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Goal-directed behavior under emotional distraction is preserved by enhanced task-specific activation

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Despite the distracting effects of emotional stimuli on concurrent task performance, humans are able to uphold goal-directed behavior. Here, we investigated the hypothesis that this effect is due to the enhanced recruitment of task-specific neural resources. In a two-step functional magnetic resonance imaging study, we first localized those areas involved in mental arithmetics by contrasting arithmetic problems with a number detection task. The resulting activation maps were then used as masks in a second experiment that compared the effects of neutral and emotional distracter images on mental arithmetics. We found increased response times in the emotional distracter condition, accompanied by enhanced activation in task-specific areas, including superior parietal cortex, dorsolateral and dorsomedial prefrontal cortex. This activation increase correlated with larger behavioral impairment through emotional distraction. Similar error rates in both conditions indicate that cognitive task performance is preserved through enhanced recruitment of task-specific neural resources when emotional distracter stimuli are present.

Keywords: affect; emotion; cognition; arithmetic; fMRI

INTRODUCTION

Even in the presence of distracting stimuli, humans are able to coherently perform cognitive tasks such as working memory functions or mental arithmetics. Emotional stimuli are particularly salient distracters. They signal potentially threatening or rewarding events and are thought to automatically attract attentional resources. A large body of research studied the question of whether and how emotional stimuli are automatically detected even under conditions of high cognitive load (Pessoa *et al.*, 2002; Erk *et al.*, 2007; Van Dillen *et al.*, 2009). These studies suggest that performing cognitive tasks reduces detection rates of emotional stimuli and emotion-related activity, for example in the amygdala. In contrast, we know less about the effects that emotional distracters have on cognitive task performance. Evidence from different cognitive tasks suggests that task performance is impaired when emotional stimuli are presented as distracters before (Pereira *et al.*, 2010) or during the task (Vuilleumier *et al.*, 2001). But these effects are rather small and rarely affect accuracy of performance. Thus, a critical question is how task performance is secured in situations of emotional distraction. One hypothesis is that more neural resources are devoted to task performance. In line with this suggestion, a few studies found increased activation in task-relevant brain regions, potentially indicating compensatory activation to preserve goal-directed behavior (Blair *et al.*, 2007; Hart *et al.*, 2010; Pereira *et al.*, 2010). A number of other studies, however, found a reduction of task-relevant activations, which was interpreted as emotion taking the cognitive processing system 'off-line' (Dolcos and McCarthy, 2006; Dolcos *et al.*, 2006; Mitchell *et al.*, 2008; Anticevic *et al.*, 2010). This discrepancy has not yet been solved, but might be due to one shortcoming of the described studies. They did not directly test if the hyper- and hypo-activations were really located in brain regions that are essential and specific for processing the task. It may thus be that the observed effect was not directly related to the task, but to another concurrent process. Therefore, we targeted the question with a two-step fMRI experiment. We first localized brain regions involved in mental arithmetics by directly contrasting an arithmetic task with a number detection task (see, e.g. Rickard *et al.*, 2000). In line with previous studies, we expected this task to yield activation in bilateral parietal cortex and potentially also in dorsolateral and dorsomedial prefrontal cortex (Menon *et al.*, 2000b; Ischebeck *et al.*, 2009). We then used these activation clusters to mask the results of a second experiment in which participants performed arithmetic tasks presented on emotional and neutral distracter images. In contrast to previous studies, this ensures that

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the analyzed effect of emotional distraction on task processing really includes task-specific brain regions. If the hypothesis, that task performance is upheld by the recruitment of more neural resources is correct, then activation in these regions should be enhanced under emotional distraction, particularly in participants who show high behavioral interference effects.

MATERIALS AND METHODS

Participants

Thirty healthy volunteers (17 female, aged 18–27 years, mean age 21.8 ± 2.1 years) participated in the study. Twenty-six participants were right-handed, four participants were left-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision and were medically healthy, reported no history of mental disorders as verified by the Structured Clinical Interview for DSM-IV (SCID-I and -II; German version: Wittchen *et al.*, 1997), no history of serious head injury, neurological disorder or dyscalculia. The Ethics Committee of the University of Heidelberg approved the study and all participants gave written informed consent prior to participation.

