

Framing effects: Behavioral dynamics and neural basis

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ABSTRACT

This study examined the neural basis of framing effects using life-death decision problems framed either positively in terms of lives saved or negatively in terms of lives lost in large group and small group contexts. Using functional MRI we found differential brain activations to the verbal and social cues embedded in the choice problems. In large group contexts, framing effects were significant where participants were more risk seeking under the negative (loss) framing than under the positive (gain) framing. This behavioral difference in risk preference was mainly regulated by the activation in the right inferior frontal gyrus, including the homologue of the Broca's area. In contrast, framing effects diminished in small group contexts while the insula and parietal lobe in the right hemisphere were distinctively activated, suggesting an important role of emotion in switching choice preference from an indecisive mode to a more consistent risk-taking inclination, governed by a kith-and-kin decision rationality.

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1. Introduction

Framing effect, one of cognitive biases, shows that presenting the same option in different ways (e.g. loss vs. gain) can reverse people's risk preference (Kühberger, 1998; Levin, Schneider, & Gaeth, 1998). A widely cited example of decision bias and human irrationality is a framing effect, first demonstrated by Tversky and Kahneman (1981) using the "Asian disease problem". In the cover story of the problem, the participants 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 programs were then framed (phrased) differently. In the "positive framing" the participants 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". Given a binary choice between the two alternative plans, the majority of the participants (72%) were risk averse, preferring the sure option (Plan A) over its risky 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 participants (78%) were risk taking. They favored the gamble over the sure option.

Wang (2008) proposed an Ambiguity and Ambivalence (AA) hypothesis of framing effects with the main assumptions as follows: (1) decision cues are selected and used in accordance to their priorities; (2) cue priority reflects evolutionary and ecological validity of a cue in predicting specific risks; (3) primary cues in risk communication carry evolutionary, ecological, social significance and anchor risk preference, while secondary cues of verbal communication fine-tune the risk preference of the decision maker. Accordingly, inconsistent decision biases, including framing effects tend to occur as a result of secondary cue use when primary cues are absent in risk communication (i.e., an ambiguity condition) or when primary cues elicit conflicting preferences (i.e., an ambivalence condition). An ambiguity effect may occur when the social context of a risk problem is evolutionarily novel and thus has low ecological validity. This lack of ecologically valid cues in decision context would result in ambiguity in risk preference, which in turn causes inconsistency and biases in risk choice.

The size of a social group in the Asian disease problem may serve as a useful and parsimonious cue of structural and relational features of the group. We argue that human computational strategies are governed by a "kith-and-kin" (friendship-and-kinship) rationality, which has an inherent preference for cooperation and joint-venture with kin and friends and distinguishes "we groups"

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from “they groups” (e.g., Tajfel, Billig, Bundy, & Flament, 1971; Wang, 2008). A “kith-and-kin” rationality would process a collection of individuals in social situations as a “we group” based on group cues such as group size. An evolutionary typical “we group” is featured by both kith-and-kin relationship and a small size ranging from several (family or friends) to 100 or so (e.g., a band or tribe).

In our long evolutionary history, humans mainly lived in small groups (Cosmides & Tooby, 2000; Knauff, 1991; Lee & DeVore, 1968). Caporael, Dawes, Orbell, and van de Kragt (1989) have argued that small groups, as a basic form of social structure in hominid evolution, would have given rise to selected mental adaptations, favoring emotional and cognitive mechanisms that worked well in small group living. The size of a group prompts the closeness between the members and their degree of interdependence for completing a task. As Olson (1965) argued, “the larger a group is, the farther it will fall short of providing an optimal supply of any collective good ... in short, the larger the group, the less it will further common interests” (p. 65). It is true that some large groups consist of interdependent members and some small groups of independent members. But on average, the smaller (kith-and-kin) groups consist of closely related members. A loss of 2/3 of a large group may not be fatal, but a 2/3 loss of a 6 member family may result in functional death of the group (i.e., a failure to continue functioning as a group).

Due to a higher interdependence among the members, small group living promotes a “we all live-or-die together” risk attitude. For instance, if a three-person team is working on a construction project, the performance of each member will be highly dependent upon the others. Losing even one member would jeopardize and disable the rest of the members and the entire project. Thus, given a life-death problem, the respondents would be more willing to take risks to save all under both framing conditions. However, once a choice problem is presented in a large, anonymous group context, the respondents would be more likely to resort to secondary (verbal and communicational) cues and become more variable.

In a series of studies (Wang, 1996a, 1996b; Wang, Simons & Brédart, 2001), the authors examined the appearance and disappearance of framing effects when the size of the group (the total number of lives at stake) was systematically manipulated. The same life-death problem was framed either in terms of lives saved or in terms of lives lost. The framing effect was evident, but it occurred 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 (<100), and the majority of the participants unambiguously preferred the gamble option under both the saving- and losing-lives framing conditions. This group size effect is unlikely a result of difference in numerical magnitude (e.g., 6 vs. 600) involved in decision calculation. Wang (1996a) demonstrated that framing effects occur in large groups of 6000 as well as 600 people, and disappear in small groups of 60 as well as 6 people. The tenfold difference between the two large groups and between the two small groups does not make a difference in choice preference. Further evidence comes from the Wang et al. (2001) study, where typical framing effect occurs in the context of 6 billion human lives but disappears in the context of 6 billion ET (extraterrestrials) lives at stake. Thus, framing effect is not a large number effect, but is human group size-sensitive. Such findings are in sharp contrast to predictions from normative models of expected utility theory. That is, formally identical life-death questions would yield the same choice preference. According to the independence axiom of expected utility theory (Savage, 1954), if one prefers the sure option of $1/3U(6)$ to the gamble of $U(1/3*6 + 2/3*0)$, the person should also prefer $1/3U(600)$ to $U(1/3*600 + 2/3*0)$. Note that the second pair of options can be reduced to the first pair by multi-

plying a common ratio of 1/100. Thus, the normative model would predict no group size effects.

