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Neurobiological Correlates of Decision-Making in Framing Conditions

Original research

Human decision-making is a complex process and often influenced by emotionally relevant information. To date, the associated neurobiological correlates are not well understood. Previously, De Martino et al. (2006) assessed the effect of framing on decision-making. The framing effect, which is part of Prospect theory, refers to a cognitive bias leading to differential decision-making based on the context and the connotation that information is presented in. The current study aimed at replicating De Martino et al.'s findings and thus supporting the hypothesis that decision biases occur when framing information and that increased amygdala activation underlies such emotional responses. Participants performed a computerised task in which they were first presented with an initial starting amount of money and then underwent different trials consisting either of deciding between gambling and keeping or gambling and losing a certain amount of money. The task was performed both outside and inside a 3T fMRI scanner by separate groups. Behavioural results indicated a tendency to act in accordance with the frame. fMRI analysis revealed no increase in amygdala activation when complying to the bias. When making frame-incongruent decisions, increased anterior cingulate cortex (ACC) activation was established. Increases in ACC activation can be related to acting in a more rational instead of emotional manner. Furthermore, activity in the cerebellum was increased when making a choice, indicating the involvement of this brain area in decision-making under uncertainty.

Keywords: decision-making, framing effect, amygdala, rationality, gambling

INTRODUCTION

The underlying mechanisms of human decision-making have been of great interest for several decades. Multiple theories, such as Game theory and Prospect theory, have been postulated attempting to explain and predict decision-making. The proposition of Game theory by Morgenstern and von Neumann describes a decision maker´s behaviour in terms of a mathematical utility function and assumes rational decision-making (Osborne & Rubinstein, 1994; Von Neumann & Morgenstern, 1944). This theory is applied in instances where strategic thinking is used, for example in the field of social sciences, such as business, economics, and politics (e.g. war strategies) (Riechert & Hammerstein, 1983).

Despite the theory's applicability in some of the fields mentioned above, Kahneman and Tversky encountered several examples in which the theory's axioms including descriptive invariance and rationality were violated. This led to the development of Prospect theory, a non-utility theory which explains human decision-making by not assuming rationality only. One central concept of the theory is the framing effect which refers to the phenomenon that the context an option is presented in, alters choice behaviour (Kahneman & Tversky, 1979). For example, a choice may depend on whether something is to be lost or gained, as these two scenarios are evaluated differentially (defined as loss aversion in Prospect theory) (Kahneman & Tversky, 1979; Schindler & Pfattheicher, 2017).

The cognitive framing bias has been observed in several societal contexts (Kahneman & Tversky, 1984; Piñon & Gambara, 2005; Tversky &

Kahneman, 1981). For instance, in the health-domain it has been demonstrated that decisions by doctors and patients are influenced by the frame that information is presented in. When a person was presented with a positive (40 percent chance of surviving) instead of a negative frame (60 percent chance of dying) they were more likely to agree to surgery in the positive frame (Marteau, 1989). In the field of consumer behaviour, biased decision-making due to framing is often observed. For example, evaluations of ground beef were better when the product was presented as “80% lean meat” compared with “20% fat meat” (Levin & Gaeth, 1988). Abovementioned examples emphasise that humans rarely make decisions strategically and instead often misinterpret information due to a cognitive framing bias. These findings illustrate that Prospect theory is more suitable than Game theory in explaining daily decision-making.

It is postulated that the aforementioned bias occurs due to a trade-off between cognitive effort and affect (Gonzalez et al., 2005). In line with this is Dual Process theory. The main assumption is that rapid, autonomous processes are properties of an emotional system (system 1) and yield default responses unless a second rational and deliberate system (system 2) intervenes. System 1 is expected to lead to biases and heuristics in decision-making (Evans & Stanovich, 2013). System 2 in turn counteracts biases and becomes active when engaging in rule-based decision-making. System 1 has been found to correlate with increased amygdala activation. System 2 has been found to correlate with prefrontal cortex (PFC) activation, which also correlates with higher order reasoning processes in different situations (Murch & Krawczyk, 2014;

Roiser et al., 2009). Despite indications that amygdala and PFC activation may be related to the framing effect, this link has not been assessed yet.

