cortex .	22	3
Xu et al. (2013)	Used monetary problems. The percentage of risk-seeking choices was 46% in the positive frame and 54% in the negative frame	The framing effect was associated with activation in the left amygdala . The reversed pattern of the framing effect was associated with activation in the right dorsal ACC .	20	6

ACC, anterior cingulate cortex; AI, anterior insular; OMPFC, orbital and medial prefrontal cortex; DLPFC, dorsal lateral prefrontal cortex; 5-HTTLPR, serotonin transporter-linked polymorphic region; OFC, the orbitofrontal cortex; IFG, inferior frontal gyrus (significant results at 0.05% in bold).

Table 2. Neural correlates of framing effects derived from ALE meta-analysis.

Cluster	Region	BA	x	y	z	ALE ($\times 10^{-2}$)	Volume (mm^3)
1	Left ACC/vmPFC	24	-4	36	-6	1.16	408
2	Left Amygdala		-24	-4	-20	0.94	232
3	Right IFG	47	32	30	-8	0.90	216

ACC/vmPFC, anterior cingulate cortex/ventromedial prefrontal cortex; IFG, inferior frontal gyrus; BA, Brodmann area.

separation of these random foci; however, clusters of activity were required to exceed 200 mm^3 in volume. The test was corrected for multiple comparisons using the false discovery rate (FDR) method (Genovese, Lazar, & Nichols, 2002).

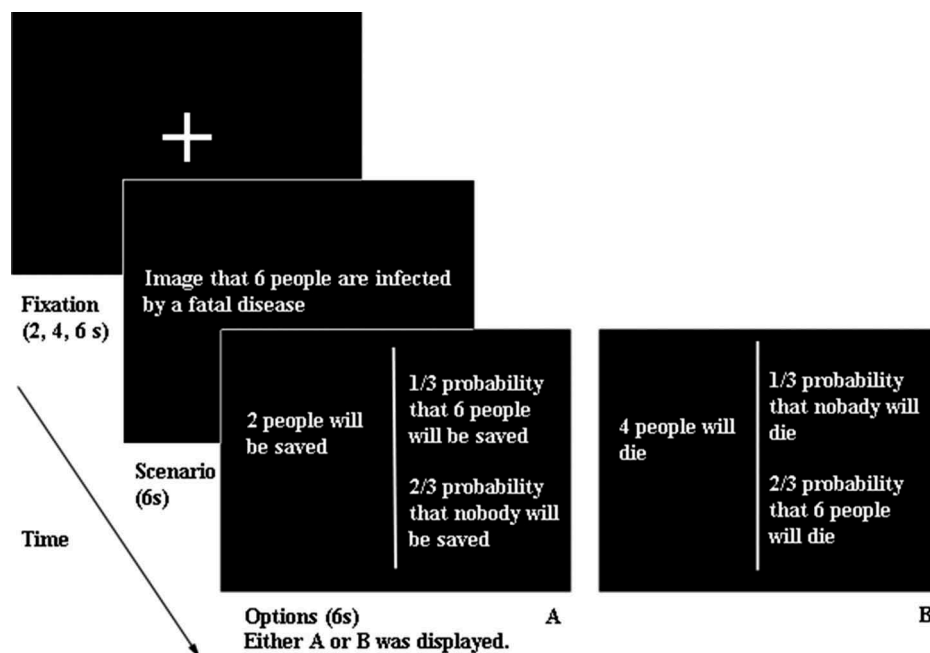
The results of this ALE meta-analysis with 29 foci converged to three brain structures with significantly high ALE values: the right inferior frontal gyrus (rIFG), the left anterior cingulate cortex/ventral medial prefrontal cortex (ACC/vmPFC), and the left amygdala, indicating that these three brain regions are the key neural correlates of framing effects (see Table 2 and Figure 1).

Preconditions of framing effects in social contexts

In general, framing effects demonstrate the impact of naming on thinking. Consider the well-known Asian disease problem demonstrated first by Tversky and Kahneman (1981). In the cover story of the problem, the respondents were asked to imagine that “the US is

preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed.” The outcomes of the disease-combating plans were then framed (phrased) differently. In the positive frame, the respondents were told, “If Plan A is adopted, 200 people will be saved. If Plan B is adopted, there is a one-third probability that all 600 people will be saved, and two-thirds probability that none of them will be saved.” Under this positive valence framing in terms of lives saved, the majority of the respondents (72%) were risk-averse, preferring the sure option (Plan A) over its gamble equivalent (Plan B). However, when the same outcomes were “negatively framed” in terms of lives lost (“If Plan A is adopted, 400 people will die. If Plan B is adopted, there is a one-third probability that none of them will die, and two-thirds probability that all 600 people will die.”), the majority of the respondents (78%) were risk-seeking, preferring the gamble option (Plan B) over its sure-thing equivalent.