In sum, these previous findings suggest that the small size of a social group signals a higher interdependence between group members and evokes a kith-and-kin rationality that guides a live-or-die together risk preference. The group size effects consist of two components: (1) people become more risk seeking; and (2) framing effects disappear when the structurally identical life-death problems are presented in small group contexts instead of in large anonymous group contexts. In contrast, risk preference of a decision maker becomes erratic when prioritized group cues are absent in a large anonymous group context. When risk preference is ambiguous, secondary cues such as verbal framing is used to direct choices.

A considerable number of studies in both cognitive and social psychology have shown that our cognitive processes are frequently influenced by our sense of group membership (e.g., Brewer, 1979; Tajfel, 1981). Findings from animal studies also suggest that group size shapes social behavior and small group contexts elicit stronger social emotions (Brosnan, Schiff, & de Waal, 2005; Estevez, Keeling, & Newberry, 2003; Pagel & Dawkins, 1997). Brosnan et al. (2005) found that chimpanzees housed in pairs show a strong response to inequity whereas those from a long-standing large social group are more tolerant to inequity. Similarly, increasing aggression with decreasing group size was found in domestic fowl (Estevez et al., 2003; Pagel & Dawkins, 1997).

Recent developments in evolutionary psychology and neuroscience shed light onto brain mechanisms implementing a kith-and-kin rationality. Stone (2007) argues that cognitive algorithms possess evolutionary design features that allow automatic and rapid reactions to valid social cues. Lieberman and colleagues (Lieberman, Oum, & Kurzban, 2008; Lieberman, Tooby, & Cosmides, 2007) have shown specific cognitive mechanisms for kinship detection and for incest avoidance that is sensitive to group size cues. Platek and Krill (2009) have shown some neural evidence of kin detection which should be an important component of kith-and-kin rationality, particularly in a life-or-death situation. Krill and Platek (2009) in an fMRI study found that a specific brain area, the anterior cingulate cortex is sensitive to changes in group membership.

So far, we know little about neural mechanisms underlying aforementioned dynamics of framing effects. A recent fMRI study of framing effects by De Martino, Kumaran, Seymour, and Dolan (2006) using monetary gambles, reported that the framing effect was specifically associated with amygdala activity suggesting a key role for an emotional system in mediating decision biases. Moreover, across individuals, orbital and medial prefrontal cortex activity predicted a reduced susceptibility to the framing effect.

In the above study, a “rational index” was used to measure participant’s susceptibility to framing effects. The index was calculated in terms of the difference between the proportions of trials in which a given subject chose the gamble option in the loss frame, as compared to the gain frame, under the assumption that insusceptibility to framing manipulation is an index of rational thinking. De Martino and colleagues found that this index was positively correlated with the activity in the orbital and medial prefrontal cortex and concluded that more rational subjects exhibited greater activation in OMPFC.

Implied in the above study was a hypothesis that framing effects as an irrational decision bias are affect-ridden but controlled and reduced by a cognitive and rational system located in the prefrontal cortex. However, based on the AA hypothesis of framing effects, verbal framing as secondary cues are likely attended and processed by the prefrontal cortex when the choice preference of the decision making is ambiguous (e.g., in a large anonymous group context). In contrast, affect-ridden brain areas are more likely to be acti-

vated by primary cues such as small or kinship group contexts and thus reduce framing effects. The present fMRI study was designed to further examine the interplay between emotion-related brain regions and the prefrontal structures in regulating the presence and absence of framing effects. In particular, we predict that different brain areas are involved in wax and wane of framing effects. Frontal cortices are predicted to be more active when framing effects are present in large group contexts whereas affective processing brain regions in the limbic system, such as the insula or amygdala, are predicted to be more active when framing effects are absent in small group contexts.

Several key differences between the present fMRI study and the De Martino et al. (2006) study of framing effects are worth mentioning. First, the choice problems used in our study were life-death problems similar to the Asian disease problem instead of monetary gambles.

Second, in the study by De Martino et al. (2006), framing effect analysis was based on the contrast between the choices in accordance with the framing effect and the choices against the framing effect. Such analysis may be improper if other factors other than verbal framing could also result in similar changes in risk preference. For instance, in some social contexts such as in small group contexts people tend to choose the gamble option in both the positive and negative frames (e.g., Wang, 1996a, 1996b, 2008; Wang et al., 2001). In addition, this analysis may be improper considering the possibility that a brain activation pattern may be evident even before a behavioral manifestation was observed. In other words, the brain activation pattern of a participant in the positive framing condition may be different from that in the negative framing condition although his or her risk preference did not reverse in the two particular framing conditions. To avoid these potential problems, we adopted a widely accepted practice in studies of framing effects to directly compare data collected in the positive framing condition with data in the negative framing condition (Gonzalez, Dana, Koshino, & Just, 2005; Windmann et al., 2006).