Several lines of research on amygdala and PFC activation indicate a potential involvement of the two brain areas in the framing effect due to their link with system 1 and system 2. For example, amygdala activity is often associated with emotional and fear processing, and reward processing (Adolphs et al., 1994; Adolphs et al., 1995; Davis, 1992; Hampton et al., 2007; LeDoux, 2003; Whalen et al., 1998). Moreover, the amygdala mediates stimulus-value associations which play a role in decision-making in framing conditions (Baxter & Murray, 2002). Distinct neural populations that associate a positive and negative value with the presented stimuli have been observed in the amygdala (Paton et al., 2006).

The PFC has been linked to rational decision-making and activity in the area has been shown to correlate with an individual's susceptibility to framing (Deppe et al., 2005). Additionally, the two brain areas seem to be connected anatomically and functionally. It has been demonstrated that amygdala input to the ventromedial PFC modulates reward-related signals and signals associated with behavioural choice in the prefrontal region (Hampton et al., 2007). Based on abovementioned findings, the amygdala and the PFC are hypothesised to show increased activation when making frame-congruent (system 1) and frame-incongruent choices (system 2) respectively.

To test these two hypotheses, a behavioural gambling task, consisting of either a loss or a gain frame (losing a certain amount of money; gaining a certain amount of money), was performed while recording the haemodynamic response using functional magnetic resonance imaging (fMRI). Beforehand, another group of participants performed the behavioural task to establish whether a framing effect would be observed using the paradigm. It was hypothesised that decision-making will be predominantly done in a frame-congruent manner (choosing the gambling option in the loss frame and the sure option in the gain frame) instead of being frame-incongruent (choosing the sure option in the loss frame and the gamble option in the gain frame) due to loss aversion (Kahneman & Tversky, 1979; Schindler & Pfattheicher, 2017). It was expected that people were more willing to accept a riskier option when confronted with a negatively stated alternative (loss frame) as compared to a positively stated one (gain frame). By recording responses in the behavioural task and haemodynamic changes in the fMRI scanner, the current study aimed to reproduce the functional role of the amygdala in the process of decision-making in framing conditions, suggested by De Martino et al. (2006).

METHODS

Two studies were conducted and are described in separate sections below. A behavioural study was conducted in order to assess the effect of framing on decision making with a sufficiently large sample size. Another, small-scale fMRI study attempted to identify brain regions mediating this framing effect, aiming to replicate De Martino et al. (2006)'s findings.

Behavioural Study

Participants

Thirty healthy university students were recruited from the second-year cohort of the psychology bachelor at Maastricht University. The mean age was 21.4 years (± 1.7), and exclusion criteria included colour-blindness and participation in the fMRI study. Participants received compensation in the form of course credits. The study was approved by the Ethics Review Committee Psychology and Neuroscience (ERCPN). The reference number, both for this part of the study and the fMRI study described later, was RP2027_2019_33.

Materials

A computerised behaviour task was used, and responses were made via a keyboard. As the study aimed to replicate De Martino et al. (2006)'s procedure, an adjusted version of that code was used, which the researchers had published on GitHub (Folke, 2015).

Procedure and Design

The experimental paradigm consisted of a financial decision-making task in which the effect of the independent variable "Frame" on the dependent variable "Choice" was assessed. A within-subjects design was used in which all participants underwent all conditions (positive and negative framing), which each consisted of 95 trials. Due to the nature of the framing effect, participants were given incomplete information during the briefing, i.e. they were merely told that decision-making was being assessed. Furthermore, to ensure that there was an incentive to achieve a high score despite the lack of a real monetary reward, participants were promised different non-monetary prizes depending on their score. Following the briefing, each participant underwent a practice round before the main task, and a debriefing afterwards. The task itself consisted of 190 trials, distributed over three blocks separated by short breaks. Additionally, 20 so-called "catch trials", in which one choice was objectively preferable, were included per condition in order to assess whether participants understood the task.