Experimental paradigm and procedure

Two experimental tasks were presented (Figure 1). The first was a localizer to identify brain activation specific to the mental arithmetic operations of addition and subtraction. Therefore, 20 arithmetic problems (e.g. $8-3+7=12$) and 20 rows of numbers (e.g. 4 11 0 7) were presented for 6 s each. Participants decided whether the presented solution for the equation was correct or incorrect, and whether a '0' was part of the rows of numbers or not. As soon as participants pressed a button, a thin white frame line was presented around the numbers. All trials were presented in pseudo-randomized order. The task lasted ~8 min.

The second task presented arithmetic problems equivalent to, but different from the localizer task, superimposed on neutral and emotional pictures. The pictures were also presented without an arithmetic task and another condition required participants to reappraise the contents of the images to reduce the elicited emotion; the results of these conditions were presented elsewhere (Kanske *et al.*, 2011). Each trial started with a fixation cross presented with a jitter of 3000–5025 ms and followed by (i) an emotion induction phase (1000 ms), (ii) the distraction (i.e. the presentation of an arithmetic problem; 6000 ms) and (iii) a rating phase (which is not relevant for the present paper; 4000 ms). During the induction phase, participants passively viewed pictures to elicit an initial emotional response. The arithmetic problem was then presented for 6000 ms as a transparent overlay on the picture. As soon as participants pressed a button, a thin white frame line was presented around the overlay.

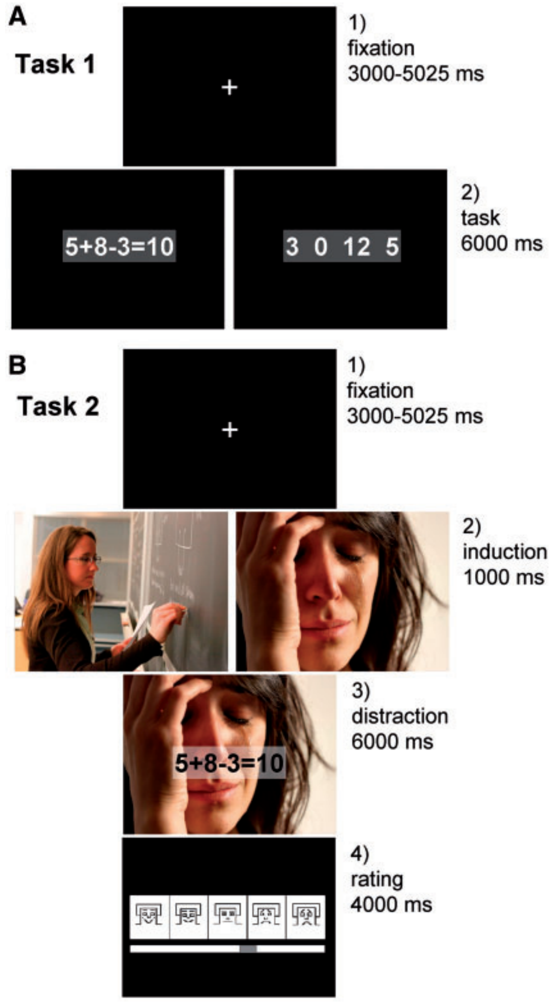

Fig. 1 Sequence of events in a trial of the localizer (**A**) and the experimental task (**B**). The example pictures resemble those in the experiment, but are not part of the IAPS.

The experiment consisted of 128 trials, which were presented in a pseudo-randomized order and lasted ~35 min. Participants received six training trials prior to the experiment, to familiarize them with the procedure.

Stimuli

Pictures were selected from the International Affective Picture System (IAPS; Lang *et al.*, 2005). Sets of 16 highly arousing, negative, 16 neutral, low in arousal and 16 highly arousing, positive stimuli, were created (see Table 1 for mean ratings). An ANOVA confirmed the selection, showing significant effects of picture category on valence and arousal ratings [$F(2,45) = 1332.84$, $P < 0.001$ and $F(2, 45) = 176.65$, $P < 0.001$, respectively]. Differences in valence ratings were observed for each category (all $P < 0.001$), while arousal ratings did not differ for positive *vs* negative, but for emotional *vs* neutral stimuli ($P < 0.001$). To assess whether the participants of the present study evaluated the stimuli similarly to the IAPS normative sample, we had each participant rate

Table 1 Mean valence and arousal ratings and s.d.'s (in parentheses) for the picture selection