Third, in the study by De Martino et al. (2006), the sure option in each choice set was presented in words while the gamble option was presented using a pie chart. To reduce possible noise due to the use of different presentation formats, we presented both the sure option and the gamble option in words in each choice task. Since the framing effect at issue is mainly a result of verbal manipulation (framing or phrasing), verbal format is more likely to elicit the effect.

2. Methods

2.1. Participants

Twenty-two healthy right-handed [screened using the Edinburgh Handedness Inventory (Oldfield, 1971)] Chinese college students volunteered to participate in this experiment. The participants include 8 males and 14 females with the mean age of 21.7 years (ranged from 18 to 27 years, $SD=2.1$ years). None of the participants had a history of neurological disorders, surgery, or serious physical illness. Written informed consent was obtained from all participants after a detailed explanation of the study. The study protocol was approved by the ethics committee of Beijing Normal University, China.

2.2. Stimuli and experimental design

The experiment was divided into three parts: an instruction phase, a scanning phase during which participants performed the task, and the debriefing phase. In the instruction phase, the participants were familiarized with the framing tasks, and performed a number of practice trials on a laptop computer.

In the scanning phase, the participants completed 32 trials [16 large group size problems (600 endangered people); 16 small group size problems (6 endangered people)] Half of the choice problems were framed positively in terms of the expected number of lives saved while half of the problems were framed negatively in terms of the expected number lives lost. These modified Asian disease (life-death) problems were presented in two scenarios: disease infection and terrorist kidnapping (i.e., "600/6 people have been kidnapped by terrorists and all hostages will die if rescue were not carried out") with four repetitions. So the 32 trials included 2 framing ver-

Table 1
Group size dependent framing effects.

Frame	Group size	Sure	Gamble	Framing effect
Positive	600	85 (48%)	91 (52%)	Yes $p=0.013$
Negative	600	62 (35%)	114 (65%)	
Positive	6	49 (28%)	127 (72%)	No
Negative	6	34 (19%)	142 (81%)	

Note: The total number of choices was 176 (22 participants \times 8 life-death problems).

sions \times 2 group size contexts \times 2 scenarios of the life-death problem \times 4 repetitions. 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).

The scanning phase lasted about 9 min. The choice problems were presented randomly. The timeline for a single trial is presented in Fig. 1. In each trial, the relative position of the sure or gamble options appearing on the left or right side of the slide was counterbalanced.

In the debriefing phase, the participants were asked how they felt about the experiment. The feedback indicated that all the participants had no problem understanding the choice questions or indicating their choice within the 6 s duration when each choice slide was displayed. Each participant received 50 RMB (about US\$ 7.3) for participation.

2.3. Image acquisition

The scanning was performed on a 3T fMRI scanner (Siemens Magnetom Trio with TIM) in the National Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University. Functional images were acquired using T2*-weighted echo-planar imaging sequence (TR=2000 ms, TE=30 ms, flip angle=90°, FOV=200 mm \times 200 mm, matrix=64 \times 64, number of slices for a whole brain=30, slice-thickness=4 mm, gap=0 mm, resolution=3.1 mm \times 3.1 mm \times 4.0 mm). T1-weighted anatomy images were acquired using SPGR sequence (TR=2530 ms, TE=3.39 ms, flip angle=7°, Matrix=256 \times 256, number of slices for a whole brain=128, slice-thickness=1.33 mm, Resolution=1.00 mm \times 1.00 mm \times 1.33 mm). Participants' heads were immobilized during the scanning sessions using a vacuum pillow.

2.4. Data analysis

The imaging data were preprocessed and analyzed using SPM5 (Wellcome Department of Cognitive Neurology, London). Image processing included: slice scan time correction, head motion correction, spatial normalization to Montreal Neurological Institute (MNI) space, and smoothing with an 8-mm full-width-at-half-maximum Gaussian kernel. Events were modeled with a general linear model time-locked with the onset of the options of modified Asian disease problems. A general linear model was used to construct the multiple time series regression design matrix. The image data were modeled using a canonical hemodynamic response function (HRF). The time derivatives and head motion parameters were included to account for extra variance in case the onsets were off by a little and to capture residual movement related artifacts respectively.

Subject-level analyses were conducted by setting up contrasts between choices in positive frames and choices in negative frames, irrespective of the choice of the sure or gamble option. Then random effect analyses of the group were conducted using the contrast images generated from each participant. Areas of significant activation were identified at a threshold of uncorrected p value of 0.001 (cluster threshold of 5 voxels). For region of interests (ROI) analysis, we calculated the percent signal change in the regions of interests defined as 6-mm spheres around the peak voxel of specific activated brain areas identified in the comparison between the two framing conditions in random effect analysis. The percent signal changes were calculated using MarsBaR 0.42 (<http://marsbar.sourceforge.net>).