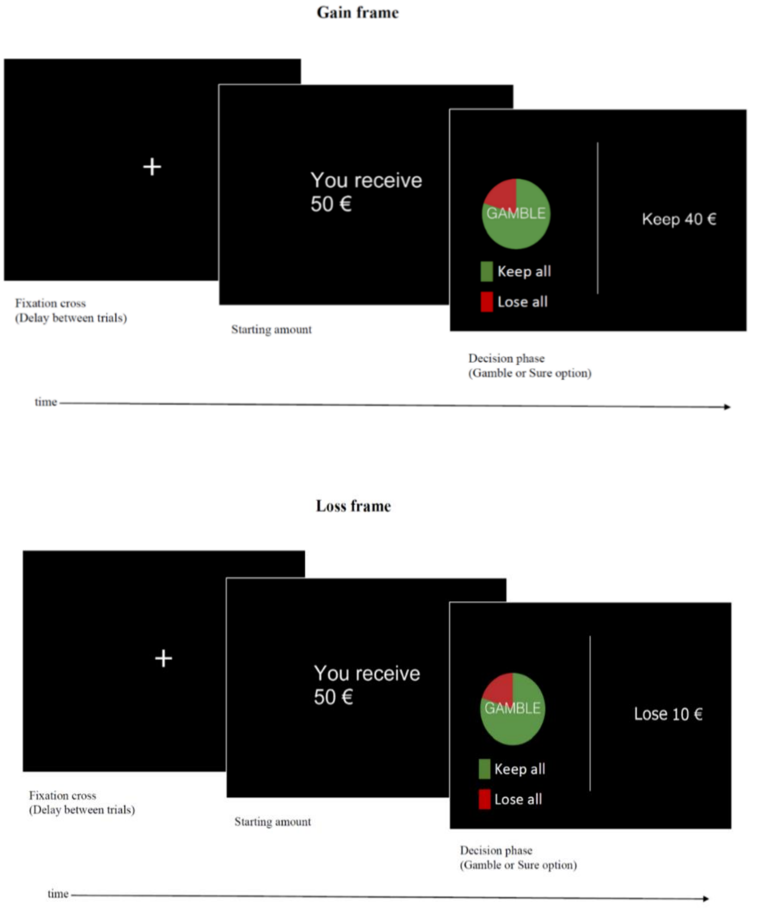

Figure 1: Stimulus Example. Overview of the course of a single trial in each experimental condition.

Each individual trial begun with a display of the initial or starting amount of money, worded as "You receive X€". This amount took the form of four different values (25€, 50€, 75€, 100€), balanced across all conditions. This was displayed for 1s followed by a delay of 0.5s before the next display, constituting the decision phase of 2.5s (Figure 1). Subjects had two choice options: "Gamble" or "Sure", that were displayed on either side of the screen. The Sure option stated how much of the starting amount of money can be kept for sure, and also incorporated the framing manipulation. This frame consisted of the message "Keep X€" ("Gain" frame) or "Lose X€" ("Loss" Frame). The Gamble option displayed a pie chart showing the probabilities to either "Keep all" (coloured green) or "Lose all" (coloured red), which was the case for both frames. The probability of winning the full starting amount took one of four different values (20%, 40%, 60%, 80%), which were balanced across all conditions.

The expected outcome of both choice alternatives (i.e. Gamble or Sure) was always equivalent, that is the proportion of money relative to the starting amount one would receive in the Sure choice option was equal to the probability of winning the full starting amount in the Gamble option. The only exception to this were the aforementioned catch trials, in which the winning probability in the Gamble option was either 95% or 5%, making one of the choice alternatives obviously preferable. After indicating their choice via pressing the arrow buttons on a keyboard, a brief delay or fixation cross period (1.5s) followed before the next trial.

As compared to the original study by De Martino et al. (2006), less catch trials were used in order to increase the power of the analysis. Furthermore, the original 4s maximum decision time was decreased, to avoid possibly giving the participants, all psychology students, too much time to become aware of the framing manipulation. The framing effect, in line with dual-process theory, is hypothesised to affect the intuitive system, which is faster and hence more prominent under time pressure (Guo et al., 2015; Guo et al., 2017). In order to investigate the framing effect, this system should therefore be employed in the respective decision-making task. By decreasing the decision time, participants were forced to decide intuitively.

Data Processing and Analysis

In order to assess the main effect of frame, choice frequencies were transformed into percentages. For instance, the number of times a participant chose the gamble option in the loss frame condition was expressed as a percentage of all responses within the loss frame. For the statistical analysis a paired samples t-test was used, comparing the percentage of gamble choices in each frame. Furthermore, a one-sample t-test was used to test for both frames the null hypothesis that participants were risk-neutral (i.e. chose both choice options 50% of the time).