Such risk preference reversals due to valence framing of virtually equivalent choice outcomes violate the consistency (invariance) axiom of normative rationality, which requires a rational decision-maker to have a consistent preference order among identical choice prospects independent of the way the prospects are presented or framed. The framing effect is thus viewed as an irrational reversal in choice preference and a cognitive illusion that equates positive framing to a gain and negative framing to a loss. Framing effects are often explained using an S-shaped value function

**Figure 1.** Meta-analysis results of neural correlates of framing effects.

based on prospect theory (Kahneman & Tversky, 1979), which is concave for gains, indicating risk-aversion, and convex for losses, indicating risk-seeking.

Many researchers have explored the antecedents and moderators of framing effects. Some factors shown to affect framing effects include sex of the decision-maker (Fagley & Miller, 1990), cognitive ability (Stanovich & West, 1998), personal involvement (Levin et al., 1998, p. 160), reflection on and rationale for the decision (Fagley & Miller, 1987; Takemura, 1994), personal knowledge about the risks involved (e.g., Bohm & Lind, 1992; Levin & Chapman, 1990), perceived ambiguity of the values presented in the problem descriptions (Kühberger, 1995), task context (e.g., medical vs. statistical, Bless, Betsch, & Franzen, 1998), and need for cognition (LeBoeuf & Shafir, 2003).

The occurrence and disappearance of valence framing effects are also regulated by various social variables, such as kinship between the decision-maker and the decision recipients at risk and the perceived interdependence between individuals at risk (Wang, 1996a, 2002; Wang, Simons, & Brédart, 2001), degree of caring about the individuals at risk (Bloomfield, Sager, Bartels, & Medin, 2006), and social group size and composition (Shimizu & Udagawa, 2011a, 2011b; Wang, 1996a, 1996b; Zhang & Miao, 2008). Moreover, Sip, Smith, Porcelli, Kar, & Delgad (2015) found that susceptibility to valence framing is modulated by social feedback from a close friend but not a stranger (confederate). This effect was reflected in the activation patterns of ventromedial prefrontal cortex and posterior cingulate cortex regions of the brain.

Wang (2008) developed an ambiguity-ambivalence hypothesis about antecedents of framing effects. The hypothesis assumes that (1) decision cues are selected and used in accordance to their priorities. (2) Primary cues (such as biological and social relationships, social group size, sex, age, health, socioeconomic status, and mating/reproductive cues, etc.) are ecologically and socially more valid predictors of risky outcomes. Secondary cues in decision-making are mainly communicational, such as verbal framing, facial expression, and tone of voice, etc. (3) Inconsistent decision biases, such as framing effects, tend to occur as a result of secondary cue use when primary cues are either absent in risk communication (i.e., an ambiguity condition) or when primary cues elicit conflicting preferences (i.e., an ambivalence condition).

To illustrate the ambiguity-induced framing effect, consider the size of the group at risk. In the original Asian disease problem, the number of people at risk was 600. Throughout human evolutionary history, a typical group is featured by its kinship structure and

by a small size, ranging from several (family or friends) to 100 or so (e.g., a band or tribe). Thus, evolved human psychology should be sensitive to social cues of face-to-face small group living and its kinship-based structure. Once a choice problem was framed in a large anonymous group context, it would result in ambiguities in the decision-maker. To reduce ambiguities in choice preference, the decision-maker would resort to secondary cues available (such as verbal framing of choice outcomes). As a result, the classical framing effect (i.e., the irrational reversal in risk preference) was evident only when the problem was presented in a large, anonymous, and thus ambiguous group context involving 600 lives or more. The framing effect was absent when the size of the endangered group was within a two-digit number, or composed of a small number of family members or friends. In such a kith-and-kin context, the majority of the participants unambiguously preferred the gamble option under both the saving- and losing-lives framing conditions. More recently, Zheng et al. (2010) further examined the brain substrate of the group size effect on risk preference under positive and negative framing conditions. Framing effects were mainly regulated by activation in the rIFG. In contrast, framing effects diminished in small group contexts while the insula and parietal lobe in the right hemisphere were distinctively activated.