3. Results

3.1. Behavioral results

As shown in Table 1, the overall choice data showed that framing effects appeared in large group contexts ($\chi^2(1)=6.179$, $p=0.013$) but diminished in small group contexts with an overall risk-seeking preference in both positive and negative framing conditions ($\chi^2(1)=3.547$, $p=0.060$). In large group contexts, the participants were more risk seeking (preferring the gamble option) under the negative framing (65%) than under the positive framing (52%). The overall choice preference under the positive framing was close to a 50–50 split between the sure option and gamble option,

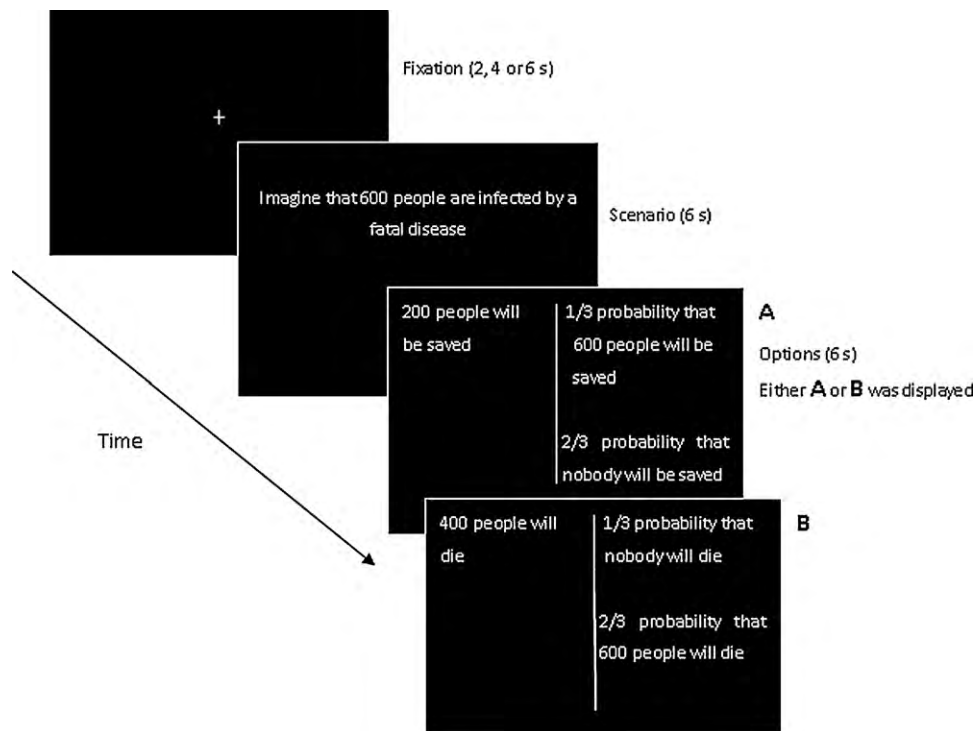


Fig. 1. Timeline for a single trial of life-death framing problems. The trial began with a cross '+' presented for 2 or 4 or 6 s randomly. Then a modified Asian disease problem was presented for 6 s. At the end of each trial, sure and gamble options under either the positive frame (A) or the negative frame (B) were presented for 6 s, during which the participant indicated his or her choice by pressing either the left or the right button of the response box corresponding to the relative position of the preferred option (either the sure thing or the gamble) on the screen.

and thus was not risk averse. This might be related to a cultural difference where in Chinese samples framing effects become more evident when the group size is even larger than 600 (see Wang, 1996a, 1996b).

3.2. fMRI results

The fMRI results indicated that in large group contexts, choice outcomes phrased in the positive frame elicited greater activation in the opercula part of the right inferior frontal cortex, which contains the homologue of the Broca's area compared with the brain activation induced by the same problems framed negatively [see Fig. 2(b)]. As predicted, different brain areas were involved in the presence and absence of framing effects. In contrast, when life-death problems were presented in a small group (6 people) context, greater activations in insula and parietal lobe were found when subtracting brain activation under the negative framing from that under the positive framing [see Table 2 and Fig. 2(c)]. As shown in Fig. 2(c) and (e), the brain activation in the right insula was greater

under the positive framing than under the negative framing, even though the behavioral framing effect was not significant. In addition and unpredicted, small group contexts also activated the parietal lobe [Fig. 2(c)].

Next, we examined the difference in brain activation patterns as a function of social group context across the two framing conditions. The large group context with 600 lives at stake activated more frontal cortical structure in the right hemisphere than the small group context with 6 lives at stake [see Table 2 and Fig. 2(a)].

As Fig. 2(d) shows, further regions of interests (ROI) analysis indicated that for the large group size framing effect, the opercula inferior frontal gyrus had a similar neural activity pattern consistent with the observed framing effects. Choice of sure options elicited greater activation in this region relative to choice of gamble options in the positive framing condition [paired $t(10) = 2.258, p = 0.024$, one tailed] whereas choice of gamble options had a greater activation in the same region than sure options in the negative framing condition [$t(10) = 2.793, p = 0.032$]. Note that the

Table 2
Brain activation by framing in large and small group contexts.

Area experimental condition	Hemisphere	Cluster size (voxels)	Z max	MNI coordinates		
				x	y	z
<i>P600 minus N600</i>						
Inferior frontal gyrus	Right	9	3.35	33	29	-8
<i>P6 minus N6</i>						
Insula	Right	12	3.61	33	-13	13
Parietal lobe	Right	17	3.42	33	-31	52
<i>600 minus 6</i>						
Middle frontal gyrus	Right	23	3.70	24	32	-8

Note: *p* denotes positive frame, and *N* denotes negative frame. The number (600 or 6) represents the number of people at stake. The Montreal Neurological Institute (MNI) coordinates are used to map images. The activation under positive framing was larger than that under negative framing condition in both 600 and 6 group size conditions. The differences were all detected at the level of uncorrected $p < 0.001$.