In addition to the main effect, possible effects of the four different values of "Starting Amount", as well as "Winning Probability" were examined. For this, percentages of gamble choices in the total trials of the four starting amounts (i.e. 25€, 50€, 75€, 100€) or winning probabilities (i.e. 20%, 40%, 60% 80%) were calculated, again for each frame separately. For instance, the percentage of a participant's gamble choices in all trials of the gain frame in which the starting amount was 25€ was calculated. The effects of starting amount and winning probability were then each separately assessed using two-way repeated measures analyses of variance, in order to check both for possible main effects of starting amount and winning probability as well as interaction effects with the framing condition.

For the purpose of comparing the extent to which participants were susceptible to the framing effect, also across the two studies, a rationality index was computed for each subject (Table 2). This was modelled after De Martino et al. (2006)'s operationalisation of rationality, which was defined by choosing the gamble option as often in the gain frame as in the loss frame. Hence the absolute value of the difference between proportions of gamble choices that occurred in the loss frame and in the gain frame was taken, and transformed so that a value of 1 indicates a complete indifference to the framing effect (i.e. equal distribution of gamble choices in both frames) while a value of 0 implies being heavily influenced by the effect of frame, so that one chooses to gamble only in either one of the frames.

fMRI Study

Participants

Eight healthy university students were recruited in line with scan time restrictions which did not allow more participants to be tested. The sample consisted of both males and females, right- and left-handed, with a mean age of 21.9 years (± 2.0). Exclusion criteria for participation included colour-blindness as well as having participated in the behavioural study. Additionally, general exclusion criteria for participation in fMRI studies applied, which were assessed using a standard safety screening form. Participants were compensated with course credits. The study was approved by the Ethics Review Committee

Psychology and Neuroscience (ERCPN), and the MRI procedure was also authorised by a Project Proposal Meeting committee.

Materials

The same computerised behaviour task and stimuli as described in the behavioural study section were used. Brain activity was measured with a Siemens Prisma 3 Tesla magnetic resonance scanner. Participants gave their responses via MRI-compatible keypads, one for each hand.

General Procedure and Design

The same experimental paradigm as in the behavioural study was used with some alterations. Most importantly the delay between trials, during which participants had to focus on a fixation cross, was longer (5s) in order to capture the haemodynamic response. Furthermore, the catch trials were removed to take full advantage of the limited scan time. In total, participants in this study underwent 192 trials, 32 per framing condition per run. The practice round was completed outside the scanner prior to measuring, and the briefing included information about fMRI. During a one-hour scan time, anatomical measurements were taken, followed by 3 functional runs separated by breaks. Furthermore, the BOLD signal constitutes the dependent variable in the fMRI study, while the behavioural decision was used as a classification factor in addition to the experimental factor Frame.

Image Acquisition, Processing, and Analysis

Gradient-echo T2*-weighted functional data with a voxel size of 2mm3 and T1-weighted structural data with a voxel size of 1mm3 were acquired with a 3 Tesla MRI scanner. A multiband pulse sequence was employed, with a repetition time (TR) of 650ms. Slices of 2mm thickness were scanned in an interleaved fashion. The first 2 volumes were discarded during scanning in order to compensate for T1 saturation effect. This resulted in a total of 1020 volumes per run. The echo time (TE) was 28ms.

The data was analysed using BrainVoyager software (Goebel et al., 2006). Preceding the statistical analysis, the data was pre-processed. In an initial step, distortion correction was applied to the data using COPE (correction based on opposite phase encoding), a BrainVoyager Plugin (Andersson & Skare, 2002). Slice scan time correction and 3D motion correction was applied to the functional magnetic resonance data,. The resulting motion parameter time courses were later also integrated in the statistical analysis as a confound predictor to remove residual motion artefacts. Further, 3D Gaussian spatial smoothing was applied with a full width at half maximum (FWHM) value of 8mm. Lastly, a temporal band-pass filter using a fast Fourier transformation algorithm (FFT) with a cut-off value of 3.0 cycles was implemented. For the anatomical volumetric magnetic resonance (VMR) data, intensity inhomogeneities were corrected, and the images were transformed into Talairach space. Finally, FMR and VMR data were aligned using boundary-based registration.