	Normative IAPS ratings		Sample ratings	
	Valence	Arousal	Valence	Arousal
Negative	1.87 (0.21)	6.28 (0.64)	2.48 (0.49)	6.00 (1.00)
Neutral	4.92 (0.28)	2.98 (0.34)	5.19 (0.42)	1.77 (0.35)
Positive	7.38 (0.39)	6.29 (0.68)	7.21 (0.35)	5.16 (0.60)

Normative IAPS ratings and the ratings of the present sample are displayed.

each image again after the scanner experiment. To ensure that these ratings were unaffected by the experimental procedures, we did not use the rating phase of the main experiment for the valence values, but conducted the rating after the experiment outside the scanner. The rating was done on a 9-point scale using the Self-Assessment Manikins (Bradley and Lang, 1994). Participants pressed one of nine buttons, each corresponding to one point on the scale (ranging from low to high arousal, and negative to positive valence). The results were comparable to the normative IAPS ratings, but differed in arousal ratings for the positive pictures, which were rated less arousing than negative pictures (see Table 1; $P < 0.001$).

All arithmetic problems were formed with three operands including a subtraction and an addition (e.g. $4 + 9 - 6 = 7$). Initially, 130 arithmetic problems were tested in an independent sample of 10 healthy participants. From these, 20 equations were selected for the localizer task and 48 equations were selected for the main experiment such that they were correctly solved by at least 75% of the sample. These selected equations were randomly assigned to the background picture condition (negative, neutral, positive) such that there were no differences in RTs or number of errors based on the data of the pilot sample (all $P > 0.25$). For the number detection task in the localizer task, the set of numbers contained as many numbers as the arithmetic problems, only the operands were missing. Thus, visual input was kept almost identical.

MRI data acquisition

MRI data were collected on a 3T scanner (Magnetom TIM Trio, Siemens Medical Solutions, Erlangen, Germany) at the Central Institute of Mental Health, Mannheim. A high-resolution T1-weighted 3D image was acquired (slice thickness = 1.1 mm, FOV = 256 mm × 256 mm × 256 mm, matrix = 256 × 256 × 256). Functional images were obtained from 40 gradient-echo T2*-weighted slices (slice thickness = 2.3 mm) per volume. A single-shot echo-planar sequence with parallel imaging GRAPPA technique (acceleration factor 2) was used with a TR of 2700 ms, a flip angle of 90°, TE = 27 ms, FOV = 220 mm × 220 mm, matrix = 96 × 96 and a slice gap of 0.7 mm.

fMRI data analysis

Image processing and statistical analysis was done with SPM5 (http://www.fil.ion.ucl.ac.uk/). Functional images were realigned, slice-time corrected and spatially normalized using the Montreal Neurological Institute (MNI) template. For normalization, images were resampled every 3 mm using sinc interpolation. Images were smoothed using a 9 mm × 9 mm × 9 mm Gaussian kernel.

Individual participants' data were analyzed using a General Linear Model for blood oxygen level-dependant (BOLD) signal changes due to the experimental conditions. Movement parameters calculated during realignment were included as parameters of no interest to control for movement artifacts. Individual statistical parametric maps were calculated for the contrasts of interest in order to investigate BOLD signal changes to (i) mental arithmetics (localizer task: arithmetic problems—number detection) and (ii) the influence of emotion on mental arithmetics (main task: arithmetic problems superimposed on emotional—neutral pictures). In a first step, the analyses were done for positive and negative emotional stimuli separately, which yielded largely comparable results. Also, directly comparing the two emotional categories only yielded stronger activation for negative stimuli in the bilateral ventral temporal cortex (see Supplement S1 in Supplementary Data), which is not part of the mental arithmetics network. To enhance statistical power, we thus pooled positive and negative stimuli, creating one emotional condition for the analyses reported here.

Second-level random-effects analyses were calculated. One-sample *t*-tests were computed on the above mentioned individual contrast images. Activations were thresholded at a whole-brain FDR corrected $P < 0.05$ with an extent threshold of 20 voxels in order to protect against false-positive activations. From the activations found in the localizer task, a mask image was created using the same thresholds. This mask was then used for the main task, which was thresholded again.

RESULTS

Behavioral results

Localizer task

Accuracy was higher for the number detection compared to the arithmetic task [$M = 96.2\%$, s.d. = 12.0; $M = 76.8\%$, s.d. = 18.1; $F(1,29) = 30.3$, $P < 0.001$]. Reaction times to number detection were also shorter than to the arithmetic tasks [see Figure 2D; $M = 1.2$ s, s.d. = 0.6; $M = 3.7$ s, s.d. = 0.5; $F(1,29) = 486.5$, $P < 0.001$].