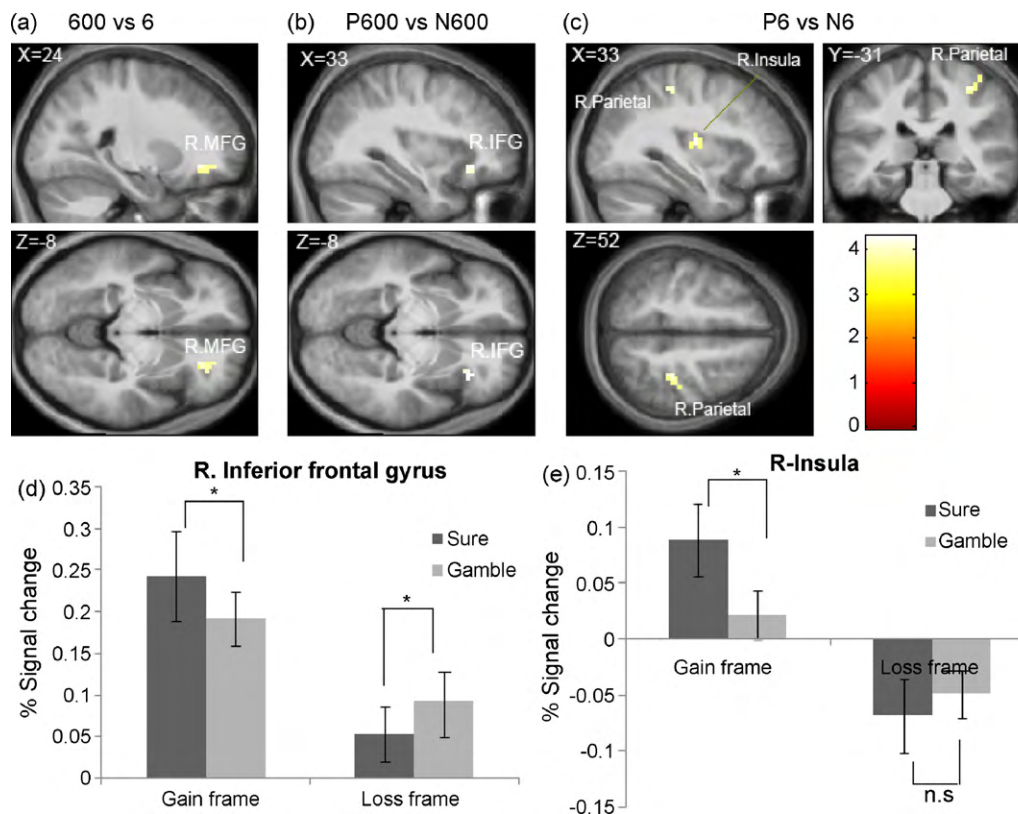


Fig. 2. Brain activations related to the group size and framing effects found in large/small group contexts using life-death problems. (a) Right middle frontal gyrus (MFG) activation after subtracting the brain image in reaction to small group problems from the brain image in reaction to large group problems, across the framing conditions. (b) Map of t statistic for the contrast between brain activations to positively framed problems and negatively framed problems in large group contexts. (c) Map of t statistic for the contrast between brain activations to positively framed problems and negatively framed problems in small group contexts while no behavioral framing effect was found. (d) Plots of percent signal changes in the right inferior frontal gyrus (IFG, 33, 29, -8) corresponding to the choices of the sure and gamble options in the gain and loss framing conditions. Error bars indicate ± 1 SEM. IFG = inferior frontal gyrus. (e) Plots of percent signal change in the right insula (33, -13, 13) corresponding to the choices of the sure and gamble options in the gain and loss framing conditions. Error bars indicate ± 1 SEM.

degrees of freedom were lowered due to the fact that some participants chose all the sure options or gamble options.

As Fig. 2(e) shows, in the small group contexts with 6 people at stake, choosing sure options elicited greater insula activation than choosing gamble options under the positive framing [$t(9) = 2.085$, $p = 0.034$]. However, no significant difference was found in insula activation between choosing gamble options and sure options under the negative framing [$t(5) = 0.840$, $p = 0.420$].

4. Discussion

The neural basis of framing effects has been explored in recent years (De Martino et al., 2006; Gonzalez et al., 2005; Windmann et al., 2006). The present study extends this line of research to examine social as well as verbal determinants of framing effects.

A common view of the framing effect is that it occurs as a result of irrational emotional interference on rational cognitive processing. Thus, amygdala activity involves negative emotional reactions and contributes to framing effects. In contrast, the activity of the orbital and medial prefrontal cortex involves in cognitive control and reduces the susceptibility of framing effects (De Martino et al., 2006). However, previous studies relating to the neural basis of framing effects neglected to explore the neural patterns of effect of social contexts, particularly the group size cues, on framing effects. In a recent review of the effects of animal group size on cognitive processing, Cronley and Newberry (2007) suggest that group size has significant effects on animal's abilities to develop either a concrete or abstract relationship. Wang (1996a, 1996b, 2008) found the group size effect on framing effects and proposed an Ambiguity

and Ambivalence hypothesis to explain this kind of social context effect. The behavioral results of the modified Asian Disease problems showed that framing effects appeared in large group life-death domain but disappeared in small group life-death domain. This result is consistent with previous research findings (Wang, 1996a, 1996b, 2008; Wang et al., 2001). Our fMRI data demonstrated that positive (gain) frame elicited greater activation in the right opercular inferior frontal gyrus when framing effects were evident in large group contexts. In contrast, the framing of choice outcomes in small group contexts although having no behavioral effect resulted in a differential activation in the insula and parietal lobe in the right hemisphere. Our results also revealed a neural basis for the dynamics of the social group context-dependent framing effects. The right middle frontal gyrus was highlighted in the comparison between choices made in large group contexts and those in small group contexts, irrespective of the framing conditions.