Due to the small sample size, a fixed effects statistical analysis was used. It should be noted that while this boosts power enormously, results only apply to the sample studied. A general linear model was employed, using various contrasts between conditions to assess effects of interest. For example, the contrast between activity in frame-incongruent and frame-congruent choices was examined. Correction for multiple comparisons was made using a false discovery rate (FDR) cluster threshold. Time courses were normalised with a baseline z standardisation. Lastly, a correction for serial correlations was applied. The design matrix included all expected variance, that is all four frame-choice combinations or conditions, as well as several predictors of no interest, e.g. a no response condition for trials in which participants failed to respond quickly enough, and motion parameters obtained during motion correction.

Several contrasts were then assessed within the GLM model. Firstly, the main effect of the frame was examined, that is gain and loss conditions were compared. Furthermore, De Martino et al. 's (2006) interaction contrast as well as reverse interaction contrast was realised via a conjunction of the two contrasts GainSure versus GainSure and LossGamble versus LossSure. The reverse interaction contrast, for example, thus took the following form: [(GainGamble + LossSure) – (GainSure + LossGamble)]. Additionally, the latter effect was also examined further by checking each of the two contrasts individually. Behavioural effects were analysed as described for the behavioural study, using SPSS (IBM Corp, 2017).

RESULTS

Behavioural Outcomes

In line with our predictions, the frame effect was shown to be robust. Confirming the results of De Martino et al. (2006), the manipulation had a significant influence on the gambling behaviour (Fig.1). On average, subjects chose the gamble option 15,5% more often within the loss frame compared to the gain frame (56,9% > 41,4%), $t(29)=6.924, p<.001$. Additionally, subjects were biased towards risk aversion in the gain frame and risk neutrality in the loss frame, but a trend towards risk seeking could be observed in the data. These results are in accordance with Prospect theory, which, in contrast to Expected Utility theory proposes that the presence of rationality is not absolute in human decision-making (Kahneman & Tversky, 1979; Von Neumann & Morgenstern, 1944).

Furthermore, it was analysed whether the amount of money that was at stake would interact with the frame manipulation. Even though the starting amount had a significant effect on the decision when it was initially presented within the gain frame, the frame effect alone showed to be robust across different starting amounts. This also applies to the varying winning probabilities. Although the winning probability influenced the gambling behaviour (Fig. S2), the effect of the frame was still expressed.

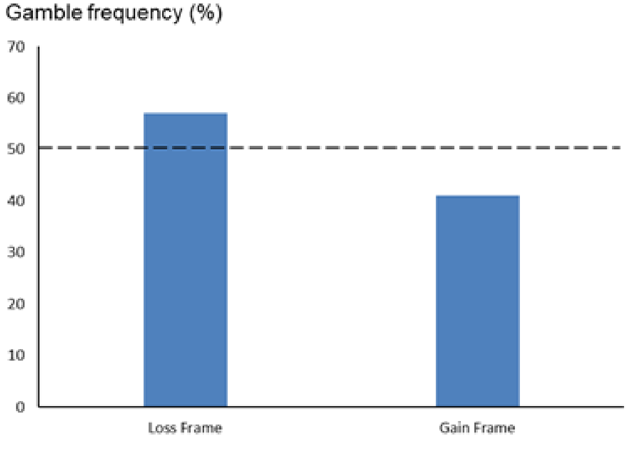

Figure 2: Gamble Frequency. Frequency of gambles within the loss frame and the gain frame, across conditions. Subjects chose the gamble option significantly more often when they were initially presented with the loss frame. The dashed line expresses risk-neutrality, which is marked by taking the gamble option in 50 percent of trials (De Martino, Kumaran, Seymour & Dolan, 2006). Additionally, subjects showed to be risk averse in the gain frame $t(29)=2.292$, $p = .029$, and risk neutral in the loss frame $t(29) = 1.6$, $p = .12$ (i.e. hypothesis that risk seeking is pronounced within the loss frame is not supported).

Catch trials and awareness of manipulation

Subjects performed highly accurate on catch trials (Fig. 3), providing evidence for sustained attention and involvement with the task. Moreover, only two subjects reported that they noticed the framing manipulation. Results can therefore be interpreted meaningfully.