Main task

As there were no significant differences between reaction times in positive and negative trials, these were averaged to an emotional condition [negative: $M = 3.55$ s, s.d. = 0.50; positive: $M = 3.51$ s, s.d. = 0.52; $F(1,29) = 0.2$, $P > 0.60$]. Reaction times were longer for this emotional compared to

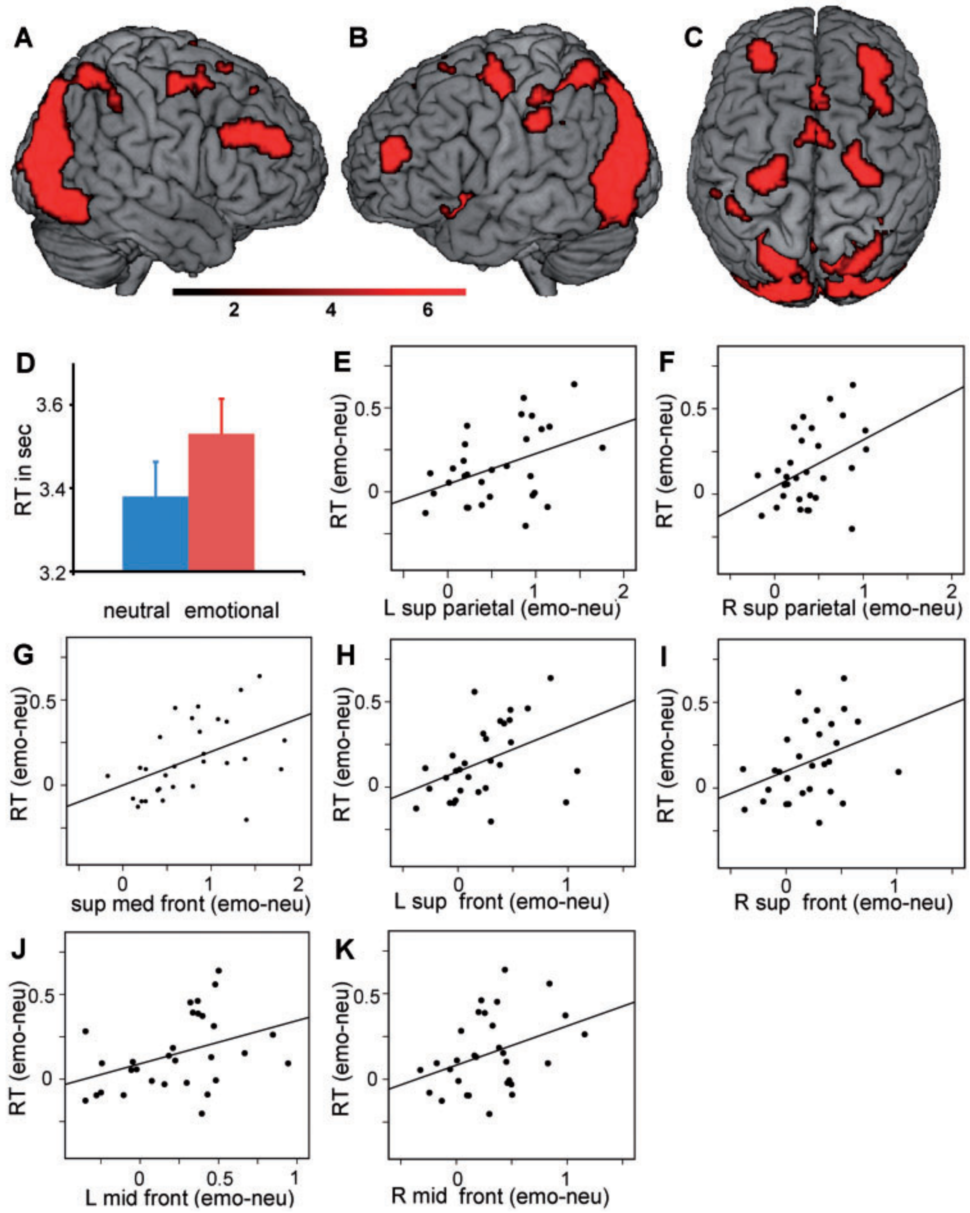

Fig. 2 Activations for mental arithmetics on emotional *vs* neutral distracters in viewed from the right (**A**) and the left side (**B**) and from above (**C**). Reaction times in the experimental task (**D**) and correlations of the reaction time difference and activation differences between emotional and neutral trials in left (**E**) and right (**F**) superior parietal cortex, superior medial frontal cortex (**G**), left (**H**) and right (**I**) superior frontal, and left (**J**) and right (**K**) middle frontal cortex.