Overall, the results of the present fMRI study lend neural support to the Ambiguity and Ambivalence hypothesis (Wang, 2008). Framing of choice outcomes as a secondary cue activates the brain regions associated with verbal processing and cognitive control while the size of a social group in question as a primary cue elicits more limbic activities. The brain activation data of the current study showed distinctive patterns for large and small group size cues, while the behavioral data showed that the framing effects occurred only in the large group context.

These results are consistent with previous findings that animals display higher behavioral control and greater tolerance to inequality in a large group but become more emotional and aggressive in small group in response to inequality (Estevez et al., 2003; Pagel

& Dawkins, 1997). Brain imaging studies found that the inferior frontal gyrus was related to verbal and phonological processing (Greenlee et al., 2004; Nixon, Lazarova, Hodinott-Hill, Gough, & Passingham, 2004) and response inhibition (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron, Robbins, & Poldrack, 2004). The go/no-go task, which taps the ability to inhibit prepotent response tendency (for instance, stop pressing a button when a red signal appears), has consistently activated the lateral prefrontal cortex, particularly the right inferior frontal gyrus (Aron et al., 2003; Asahi, Okamoto, Okada, Yamawaki, & Yokota, 2004; Chikazoe, Konishi, Asari, Jimura, & Miyashita, 2007). Some researchers consider the right inferior cortex the most important prefrontal structure that exerts inhibition and cognitive control over subcortical structures of the brain (Aron et al., 2004). The same area is also implicated in risk aversion: higher risk aversion is correlated with higher activity at the inferior frontal gyrus (Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009). Functional disruption of activity of the right inferior frontal gyrus leads to change in risk attitude with increased risk-seeking choices (Fecteau et al., 2007; Knoch et al., 2006). Together these findings suggest that one of the functions of the right inferior frontal gyrus is to exert self-control over risk-taking impulses.

In contrast to large group cues, a small group context signals a higher interdependence between group members and evokes a kith-and-kin rationality. Guided by this rationality, the respondents in our study showed a live-or-die together risk preference reflected in choosing gamble options under both the positive and negative frames. From the perspective of a kith-and-kin rationality, evolutionarily recurrent, primary cues such as small group size would activate more primary structures of the brain. The fMRI data of the present study lends some neural support to this hypothesis, showing that the framing of choice outcomes, when presented in a small group context, elicited more activities in the insula, but activated more frontal cortical structure (the opercula inferior frontal cortex), when presented in a large group context. As part of paralimbic cortex, the insula is indeed considered to be a relatively older (primary) brain structure than the frontal cortex (e.g., Aleksandrov & Fedorova, 2003). The insula has been found to be related to negative emotions, particularly disgust (Calder et al., 2007; Hayes, Stevenson, & Coltheart, 2007; Wicker et al., 2003; Wright, He, Shapira, Goodman, & Liu, 2004) and fear (Ploghaus et al., 1999; Schiller, Levy, Niv, LeDoux, & Phelps, 2008). In the context of life-death problems, insula activation may serve as a critical neural substrate to instantiate aversive somatic markers that guide risk-taking behaviors (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003).

Furthermore, framing effects found in large group contexts were related to the activation of the opercula part of the right inferior prefrontal cortex, which is a linguistic processing center (Falzi, Perrone, & Vignolo, 1982; Nixon et al., 2004), containing the homologue of the Broca's area. This correspondence between choice behavior and right prefrontal brain activity suggests that framing effects on risk preference may be driven by a cognitive and linguistic process. The ROI analysis [Fig. 2(d)] has shown a clear correspondence between the activation in the right inferior frontal gyrus and the observed framing effects. Under the positive (gain) frame, making risk-averse choice of the sure option activated significantly stronger signal reactions in this brain area than making risk-seeking choice of the gamble option. In contrast, this pattern was reversed under the negative (loss) frame, where risk-seeking choices activated stronger brain reactions in the same ROI than risk-averse choices. Thus, the prefrontal regions (particularly, the right inferior frontal gyrus) may play a facilitating rather than inhibiting role in producing the behavioral framing effects. This view stands in contrast to the argument that prefrontal areas inhibit decision biases (framing effects) by De Martino et al. (2006). However, the difference in fMRI results

between the two studies may be in part related to the difference in the implemented choice tasks where monetary problems rather than life-death problems were used in the De Martino et al. study.

Another brain region activated by the large group contexts was the parietal lobe. According to some previous research the parietal lobe was related to language and numeric computation (Cohen, Dehaene, Chochon, Lehéry, & Naccache, 2000; Menon, Rivera, White, Glover, & Reiss, 2000) and episodic memory retrieval (Wagner, Shannon, Kahn, & Buckner, 2005). These aforementioned cognitive activities may contribute to the behavioral framing effects observed in the life-death problems presented in large group contexts.