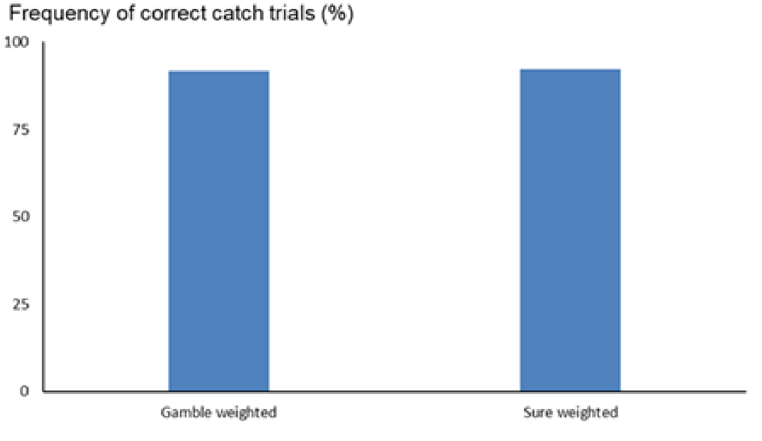

Figure 3: Frequency of Gambles in Catch Trials as Function of Choice Utility. In the 'gamble weighted' condition, the probability of winning was set to 95%. Irrespectively of the frame, the subjects were expected to choose the gamble option to make the optimal choice. In contrast, in the 'sure weighted' condition the winning probability was 5%. Here, the best choice was to choose the sure option. The number of correct trials (bars) displays the high accuracy of the subjects in choosing the better option (gamble weighted = 91,69 %, sure weighted = 92,22 %).

Analysis of fMRI Data

Amygdala activity has not been found to correlate statistically significant with framing. Within the key experimental contrast [(GainSure + LossGamble) – (GainGamble + LossSure), the amygdala was not significantly more active when subjects made decisions that were in accordance with the frame effect (GainSure and LossGamble).

The reverse interaction contrast was also of interest [GainGamble + LossSure) + (GainSure + LossGamble)]. This revealed significantly more activation in the anterior cingulate cortex (ACC) when subjects were not affected by the frame effect (GainGamble and LossSure; Fig. 3). Furthermore, it was examined whether this effect could also be observed for each frame independently [(GainGamble) – (GainSure) and (LossSure) – LossGamble)] and it showed to be robust. The activation of the ACC was significantly greater when subjects chose the gamble option in the gain frame, (3,10,42), $t=4.94$, $p<.00001$, and the sure option in the loss frame, (-1,26,31), $t=4.42$, $p<.0001$.

In an additional analysis, the frames were contrasted with each other [(GainSure + GainGamble) + (LossGamble + LossSure)]. Interestingly, the ventromedial prefrontal cortex showed to be significantly more active when subjects were presented with the gain frame than with the loss frame, right hemisphere (3,56,6), $t= 4.22$, $p<.001$; left hemisphere (-1,53,5), $t=3.71$, $p<.001$].

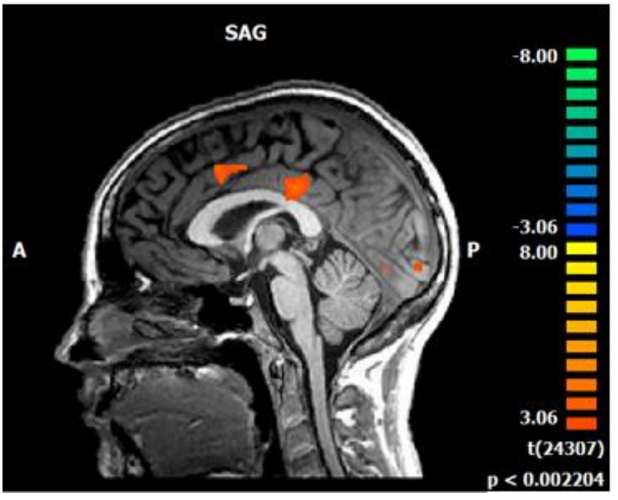

Figure 4: fMRI Results of the Decision Task. The reverse interaction contrast [(GainGamble + LossSure) - (GainSure + LossGamble)] reflected the following activity of the Anterior Cingulate Cortex, Talairach space coordinates (x, y, z]: left hemisphere -3, 8, 42 (t-value = 4.14); right hemisphere 2, 14, 41 (t = 3.82). The effect was significant at $p < .0001$. For display purposes it is shown at $p < .002204$.