The present fMRI study addresses another social variable that regulates the occurrence of framing effects: group composition (Wang et al., 2001). To test how ambiguity and ambivalence in risk preference induce framing effects, Wang et al. (2001) presented a life-death problem involving six individuals in either a homogeneous group or a heterogeneous group context under either positive or negative framing. The group composition included the following five conditions: six kin, three kin, and three anonymous individuals, two kin and four anonymous individuals, one kin and five anonymous individuals, and six anonymous individuals. The second manipulation was the framing of the choice outcomes in terms of either survival or mortality. Using a between-subjects design, participants were assigned to 1 of the 10 (five group compositions by two frames) experimental groups. Each participant responded to only one version of the life-death problem. Based on the ambiguity-ambivalence hypothesis, in a heterogeneous group, a risk-seeking preference ("we-live-or die together") for kin would be incongruent with a less risk-seeking preference for anonymous individuals in a small group. As a result of this ambivalence in risk preference, framing effects would occur. Consistent with this prediction, no framing effects occurred in the homogeneous group situations where

six kin or six anonymous individuals were at stake. The risk preference for kin was more risk-seeking than that for anonymous individuals. The choice pattern in the situation of “three kin and three anonymous individuals” resembled that of the kinship situation, suggesting that the participants treated the group as a kin group. The critical finding concerning the ambivalence hypothesis is that framing effects occurred only in two mixed-group situations, when it was difficult to classify the groups as either a kin group or anonymous/stranger group (i.e., one kin and five anonymous individuals, or two kin and four anonymous individuals).

We view this phenomenon as an ambivalence effect due to incongruent risk attitude elicited by the mixed-group composition. When experiencing conflicting choice preferences, the decision-makers are more likely to resort to other cues such as valence framing of the choice outcomes to settle their ambivalent risk preference. Brain imaging provides a unique way of testing this ambivalence hypothesis of framing effects. We predict that the rIFG and ACC would be implicated in the framing effect occurred in a heterogeneous group context, where a conflict in risk preference is likely to be detected.

The role of the ACC in conflict monitoring has been well documented (for reviews, see Botvinick, Cohen, & Carter, 2004; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). The ACC has been further linked to value-based decision-making (e.g., Botvinick, 2007; Rushworth, Walton, Kennerley, & Bannerman, 2004). Thus, when a conflict in choice preference arises, the ACC would be activated. Once a conflict is well detected and monitored, a final resolution may be reached. We hypothesize that in contrast to homogeneous group contexts, a heterogeneous group context would be more likely to elicit ambivalent and conflicting risk preferences. As a result, valence framing would become more influential, and thus induce framing effects. These behavioral changes would be associated with corresponding changes in the ACC where the activation patterns are expected to be both valence framing-dependent and group composition-dependent.

In sum, we hypothesize that ambiguous social conditions result in ambiguous choice preference. To reduce the ambiguity in choice preference, decision-makers would search for additional information. As a result, they become more sensitive to subtle cues, such as verbal cues of valence framing. We predict that framing effects would be likely to occur in a heterogeneous group context with a mixture of kin and strangers, but would disappear in a homogeneous group context with either all strangers or all kin members. Such social context-dependent framing effects would

be implicated in the three brain regions of interest: the right IFG, the left ACC/vmPFC, and the left amygdala.

Methods

Sample

Twenty-two undergraduate and graduate students (eight males, mean age 21.7 years, SD = 2.1) recruited from universities in Beijing, China, participated in this study. Two participants were excluded from the analyses because of excessive head motion (>2 mm), leaving a total of 20 participants whose data were analyzed. All participants were in good health with no previous history of psychiatric or neurological disease and with normal or corrected to normal vision; and each gave written informed consent.

Experimental design and task

Each participant was presented with 48 pairs of options involving a small group of six hypothetical endangered individuals. Each pair offered a choice between a certain option and a risky option (Figure 2). The probabilities of all live or all die in gamble options across all trials in our study were constant as 1/3 or 2/3, respectively, which was the same as the classic framing effects by Tversky and Kahneman (1981). Half of the choice problems were framed positively, in terms of the number of lives expected to be saved, while half of the problems were framed negatively in terms of the num-

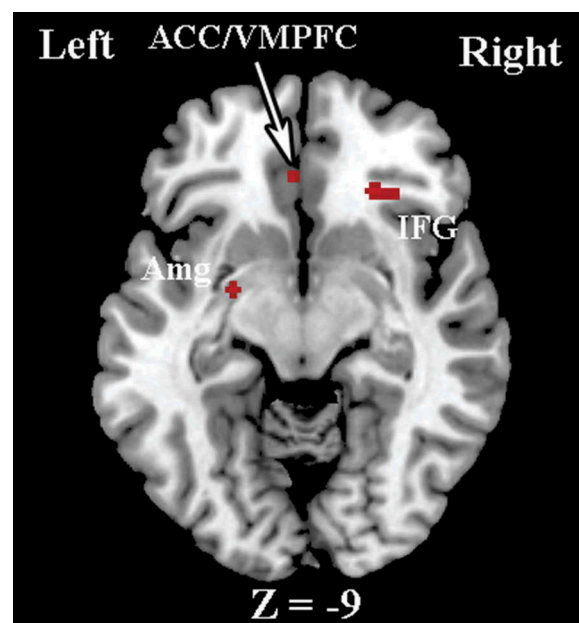


Figure 2. Timeline for a single trial choice task with a life-death problem under positive framing.

ber lives expected to die. These modified Asian disease (life–death) problems were presented in two scenarios: disease infection and terrorist kidnapping (i.e., “6 people have been kidnapped by terrorists and all hostages will die if a rescue was not carried out”). The group composition was manipulated by the number of kin in each endangered group. This number had three different levels (0, 1 or 2, 3 or 6) in a six-person group.