neutral distracter trials [see Figure 2; neutral: $M = 3.38$ s, s.d. $= 0.45$; emotional: $M = 3.53$ s, s.d. $= 0.46$; $F(1,29) = 14.1$, $P < 0.001$]. Arithmetic problems (90.8%) were correctly solved (s.d. 6.2), there were no significant differences between conditions [$F(1,29) = 0.6$, $P > 0.45$].

fMRI results

Localizer task

The contrast of arithmetic tasks with the number detection tasks in the localizer yielded activation in widespread network of brain regions including the parietal cortex, lateral and medial prefrontal cortex, and the insula (Table 2).

Main task

The activation clusters identified in the localizer task were used as masks for the contrast of arithmetic problems presented on emotional and neutral distracters. We observed no significant activation for the neutral over the emotional distracter condition (even with a more lenient threshold of $P < 0.001$ uncorrected, and also when conducting a whole-brain analysis). However, the parietal cortex, regions in the lateral prefrontal cortex and the left insula were activated more strongly for mental arithmetics in emotional when compared to neutral distracter trials (Table 2 and Figure 2).

Table 2 Peak activations in the localizer and main task for mental arithmetics and mental arithmetics on emotional *vs* neutral distracters

	H	BA	MNI coordinates			CS	Z
			x	y	z		
Arithmetic—number detection							
Superior frontal	L	6/8	−27	0	60	1092	6.40
Middle frontal	L	10/45/46	−36	54	15	[a]	5.79
Superior frontal	R	6/8	30	3	57	1164	5.90
Middle frontal	R	10/45/46	45	42	27	[a]	5.51
Medial frontal/anterior cingulated	R	6/8/24/32	6	18	51	425	7.24
Insula	L	6/8/24/32	−6	15	45	[a]	6.64
	R	48	36	21	−3	265	7.46
	L	48	−33	21	−3	230	7.43
Inferior parietal	L	40	−42	−39	42	2941	7.63
Superior parietal	L	7	−24	−59	39	[a]	7.30
Inferior parietal	R	40	45	−39	45	[a]	6.64
Superior parietal	R	7/40	33	−48	45	[a]	6.91
Middle occipital	L	17/18/19	−33	−84	12	[a]	7.19
	R	17/18/19	30	−96	3	[a]	6.82
Arithmetic emotional—arithmetic neutral							
Superior frontal	L	6	−21	−6	72	133	3.19
Middle frontal	L	46	−30	−54	24	57	3.54
Superior frontal	R	6	21	0	55	104	3.90
Middle frontal	R	46	30	51	27	122	3.99
Superior medial frontal	L	8/32	−3	18	44	72	2.79
Anterior cingulated	R	24/32	6	39	27	63	3.16
	L	24/32	−5	33	27	[a]	3.05
Insula	L	48	−27	15	−14	37	3.87
Middle occipital	L	17/18/19	−42	−81	12	4396	5.50
	R	17/18/19	30	−75	30	[a]	5.17
Superior parietal	R	7/40	24	−60	63	[a]	3.16
	L	7/40	−18	−60	60	[a]	4.06

[a]Indicates that this peak is part of the cluster listed earlier.
H = Hemisphere; CS = Cluster size in number of activated voxels.

Correlations

To further assess the relation of the increased task-related activation under emotional distraction to the behavioral distraction effect, we conducted a correlational analysis. We extracted the first eigenvariate of the time-course of the activations in Table 2 with a spherical 5-mm radius ROI and correlated it to the RT difference between emotional and neutral trials (Table 3). This yielded significant correlations with left and right superior parietal cortex, superior medial frontal cortex, as well as left and right middle and superior frontal cortex. The data indicate that larger behavioral interference was accompanied by increased activation in the respective brain regions. To assess the specificity of these correlations to task-related processing, we also calculated correlations with activity in the left and right amygdala, which we had found to be active when comparing emotional with neutral images in a simple viewing condition (Kanske *et al.*, 2011), but which was not part of the network for arithmetic processing as identified in the localizer task. For this analysis, we extracted the first eigenvariate for the present contrast (arithmetic tasks on emotional *vs* neutral background images) from 5 mm spheres defined by the amygdala