Table 1: Brain Areas Significantly More Active During the Reverse Interaction Contrast [(GainGamble + LossSure) - (GainSure + LossGamble)]

Region	**Laterality**	**x**	**y**	**z**	**t-value**
Anterior Cingulate Cortex	L	-3	8	42	4.14
	R	2	14	41	3.82
Posterior Cingulate Cortex	L	-3	-25	30	4.10
Cuneus	L	-14	-72	12	4.23
Lingual Gyrus	R	12	-72	-5	4.18
Cerebellum	R	18	-71	-24	3.68

Table 2 Rationality Indices of fMRI Participants

Subject	Rationality Index
1	0,767676768
2	0,816901408450704
3	0,654205607476636
4	0,926829268292683
5	0,972602739726027
6	0,816901408
7	0,888888888888889
8	0,9375
Mean	0,8477
Std. Deviation	0,10513

DISCUSSION

To investigate the hypothesised framing effect, we conducted a separate behavioural study before implementing the same experimental paradigm in the fMRI scanner. The aim of the behavioural part was to investigate whether people are more willing to accept a riskier option when confronted with a negatively stated alternative (loss frame) as compared to a positively stated one (gain frame). The results of the behavioural experiment match the findings of De Martino et al. (2006) as a significant main effect for the framing manipulation was found. Participants chose the frame-congruent option (choosing the gambling option in the loss frame and the sure option in the gain frame) significantly more often than the frame incongruent one (choosing the sure option in the loss frame and the gamble option in the gain frame). This is in accordance with a study by Gonzalez et al. (2005), who found similar results. People proved to be more risk-seeking (i.e., choosing the gamble option more often) when confronted with negatively framed options (i.e., the loss frame) and more risk-averse when confronted with positively framed options (i.e., the gain frame), following the predictions made by Prospect theory (Kahneman & Tversky, 1979). Even though the obtained data reveals interaction effects in terms of winning probability (i.e., 20%, 40%, 60% 80%) and starting amount (i.e., 25€, 50€, 75€, 100€), the framing effect still proved to be existent.

Importantly, significant activation in the ACC was found during decisions that ran counter to the assumed framing effect. This corroborates findings of De Martino et al. (2006) who found the ACC to be activated in this context as well. A possible explanation for this activity comes from Rushworth et al. (2004) who state that one role of this brain area is to relate actions to their consequences. It is suggested that the ACC processes information about the expected consequence of an action and whether this outcome is worth it to act upon. Since the activity was significantly more pronounced in the frame-incongruent conditions, this could reflect a tendency of the participants to not act upon the frame effect but to behave more rationally. Further, acting congruent to the framing effect or not could be related to the orbitofrontal cortex (OFC) and the ACC (Talmi et al., 2010). Stalnaker et al. (2007) propose that the OFC can be associated with cognitive flexibility which is needed in order to overcome risk-averse associations encoded in the amygdala. Therefore, future research should examine the role of the OFC and the ACC in decision-making under the influence of the framing effect.

Unexpectedly, our results revealed cerebellum activation could be seen when making "Sure vs. Gambling" decisions. Blackwood et al. (2004)

showed that the cerebellum mediates probabilistic decisions made under uncertainty, which gambling behaviour can be linked to. This uncertainty may be induced by presenting a pie chart and prodding the participant to make an intuitive probabilistic decision on its basis (i.e., uncertainty regarding the outcome and probabilistic decision because of the pie chart). This supports the emerging view that the cerebellum is involved in more complex thought-processes (Schmahmann & Caplan, 2006).