Prior to entering the scanner, the participants took part in a practice version to minimize learning effects during the actual scanning and to enable them to fully understand the paradigm. The scanning phase lasted about 9 min. The choice problems were presented randomly. The timeline for a single trial is presented in Figure 2. On each trial, after a 6 s presentation of the scenario instruction, participants were presented with the two options and asked to make their decision by pressing one of the two buttons corresponding to the location of the options on the screen within 6 s. After this decision phase, there was a variable fixation period (2, 4, or 6 s) before the next trial began (Figure 2). The relative position of the sure option and the gamble option appearing on the left or right side of the screen was counterbalanced. At the end of the experiment, each participant received 50 RMB (about \$7) for participation.

Acquisition of fMRI data

Magnetic images sensitized to changes in blood-oxygen-level dependent (BOLD) signals were obtained by an echo planar imaging sequence (repetition time = 2000 ms; echo time = 30 ms; flip angle = 90°, matrix = 64 × 64; field of view = 200 × 200 mm²; slice thickness = 4 mm; slice gap = 0 mm) on a 3.0-Tesla Siemens magnetic scanner (Siemens, Erlangen, Germany). Each brain volume was composed of 30 axial sections. Stimuli were presented using E-prime software (Psychology Software Tools, Pittsburgh, PA) on a personal computer, back-projected onto a screen using a liquid crystal display projector and viewed by the participants through a mirror mounted on the MRI head coil.

Preprocessing of the fMRI data

Data preprocessing and analyses were conducted with the Statistical Parametric Mapping 8 (SPM8) software (<http://www.fil.ion.ucl.ac.uk/spm>) running under MATLAB 7.10 (The MathWorks, Inc, Natick, Massachusetts). Functional images were slice time-corrected to the onset of the middle slice and spatially realigned using a six-parameter affine transformation. Based on a visual

inspection of the motion correction estimates, two participants who had more than 2-mm maximum displacement in any of the x, y, or z directions or more than 2° of angular rotation about any axis were excluded from this study. The realigned images were spatially normalized to the standard EPI template, resampled to 3 mm × 3 mm × 3 mm and subsequently smoothed with a Gaussian kernel of 8 mm full-width at half-maximum. Motion parameters were stored and used as nuisance variables in the following analysis. A high-pass filter with a cutoff period of 128 s was used to remove low-frequency noise.

Data analysis and statistics

Behavioral data analyses and statistics

Behavioral data was analyzed using the chi-square test. Statistical significance was determined by $p \leq 0.05$.

Neuroimaging data analyses and statistics

Event-related analysis was performed by using a general linear model (GLM). Events were modeled at the time when the choice options were presented in each trial with a duration of 6 s. Null events were not explicitly modeled, and therefore constituted an implicit baseline. In the first-level analysis, a 3 (kin number: 0 vs. 1–2 vs. 3–6) × 2 (frame: positive vs. negative) design was used to characterize the activity pattern in each condition. First-level contrasts were performed for each experimental condition of the aforementioned factorial design, where the scenario presentation was included as nuisance events. Second-level random effect analysis was performed using a two-way ANOVA on these contrasts, with frame and the number of kin in each group in the scenario as the within-subject factors.

To assess the significance of differences in regional activity, we performed ROI analyses based on the results of our meta-analysis. In particular, ROIs were defined in the ACC/vmPFC, left amygdala, and the right IFG, to test the hypothesis that activity within these regions would depend on the frame and group composition as measured by the number of kin in each hypothetical six-person group. The scope of each ROI was defined by two 6-mm radius spheres around the activation peaks as listed in Table 2. Given that we were interested in three precisely and narrowly defined regions with a strong a priori hypothesis based on the ALE meta-analysis, small volume correction (SVC) was performed on the resulting statistical parametric maps using the three identified ROIs to prevent errors of multiple comparisons. All results were significant at $p < 0.05$, family-wise error corrected (FWE) for small

volumes (see Worsley et al., 1996; for more detailed statistical procedures).