Table 3 Correlations of the activations observed in the contrast of 'arithmetic emotional—arithmetic neutral' (Table 2) with the behavioral distraction effect, i.e. RTs emotional—neutral

	H	r	P
Superior frontal	L	0.42	0.010*
	R	0.37	0.023*
Middle frontal	L	0.39	0.016*
	R	0.37	0.023*
Superior medial frontal	L	0.47	0.005**
Anterior cingulated	R	0.01	0.463
	L	0.14	0.217
Insula	L	0.25	0.090
Middle occipital	L	0.01	0.487
	R	0.29	0.061
Superior parietal	R	0.41	0.010*
	L	0.42	0.013*
Amygdale	L	0.19	0.149
	R	−0.03	0.426

Additionally, the correlation of the RT effect with left and right amygdala activity extracted from the same contrast, but without the localizer mask, is reported.
H = Hemisphere, r = Pearson correlation coefficient, $*P < 0.05$, $**P < 0.01$.

activation, we had found when contrasting emotional and neutral stimuli in a simple viewing condition in which participants attended to the images, but performed no parallel task (see Kanske *et al.*, 2011). Here, we found no significant correlation (Table 3).

DISCUSSION

The present study gives new insights into the effects of emotional distraction on cognitive task performance. Emotional background images increased response times, but did not affect error rates, indicating that emotion did have a distracting effect, but that participants were still able to uphold goal-directed behavior. This effect was accompanied by increased activation for mental arithmetics in task-specific brain regions. This increase was particularly strong in participants showing larger behavioral interference. The data suggest that it is enhanced recruitment of task-specific neural resources that ensures continued task performance even when emotional distracters are present.

Thereby, the present results clarify previous data with inconsistent effects of emotional distraction on cognitive tasks. While some studies found enhanced activation in dorsal 'cognitive' brain regions (Blair *et al.*, 2007; Hart *et al.*, 2010; Pereira *et al.*, 2010), others reported an activation decrease in these areas (Dolcos and McCarthy, 2006; Dolcos *et al.*, 2006; Mitchell *et al.*, 2008; Anticevic *et al.*, 2010). The present study differs from previous approaches in the direct localization of task-specific brain regions, before measuring the distraction effects in these areas. As our data show enhanced activations under emotional distraction, they conform to the hypothesis that task-specific activation is boosted in order to overcome the distraction effect. This suggests that the activation reduction found in some studies is not directly task-related, but reflects some other cognitive process. The exact nature of this process is unclear, however, one putative role is the inhibition of task-irrelevant information and the protection against interference (Shimamura, 2000; Jha *et al.*, 2004). A study by Sommer *et al.* (2008) hints at that. The authors used a spatial conflict paradigm in which the shape of a stimulus determined the response, while the stimulus location elicited an interfering response tendency in some trials. Here, emotion caused disturbed behavioral conflict resolution along with reduced dlPFC and ACC activation. Future studies should target this question, possibly by combining conflict paradigms with the present approach.

The results differ markedly from previous reports of facilitated cognitive task performance induced by emotional stimuli, for example, of attention (Keil *et al.*, 2005) or cognitive control (Kanske and Kotz, 2011b). This discrepancy is best explained by the role of the emotional stimuli in the respective tasks. While they were not behaviorally relevant and presented in the background of the target stimuli in the present study, facilitation effects are observed when the task-specific target stimuli themselves are emotional. Interestingly, this emotional facilitation is accompanied by increased activation in brain regions involved in the processing of conflict (Kanske and Kotz, 2011a), which complements the data by Sommer *et al.* (2008) discussed earlier.