Counter to our hypothesis and the findings of De Martino et al. (2006), no increased amygdala activation was found during frame-congruent behaviour. This is surprising given that other studies found a significant contrast between the conditions (Hampton et al., 2007; Murray, 2007; Roiser et al., 2009). Several reasons for this finding are suggested: first, due to restricted scanning hours, we were only able to test eight participants. Because of that, the signal in the region of interest was not enough to acquire an acceptable signal-to-noise ratio (SNR), potentially explaining our null finding in terms of amygdala activation. Future experiments should try to recruit more participants to circumvent this risk. Additionally, slow event-related fMRI experiment designs such as the one used in the present study are prone to have a lower SNR in general, resulting in a loss of statistical power (Murphy et al., 2007). It is advisable that future studies expand the time spent in the scanner to allow for more time between the trials, which in turn would increase the statistical power, so that the haemodynamic response can set back to baseline.

Furthermore, the participants in the fMRI experiment were not susceptible to the framing and acted in a rational manner. The rationality indices of all eight participants were located in the upper half of the scale, therefore the sample might not have been heterogeneous enough in to detect differences in amygdala activity. Moreover, as a multiband sequence with a relatively fast TR was used (650 ms) our data is more sensitive to movement and artefacts (Boubela et al., 2014) We can therefore not recommend this sequence as it created most of the distortions in the medial part of the brain, which was our main area of interest. This might have had consequences for our data as a possible activation in the amygdala might be concealed by these distortions. Lastly, findings of amygdala activation have been found to be susceptible to confounders such as interplays between the scanner sequence settings and the specific properties of the tissue surrounding the region of interest (Boubela et al., 2015; Murphy et al., 2007).

In addition to the potential effects of our small sample on SNR, Turner et al. (2018) pointed out that moderate sample sizes might impede the adding up to the ongoing discussion about a possible reproducibility crisis (Aarts et al., 2015). To counteract the small sample size, we conducted an additional behavioural study using the same experimental paradigm and bigger sample size, which turned out to be significant. We therefore assume that the found framing effect in the fMRI analysis can be generalised. Additionally, subjects reported that the decision task got monotone after some time, probably due to its relative simplicity. Due to scanning constraints, catch trials to retain attention and counteract fatigue effects were not included in the fMRI experiment. It is advisable that future research incorporates a controlling factor to prevent possible confounding, for example computer game-like elements.

Even though our study does not provide clear support for the dual process theory, other studies found such evidence. A study conducted by

Cassotti et al. (2012) found that the framing effect can be eliminated if the subject is shown a picture describing a positive emotional context. Strikingly, this study used the same experimental paradigm as De Martino et al. (2006), suggesting that this effect would probably also be existent in our experiment. In line with this finding is a study by Thomas and Millar (2011) who showed that when subjects are provided with additional information during the decision-making process they are less susceptible to the framing effect. This, on one hand, might be considered support for the dual process theory as it shows that a more deliberate system can overrule a predominantly emotional system, given that analytical behaviour is encouraged. On the other hand, there might only be one system which is differentially modulated by the amygdala depending on the context.

An unexpected result was found by Talmi et al. (2010) who conducted a framing study with patients suffering from Urbach-White disease (UW) which is associated with bilateral amygdala degeneration. It was shown that UW patients were influenced by the loss condition to the same extent as the healthy control group. However, UW patients chose the riskier option more frequently in the gain condition as compared with the control group. Therefore, the researchers suggest that amygdala activity is more likely to be associated with conditioned risk-aversion rather than with the framing effect itself. Alternatively, it is possible that the amygdala is not solely responsible for the framing effect but rather that it modulates the system of cognitive processes which together lead to this bias in decision-making (Talmi et al., 2010).

Even though our study focused on decision-making in monetary settings, it can be applied to other contexts as well. Next to general media and commercial advertisements, framing has been of particular political interest in the past. Politicians are using framing in order to pursue their political goals and to convince potential voters. For example, former US president Donald Trump made use of framing in his election campaign by calling publications of the media "fake news", therefore discrediting them to attract voters (Vlatković, 2018).

Our study provides an extended framework for future research, as it shows that the brain processes underlying decision-making are still not fully understood. Nevertheless, we provide further evidence for the framing effect in terms of behavioural results. As a dual process approach was neither accepted nor refuted, it is concluded that further research is needed in order to find out to what extent certain brain areas contribute to decision-making. Especially, research should try to focus on the question whether the neural underpinnings of decisions are rather subject to a dual system where the amygdala is active depending on the context or rather one system where the amygdala is always active but gets more active depending on the situation.

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