To facilitate the generation of future hypotheses, we also report data for activation clusters that fell outside of the three identified ROIs. Clusters of activation falling outside of the a priori hypothesized ROIs were statistically corrected for multiple comparisons across the entire brain by performing Monte Carlo simulations with the following parameters: individual voxel p -value = 0.005, 1000 simulations, and cluster connection radius $r = 5$ mm, with a gray mask of 55,342 voxels. These analyses were conducted using the AlphaSim program in the REST 1.8 software (<http://www.restfmri.net>). According to the simulations, a corrected significance level of $p < 0.05$ could be obtained with an individual voxel height threshold of $p < 0.005$ and a cluster size dependent on the simulation to each statistical map.

Results and discussion

Behavioral results

As found in the previous study (Wang et al., 2001; Zheng et al., 2010), the significant framing effects were found in both the one-kin condition and the two-kin condition, with no significant differences between these two conditions. In contrast, no framing effect was found in either the three-kin condition or the six-kin condition; and the choice patterns in both conditions were equally risk-seeking. As such, the data in the one-kin and the two-kin conditions were combined as a heterogeneous group condition. The data in the

three-kin and the six-kin conditions were combined as a kinship condition.

Table 2 illustrates the behavioral results. As predicted, the chi-square test revealed a significant framing effect only in two of the heterogeneous group contexts, with one or two kin in the group ($\chi^2 = 5.013$, $p = 0.025$, $\Phi = 0.125$). The choices were overall more risk-averse (53% chose the sure option) under positive framing; but it was reversed under negative framing, where the majority of the choices were risk-seeking (59% chose the gamble option). In contrast, no framing effect on risk preference was found in the non-kin condition ($\chi^2 = 2.400$, $p = 0.121$, $\Phi = 0.087$) or in the 3–6-kin condition ($\chi^2 = 0.025$, $p = 0.873$, $\Phi = 0.009$).

Second, we examined whether risk preference in the anonymous condition was different from the kinship condition. Although choice preferences were both risk-seeking, the two were significantly different in the degree of risk-seeking: Across the framing conditions, the percentage of risk-seeking choices was 75% in the non-kin condition and 89% in the kinship (3–6 kin) condition ($\chi^2 = 25.52$, $p < 0.001$, $\Phi = 0.283$). This difference suggests a potential conflict in risk attitude toward kin vs. strangers, which was further examined in the next analyses of the neuroimaging data.

Neuroimaging results

The ANOVA results revealed that the ACC/vmPFC (BA 24) showed greater activity in the positive frame condition than in the negative frame condition ($p < 0.05$, FWE SVC) (see Figure 3). This result, a relatively higher activity under positive framing while the engagement

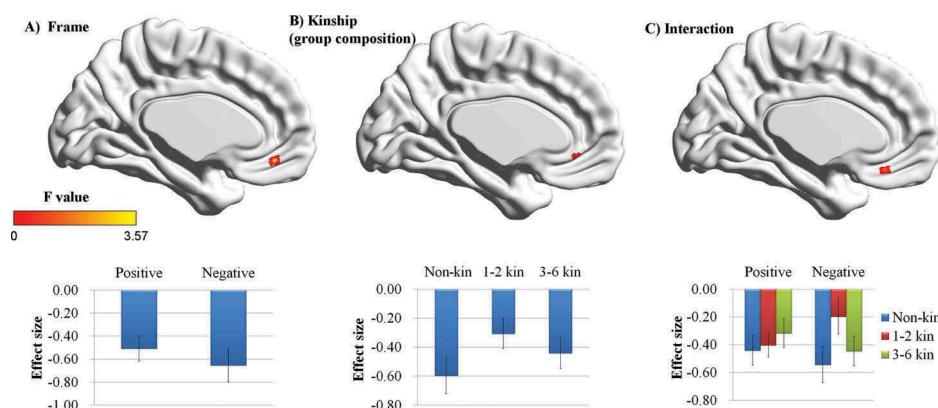


Figure 3. ACC/vmPFC deactivation by valence framing, kinship between the participant and endangered group members in decision scenarios, and the frame–kinship interaction.

(A) Main effect of frame.

(B) Main effect of kinship.

(C) Interaction effect of frame and kinship on the ACC/vmPFC activity.

Error bar denotes the standard error.

in the risky choice task overall deactivated the ACC/vmPFC, is consistent with previous findings. For example, Xue et al. (2009) found that when making risky choices, the extent of de-activation in the vmPFC, including part of ACC, was gain-loss-specific, with a relatively higher activity in gains than in losses.