A few caveats about the present study should be mentioned. First, the group size cue and framing cue were not separated in design. In future studies, group size effects can be studied using balanced framing of choice outcomes (e.g., 200 people will be saved and thus 400 people will die). Second, the present study only explored the homogeneous group situations where group members were either strangers or kin. In future studies, mixed (heterogeneous) group situations can be presented in the cover story where a group at risk consists of both strangers and kin (or friends).

5. Conclusion

We found different neural patterns of framing effects across different group size contexts. Overall, large group cues, in contrast to small group cues were associated with additional activation in the middle frontal gyrus in the right hemisphere. The behavioral framing effects observed in reaction to a life-death problem presented in a large group context were mainly related to differential activations in the right inferior frontal cortex. This brain region including the homologue of the Broca's area may be involved in implicit cognitive processing of linguistic cues that induces framing effects. However, in a small group life-death context and when the respondents were unambiguously risk seeking under both framing conditions, verbal framing of choice outcomes were related to unilateral activation of the insula and parietal lobe in the right hemisphere. This finding suggests an important role of negative emotion in switching choice preference from an indecisive mode to a more consistent risk-taking inclination. As proposed by Damasio (1994) in his somatic marker hypothesis, risk cues activate somatic markers and subsequent emotions and feelings to serve as a necessary component in decision making. We suggest further that the right inferior frontal gyrus and the insula both encode and react to the framing of decision problems to relate verbal and social cues to an anticipatory somatic state of "what it feels like" to be in a given risky situation. Such feeling-based anticipation would make it possible for the decision maker to react quickly and holistically in a risky situation.

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References

- Aleksandrov, V., & Fedorova, K. (2003). Structure of the insular region of the rat neocortex. *Neuroscience and Behavioral Physiology*, 33, 199–202.
- Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience*, 6, 115–116.