An alternative explanation for the present results is that the observed hyper-activation directly reflects emotional processing and not the effect of emotion on task-performance. However, this possibility is highly unlikely. First, the results were masked with the activation clusters found for arithmetic processing in the localizer task. This task did not involve emotional stimuli, the resulting mask image should therefore not include emotion specific activations. Second, contrasting emotional with neutral stimuli without specific task demands activates a more ventral–limbic network that does not overlap with the task-related activations reported here (Kanske *et al.*, 2011). Furthermore, the correlation of the activation increase with the RT interference effect may also suggest that the observed areas are directly relevant for task performance. Even though it is principally possible that increased behavioral interference is related to enhanced activity in emotion-related brain regions, the lack of a significant correlation between RTs and amygdala activity suggests otherwise. The amygdala was found to be active when contrasting emotional and neutral images in a simple viewing condition without any active task superimposed (Kanske *et al.*, 2011), but not in the arithmetic localizer task, which demonstrates its involvement in emotional, rather than cognitive processing. As the correlations between behavior and brain activity were restricted to regions activated in the localizer task, this correlation seems to be specific for task-related activation.

Interestingly, significant correlations were not observed across all of the observed activations, but only in superior parietal, superior and middle frontal and superior medial frontal cortex. These regions are those most consistently found in studies on arithmetic processing, in particular parietal and middle prefrontal cortex have been described as hosting representations of quantity and mental calculation (for a review, see Dehaene *et al.*, 2004). It is, therefore, possible that while activity in a larger task-related network is enhanced to overcome emotional distraction effects and ensure correct task performance, only those regions directly involved in arithmetic operations show a relation to increased RTs during distraction. According to Perneger (1998), we did not correct the correlations for multiple comparisons. Testing the whole pattern of correlations between the RT and fMRI data provides more and very specific information, for example, by including the amygdala activity, for which we expected no significant effects (see also Hensch *et al.*, 2007). To allow an evaluation of the psychological importance of the results, we report the exact *P*-values along with the correlations (as standardized effect sizes) as recommended by Nakagawa (2004).

One limitation of the present study concerns the question how specific the neural network that was identified in the localizer task is for arithmetic processing. Because of lower accuracy and longer RTs, task difficulty seems to have been higher in the arithmetic compared to the number detection task. It is therefore possible that some of the observed activations are due to task difficulty and not mental arithmetics. This argument applies to a number of previous studies on arithmetic processing that also used number detection as control conditions (Menon *et al.*, 2000a, 2000b; Rickard *et al.*, 2000). Nevertheless, the neural network identified for arithmetic processing across different types of tasks including a variety of different control conditions is largely overlapping and corresponds well to the clusters observed in the present study (Fehr *et al.*, 2007; Grabner *et al.*, 2007; Zago *et al.*, 2008; Ischebeck *et al.*, 2009). This suggests that there is some functional specificity for arithmetic processing in the network. Future studies should validate this point, potentially using the conjunct activity of different tasks as mask images. In a similar vein, as the results were masked it seems odd that we observed activation in the insula, which has been mainly implicated in emotional processing (Singer *et al.*, 2009). However, insula activation is also a common finding in studies of arithmetic processing (Menon *et al.*, 2000b; Grabner *et al.*, 2007, 2009; Ischebeck *et al.*, 2009) and was also part of the network identified in the localizer task. The arithmetic activation seems to be slightly anterior to the emotional activation (see also Kanske *et al.*, 2011), but the exact role of the insula in mental arithmetics still needs to be elucidated.

A second limitation concerns the differentiation of the emotional distraction effects. We observed no relevant differences in behavior and neural activity between positive and negative images, which could suggest that it is mainly the increased arousal in the emotional conditions that drives the distraction effects. This could be tested in future studies by systematically manipulating valence and arousal values of the presented stimuli. Furthermore, it is conceivable that the distraction effects may vary for different emotions such as anger, fear or joy (for a meta-analysis on commonalities and differences in the neural underpinnings of different emotions see Phan *et al.*, 2002), which is also an empirical question for future studies.

The present data are also relevant for the interpretation of previous results from patients with mental disorders. Despite preserved behavioral task performance, patients with depression or bipolar disorder, for example, show enhanced task-related activity under emotional distraction (Wessa *et al.*, 2007; Dichter *et al.*, 2009). Our data support the authors' interpretation of these effects as a compensatory mechanism to deal with greater emotional interference, which may be caused by hyper-activation in limbic regions involved in affective processing (Phillips *et al.*, 2008).

To conclude, the present study showed that task performance under emotional distraction is preserved through enhanced activation in task-specific brain regions. The use of a two-step fMRI procedure, which first localized task-related activations before investigating the effect of emotion on them, was fruitful and is recommended for future studies.

SUPPLEMENTARY DATA

Supplementary Data are available at *SCAN* online.

Conflict of Interest

None declared.

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