The main effect of kinship was also significant in ACC/vmPFC activity ($p < 0.05$, FWE SVC). The relative activity of the ACC/vmPFC was greater in the 1–2-kin condition than in the non-kin and the 3–6-kin conditions ($p < 0.05$, FWE SVC), with no significant difference between the non-kin and the 3–6-kin conditions. This result is consistent with the prediction that heterogeneous group contexts elicit incongruent and ambivalent risk preferences and activate the ACC detection mechanism.

As shown in Figure 3, although the relative activation was higher in the 1–2-kin heterogeneous group contexts, the life–death choice scenarios overall reduced ACC/vmPFC activity. As a major structure in the brains' default network which is preferentially active when individuals are not focused on the external environment (Buckner, Andrews-Hanna, & Schacter, 2008), deactivation of vmPFC is implicated in the process of task-related cues. Thus, the observed overall deactivation in the ACC/vmPFC region in our study indicates task engagement; and the relative activation or less deactivation at the ACC/vmPFC indicates reduced engagement in ambiguous social contexts (i.e., heterogeneous groups). The differential deactivation pattern found in the ACC/vmPFC suggests that the participants were more engaged in the more homogenous conditions than heterogeneous conditions. This argument is also consistent with the behavioral results showing that the risk preference in both the stranger and kinship situations was stronger than in the mixed-group situations (see Table 3, and also Wang, 2002).

The participants with ambiguous and ambivalent risk preferences in the heterogeneous conditions became

more susceptible to verbal cues of valence framing. Negative framing resulted in more ACC deactivation than the positive framing in such ambiguous conditions, whereas framing had no effect on ACC activation levels when the same choice problems were presented in a less ambiguous, homogeneous group context.

There was a significant interaction between group composition and frame on ACC/vmPFC activity ($p < 0.05$, FWE SVC). *Post hoc* analyses revealed that the ACC/vmPFC activity in the negative frame was greater in the 1–2-kin condition than in the 3–6-kin condition ($p = 0.027$) and marginally greater than that in the non-kin condition ($p = 0.058$).

To further examine whether the ACC/vmPFC activity was involved in the modulation of the framing effect by group composition, a correlation was conducted between the behavioral contrast [i.e., the percentage of risky choice in the negative frame in the 1–2 kin group context – the percentage of risky choice in the positive frame in the 1–2 kin group context – (the percentage of risky choice in the negative frame in the 3–6 kin group context – the percentage of risky choice in the positive frame in the 3–6 kin group context + the percentage of risky choice in the negative frame in the non-kin group context – the percentage of risky choice in the positive frame in the non-kin group context)/2] and the corresponding fMRI contrast $[(1-2\text{kin_Negative}_{\text{gamble}} - 1-2\text{kin_Positive}_{\text{gamble}}) - (3-6\text{kin_Negative}_{\text{gamble}} - 3-6\text{kin_Positive}_{\text{gamble}} + \text{non-kin_Negative}_{\text{gamble}} - \text{non-kin_Positive}_{\text{gamble}})/2]$. The result showed a significant positive correlation ($r = 0.440$, $p = 0.05$). This behavioral-neural correlation suggests that the interaction between frame and group composition contributes to the group context-dependent framing effect via differential activations in the ACC/vmPFC region in the brain.

Our ROI analysis on the left amygdala activity also revealed significant effects. A one-way ANOVA revealed that the left amygdala activity was sensitive to group composition manipulated by kinship between the participant and the endangered group members in the decision scenarios ($p < 0.05$, FWE SVC). The relative activity of the left amygdala was the highest in the 1–2 kin heterogeneous group condition. As Figure 4 illustrates, the activity of the left amygdala in the non-kin (anonymous) condition was lower than that in the 1–2-kin condition and the 3–6-kin condition ($p < 0.05$, FWE SVC).

No significant frame-dependent effect was found on the activity of the rIFG (BA 47) in the present, more focused ROI analysis. However, the activity of a broader cortical scope containing the rIFG was found to be frame-dependent. The whole-brain analysis as reported

Table 3. Choice frequencies (percentages) under different framing and group composition conditions.

Group Composition	Frame	Sure	Gamble	Framing Effect
0	Positive	46 (28.8%)	114 (71.3%)	No
	Negative	34 (21.3%)	126 (78.8%)	
1–2	Positive	86 (53.8%)	74 (46.3%)	Yes
	Negative	66 (41.3%)	94 (58.8%)	
3–6	Positive	17 (10.7%)	142 (89.3%)	No
	Negative	18 (11.3%)	142 (88.8%)	

The total number of choices was 160 (20 participants \times 8 life–death problems). The numbers 0, 1–2, 3–6 indicate that the number of kin in a 6-person group was zero, one or two, or three or six, respectively. There was one missing datum point in the 3–6 condition under positive framing.