- Aron, A. R., Robbins, T., & Poldrack, R. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, 8, 170–177.
- Asahi, S., Okamoto, Y., Okada, G., Yamawaki, S., & Yokota, N. (2004). Negative correlation between right prefrontal activity during response inhibition and impulsiveness: An fMRI study. *European Archives of Psychiatry and Clinical Neuroscience*, 254, 245–251.
- Brewer, M. B. (1979). Ingroup bias in the minimal intergroup situation: A cognitive-motivational analysis. *Psychological Bulletin*, 86, 307–324.
- Brosnan, S. F., Schiff, H. C., & de Waal, F. B. M. (2005). Tolerance for inequity may increase with social closeness in chimpanzees. *Proceedings of Royal Society B: Biological Sciences*, 272, 253–258.
- Calder, A. J., Beaver, J. D., Davis, M. H., Van Ditzhuijzen, J., Keane, J., & Lawrence, A. D. (2007). Disgust sensitivity predicts the insula and pallidum response to pictures of disgusting foods. *European Journal of Neuroscience*, 25, 3422–3428.
- Caporael, L. R., Dawes, R. M., Orbell, J. M., & van de Kragt, A. J. C. (1989). Selfishness examined: Cooperation in the absence of egoistic incentives. *Behavioral and Brain Sciences*, 12, 683–739.
- Chikazoe, J., Konishi, S., Asari, T., Jimura, K., & Miyashita, Y. (2007). Activation of right inferior frontal gyrus during response inhibition across response modalities. *Journal of Cognitive Neuroscience Archive*, 19, 69–80.
- Christopoulos, G. I., Tobler, P. N., Bossaerts, P., Dolan, R. J., & Schultz, W. (2009). Neural correlates of value, risk, and risk aversion contributing to decision making under risk. *Journal of Neuroscience*, 29, 12574–12583.
- Cohen, L., Dehaene, S., Chochon, F., Lehéry, S., & Naccache, L. (2000). Language and calculation within the parietal lobe: A combined cognitive, anatomical and fMRI study. *Neuropsychologia*, 38, 1426–1440.
- Cosmides, L., & Tooby, J. (2000). Toward mapping the evolved functional organization of mind and brain. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1167–1178). Cambridge, MA: MIT Press.
- Croney, C. C., & Newberry, R. C. (2007). Group size and cognitive processes. *Applied Animal Behaviour Science*, 103, 215–228.
- Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Putnam.
- De Martino, B., Kumaran, D., Seymour, B., & Dolan, R. J. (2006). Frames, biases, and rational decision-making in the human brain. *Science*, 313, 684–687.
- Estevez, I., Keeling, L. J., & Newberry, R. C. (2003). Decreasing aggression with increasing group size in young domestic fowl. *Applied Animal Behaviour Science*, 84, 213–218.
- Falzi, G., Perrone, P., & Vignolo, L. A. (1982). Right–left asymmetry in anterior speech region. *Archives of Neurology*, 39, 239–240.
- Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., et al. (2007). Activation of prefrontal cortex by transcranial direct current stimulation reduces appetite for risk during ambiguous decision making. *Journal of Neuroscience*, 27, 6212–6218.
- Gonzalez, C., Dana, J., Koshino, H., & Just, M. (2005). The framing effect and risky decisions: Examining cognitive functions with fMRI. *Journal of Economic Psychology*, 26, 1–20.
- Greenlee, J. D. W., Oya, H., Kawasaki, H., Volkov, I. O., Kaufman, O. P., Kovach, C., et al. (2004). A functional connection between inferior frontal gyrus and orofacial motor cortex in human. *Journal of Neurophysiology*, 92, 1153–1164.
- Hayes, C. J., Stevenson, R. J., & Coltheart, M. (2007). Disgust and Huntington's disease. *Neuropsychologia*, 45, 1135–1151.
- Knauff, B. M. (1991). Violence and sociality in human evolution. *Current Anthropology*, 32, 391–428.
- Knoch, D., Gianotti, L. R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., et al. (2006). Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior. *Journal of Neuroscience*, 26, 6469–6472.
- Krill, A., & Platek, S. M. (2009). In-group and out-group membership mediates anterior cingulate activation to social exclusion. *Frontiers in Evolutionary Neuroscience*, 1, 1–7.
- Kühberger, A. (1998). The influence of framing on risky decisions: A meta-analysis. *Organizational Behavior and Human Decision Processes*, 75, 23–55.
- Lee, R. B., & DeVore, I. (Eds.). (1968). *Man the hunter*. Chicago: Aldine.
- Levin, I. P., Schneider, S., & Gaeth, G. J. (1998). All frames are not created equal: A typology and critical analysis of framing effects. *Organizational Behavior and Human Decision Processes*, 76, 149–188.
- Lieberman, D., Oum, R. E., & Kurzban, R. (2008). Does the family of fundamental social categories include kinship? *European Journal of Social Psychology*, 38, 998–1012.
- Lieberman, D., Tooby, J., & Cosmides, L. (2007). The architecture of human kin detection. *Nature*, 445, 727–731.
- Menon, V., Rivera, S., White, C., Glover, G., & Reiss, A. (2000). Dissociating prefrontal and parietal cortex activation during arithmetic processing. *Neuroimage*, 12, 357–365.
- Nixon, P., Lazarova, J., Hodinott-Hill, I., Gough, P., & Passingham, R. (2004). The inferior frontal gyrus and phonological processing: An investigation using rTMS. *Journal of Cognitive Neuroscience*, 16, 289–300.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97–113.
- Olson, M. (1965). *The logic of collective action*. Cambridge, MA: Harvard University Press.
- Page, M., & Dawkins, M. S. (1997). Peck orders and group size in laying hens: 'Futures contracts' for non-aggression. *Behavioral Processes*, 40, 13–25.
- Paulus, M. P., Rogalsky, C., Simmons, A., Feinstein, J. S., & Stein, M. B. (2003). Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. *Neuroimage*, 19, 1439–1448.
- Platek, S. M., & Krill, A. L. (2009). Self-face resemblance attenuates other-race face effect in the amygdala. *Brain Research*, 1284, 156–160.
- Ploghaus, A., Tracey, I., Gati, J. S., Clare, S., Menon, R. S., et al. (1999). Dissociating pain from its anticipation in the human brain. *Science*, 284, 1979–1981.
- Savage, L. J. (1954). *The foundations of statistics*. New York: Wiley.
- Schiller, D., Levy, I., Niv, Y., LeDoux, J. E., & Phelps, E. A. (2008). From fear to safety and back: Reversal of fear in the human brain. *Journal of Neuroscience*, 28, 11517–11525.
- Stone, V. E. (2007). An evolutionary perspective on social intelligence. In E. Harmon-Jones, & P. Winkielman (Eds.), *Social neuroscience: Integrating biological and psychological explanations of social behavior* (pp. 316–352). NY: Guilford Press.
- Tajfel, H. (1981). *Human groups and social categories: Studies in social psychology*. Cambridge: Cambridge University Press.
- Tajfel, H., Billig, M., Bundy, R., & Flament, C. (1971). Social categorization and intergroup behavior. *European Journal of Social Psychology*, 1, 149–178.
- Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, 211, 453–458.
- Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval. *Trends in Cognitive Sciences*, 9, 445–453.
- Wang, X. T. (1996a). Domain-specific rationality in human choices: Violations of utility axioms and social contexts. *Cognition*, 60, 31–63.
- Wang, X. T. (1996b). Framing effects: Dynamics and task domains. *Organizational Behavior and Human Decision Processes*, 68, 145–157.
- Wang, X. T., Simons, F., & Brédart, S. (2001). Social cues and verbal framing in risky choice. *Journal of Behavioral Decision Making*, 14, 1–15.
- Wang, X. T. (2008). Risk communication and risky choice in context: Ambiguity and ambivalence hypothesis. *Annals of the New York Academy of Sciences*, 1128, 78–89.
- Wicker, B., Keysers, C., Plailly, J., Royet, J.-P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in my insula: The common neural basis of seeing and feeling disgust. *Neuron*, 40, 655–664.
- Windmann, S., Kirsch, P., Mier, D., Stark, R., Walter, B., Güntürkün, O., et al. (2006). On framing effects in decision making: Linking lateral versus medial orbitofrontal cortex activation to choice outcome processing. *Journal of Cognitive Neuroscience*, 18, 1198–1211.
- Wright, P., He, G., Shapira, N., Goodman, W., & Liu, Y. (2004). Disgust and the insula: fMRI responses to pictures of mutilation and contamination. *Neuroreport*, 15, 2347–2351.