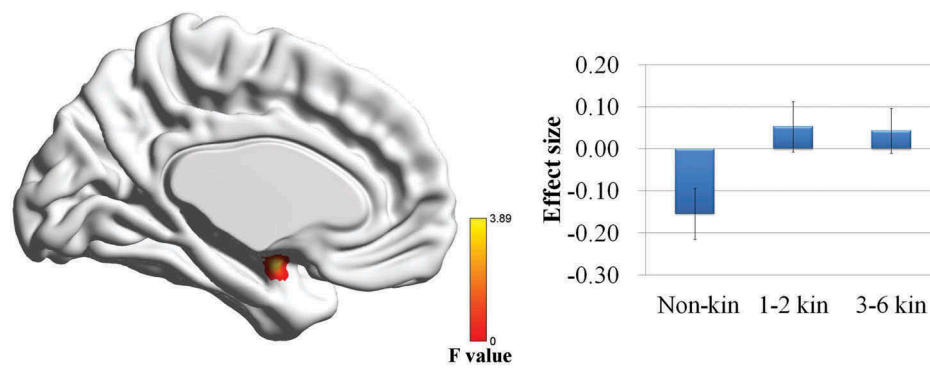


Figure 4. Left amygdala activity regulated by kinship between the participant and endangered group members in decision scenarios. Error bar denotes the standard error.

Table 4. A whole-brain analysis of activation clusters for frame- and group composition-related contrasts.

Cluster size	Region	BAs	Peak <i>T</i> -value	Peak MNI coordinates
Frame: positive < negative				
407	Right middle/inferior frontal gyrus	9/46	4.47	48 27 30
370	Left inferior parietal lobule	40	4.27	-42-48 45
339	Left middle frontal gyrus	9	4.14	-42 9 36
Anonymous > 1-2 kin				
3870	Bilateral middle occipital gyrus	7/17/18/19/37	9.86	12-99 12
731	Left middle/inferior frontal gyrus	6/9	5.76	-45 3 33
596	Right middle/inferior frontal gyrus	6/9/46	5.10	48 9 24
Anonymous < 1-2 kin				
578	Posterior cingulate cortex	5/6/7/24/31	4.78	-3-33 45
254	Left angular gyrus	19/39/40	4.31	-45-78 39
341	Right inferior parietal lobule	22/39/40	3.61	57-69 30
Anonymous > 3-6 kin				
3534	Bilateral middle occipital gyrus	7/17/18/19/37	10.22	12-96 12
641	Left middle frontal gyrus	6/8/9	5.54	-36-3 51
519	Right middle/inferior frontal gyrus	6/9/46	4.94	39 0 33
Anonymous < 3-6 kin				
637	Middle/posterior cingulate cortex	5/6/7/24/31	4.70	6-33 51
321	Left angular gyrus	19/39/40	4.55	-45-78 39
1-2 kin vs 3-6 kin				
None				
Frame × Kin				
None				

Anonymous denotes six anonymous individuals at risk in the life-death problem. 1-2 kin denotes one kin and five anonymous individuals or two kin and four anonymous individuals at risk. 3-6 kin denotes three kin and three anonymous individuals or six kin at risk.

below (see Table 4) revealed that activation of the right middle/inferior frontal gyrus was greater under the negative framing than under the positive framing.

To report unbiased results for non-hypothesized regions beyond the three ROIs discussed above and to provide data that might reveal additional brain regions underlying framing effects, we also conducted a whole-brain SPM analysis with the voxel-wise height threshold set for $p < 0.005$ and whole-brain correction for multiple comparisons at $p < 0.05$.

Table 4 summarizes the regions of activation surviving the above correction. The right middle/inferior frontal gyrus (BA 9/46), left middle frontal gyrus (BA 9), and the left inferior parietal lobule (BA 40) showed greater activity in the negative frame than in positive frame.

The bilateral middle occipital gyrus and the bilateral middle/inferior frontal gyrus showed greater activity in the anonymous condition than in the 1-2-kin and in the 3-6-kin conditions. The posterior cingulate cortex, left angular gyrus, and the right inferior parietal lobule showed a greater activity in the heterogeneous 1-2-kin condition than in the anonymous condition. A similar result was found in the contrast between the 3-6-kinship condition and the anonymous condition.

From the whole-brain analysis, three more brain regions were implicated in framing effects. Together with the two framing effect-related ROIs (i.e., left ACC/vmPFC, and left amygdala), we added the coordinates of three new foci (i.e., right middle/inferior frontal gyrus, left middle frontal gyrus, and left inferior parietal

lobule) into an updated ALE meta-analysis. The brain localization results for framing effects based on the 32 foci remain the same.

General discussion and conclusions

Based on the ambiguity–ambivalence hypothesis (Wang, 2008), framing effects tend to occur as a result of ambiguity in decision cues or/and ambivalence in choice preference caused by conflicting desires and incongruent preferences. Consistent with previous findings (Wang et al., 2001), the framing effect was absent in homogeneous small group contexts with either kin members or anonymous individuals. However, the framing effect appeared in the social contexts of small heterogeneous groups which consisted of both anonymous individuals and kin members. To further test if the occurrence of the framing effect in the heterogeneous group contexts was a result of ambivalent choice preference caused by different degrees of risk-seeking toward kin members vs. anonymous individuals, we conducted ROI analyses with neuroimaging data, based on the results of the ALE meta-analysis.

The three brain regions derived from the meta-analysis play different roles in regulating social context-sensitive framing effects. First, in previous research, the rIFG was frame-sensitive in that risk-averse choices were associated with greater rIFG activation under positive framing whereas risk-seeking choices were associated with greater rIFG activation under negative framing (Zheng et al., 2010). The rIFG is also involved in response selection (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003). It is interesting to note that the rIFG contains the homologue of the Broca's area and is implicated in automatic and affect-laden speeches (Van Lancker, 1997; Van Lancker & Cummings, 1999). Together, these findings suggest that the rIFG plays a pivotal role in implicit and automatic linguistic processing of valence framing of choice options, which is both semantic and hedonic. Consistent with this view, our fMRI results showed a frame-related main effect for rIFG in the whole-brain analysis (see Table 4). The activation of the right middle/inferior frontal gyrus under the negative framing was greater than that under the positive framing (see Table 4).

Second, the ACC activity was thought to reduce framing effects, because ACC activation was greater when participants' monetary choices were incongruent with framing effects (De Martino, Kumaran, Seymour, & Dolan, 2006). This effect of the ACC may be mediated by other brain structures. Roiser et al. (2009) found that participants who were less susceptible to the frame had a greater coupling between the ACC and the amygdala.

A similar mediating role might be attributed to the orbital and medial prefrontal cortex (OMPFC), with which the ACC has strong reciprocal connectivity (Kringelbach & Rolls, 2004). Greater activity in these regions predicted a reduced susceptibility to monetary framing effects (De Martino et al., 2006). In addition to monetary choices, the ACC/vmPFC activity was implicated in the framing effect in social contexts in the present study.

As predicted from the ambiguity–ambivalence hypothesis, mixed membership in the heterogeneous group situations would likely make choice preference of the decision-maker ambiguous or ambivalent. To reduce the ambiguity and make a choice, the decision-maker would search for additional information and become more sensitive to subtle differences in verbal framing of the choice outcomes. Consistent with the above hypothesis, the framing effects were observed only in the heterogeneous group situations. Furthermore, a higher relative ACC activation (or less deactivation) was most significant in the heterogeneous group condition. Brain activation in the ACC was also modulated by framing in the ambiguous heterogeneous group condition. These results suggest that the ACC serves as a neural substrate responsible for reducing ambiguity in decision-making and for the observed social context-dependent framing effects.

In addition, the involvement of the vmPFC is consistent with the view that the hedonic tone of valence framing can be used to settle indecisive risk preferences (Wang, 2004) and indicates the role of the vmPFC in using emotions to aid in decision-making (e.g., Naqvi, Shiv, & Bechara, 2006).

Third, the amygdala plays a critical role in encoding valence framing (De Martino et al., 2006; Roiser et al., 2009) and in experiencing emotions (Domschke & Dannlowski, 2010). In response to the valence of verbal framing, the amygdala may regulate approach and avoidance behavior (Aupperle & Paulus, 2010). As a result, the decision-maker would be more likely to be risk-averse to secure a gain under positive framing and to be risk-seeking to avoid a loss under negative framing (Kahneman & Frederick, 2007). In the present study, the amygdala was sensitive to group composition but insensitive to framing, showing greater activation in the kinship context than in the anonymous context. Amygdala activation likely contributed to the overall risk-seeking choices.

In sum, we examined the neural substrates of framing effects in social contexts. By adopting a meta-analytic approach to identify key brain regions underlying valence framing effects, we were able to target three

specific ROIs in analysis. Coupled with the behavioral results, our neuroimaging data suggest that decision biases, including framing effects, are more likely to occur in heterogeneous social group contexts than homogeneous group contexts. While the right middle/inferior frontal gyrus was sensitive to valence framing, the amygdala encoded the difference in social group composition. In the face of ambivalent and conflicting risk preferences, the ACC/vmPFC became less deactivated, indicating reduced task engagement (Buckner et al., 2008), and more sensitive to verbal cues of valence framing in an attempt to resolve ambiguity and/or ambivalence in choice preference and reach a final decision.

Disclosure statement

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