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ORIGINAL ARTICLE

Differences between endogenous and exogenous emotion inhibition in the human brain

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Abstract The regulation of emotions is an integral part of our mental health. It has only recently been investigated using brain imaging techniques. In most studies, participants are instructed by a cue to inhibit a specific emotional reaction. The aim of the present study was to investigate the alternative situation where a person decides to inhibit an emotion as an act of endogenous self-control. Healthy participants viewed highly arousing pictures with negative valence. In the endogenous condition, participants could freely choose on each trial to inhibit or feel the emotions elicited by the picture. In an exogenous condition, a visual cue instructed them to either feel or inhibit the emotion elicited by the picture. Participants' subjective ratings of intensity of experienced emotion showed an interaction effect between source of control (endogenous/exogenous) and feel/inhibit based on a stronger modulation between feel and inhibition for the endogenous compared to the exogenous condition. Endogenous inhibition of emotions was associated with dorso-medial prefrontal cortex activation, whereas exogenous inhibition was found associated with lateral prefrontal cortex activation. Thus, the brain regions for both endogenous and exogenous inhibition of emotion are highly similar to those for inhibition of motor actions in Brass and Haggard (J Neurosci 27:9141–9145, 2007), Kühn et al. (Hum Brain Mapp 30:2834–2843, 2009). Functional connectivity analyses showed that dorsofrontomedial cortex exerts greater control onto pre-supplementary motor area during endogenous inhibition compared to endogenous feel. This functional dissociation between an endogenous, fronto-medial and an exogenous, fronto-lateral inhibition centre has important implications for our understanding of emotion regulation in health and psychopathology.

Keywords Inhibition · Volition · Emotion regulation · fMRI · Dorsofrontomedial cortex

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Introduction

Self-control is an essential part of human existence. It has been defined as the capacity to alter one's behaviour, notably by overriding immediate impulses to bring behaviour in line with goals and standards (Carver and Scheier 1981). Importantly, self-control can also be applied to emotions, as when we try to control our fears in a frightening situation, or try to put an unpleasant image out of our mind after a dream. Further, self-control of emotion is compromised in some psychopathologies such as anxiety and depression (Aldao et al. 2010).

Social neuroscience has used emotion regulation paradigms to explore emotion control. In many studies, participants try to control emotions elicited by specific cues. They are often instructed to use a specific cognitive strategy, such as detachment or reappraisal, to reduce certain emotions (Beauregard et al. 2001; Goldin et al. 2008; Ochsner et al. 2004; Phan et al. 2005). Crucially, participants generally receive external cues telling them whether to feel or inhibit the emotion. However, we are rarely told

not to feel an emotion in everyday life. Rather, we usually have to decide ourselves whether to feel or inhibit an emotion. We hypothesise that intentional inhibition of emotions is a distinct form of self-control, and may differ from the ability to inhibit emotions in response to an external instruction.

Evidence for a distinction between intentional and external inhibition processes comes from previous research on action control. Several studies of exogenous inhibition have suggested an inhibitory 'control process' housed in the lateral prefrontal cortex. In a meta-analysis on the so called Go/NoGo tasks, in which participants have to respond to Go stimuli and inhibit responding to less frequent NoGo stimuli, Aron and Poldrack (2005) identified the right inferior frontal cortex as the core brain area for response inhibition (see also Aron et al. 2004). Other studies used stop-signal tasks, in which participants prepare to respond and are then instructed to inhibit the action. Trials in which participants successfully inhibited their response showed activation of similar lateral prefrontal brain areas, namely inferior frontal cortex and middle frontal gyrus (Aron and Poldrack 2006; Li et al. 2006). Crucially, in both types of experiment, the inhibition of an ongoing action is triggered by an external stimulus.

Endogenous inhibition of action has been less researched, though the idea has a long heritage (Descartes 1649; Libet 1983), and a natural link to the philosophical concept of willpower (Hagger et al. 2010). Brass and Haggard (2007) asked participants to press a button at a time of their choice while monitoring a rotating clock. At the end of each trial, participants reported the time of the decision to press the key. Moreover, they were instructed to inhibit the execution of their action in some trials that they were free to choose. When comparing endogenous inhibition with action trials, brain activation was found in dorsal frontomedial cortex (dmPFC), but not in the lateral prefrontal areas associated with exogenous inhibition. A further study replicated this finding using a very different paradigm involving intentional inhibition of highly prepotent responses (Kühn et al. 2009).

Up to now there is no evidence whether the distinction between exogenous and endogenous inhibition applies only to actions, or whether it may generalise to emotions as well. However, if an endogenous form of emotion inhibition can be distinguished, its relevance for day-to-day emotion regulation would be clear. To address this issue, we directly compared endogenous and exogenous control of negative emotions. Participants saw fear-inducing pictures (e.g. weapons). In one condition they were then instructed to inhibit or feel the emotions elicited by the picture, while in another condition they freely chose for themselves whether to inhibit or feel the emotion.

Therefore our experimental design allows us to compare the neural structures involved in endogenous and exogenous control of emotions directly.

Methods

Participants

Fifteen healthy female students (age: mean = 22.6 years, ranging from 18 to 27) participated on the basis of informed consent. The study was conducted according to the Declaration of Helsinki, with approval of the local ethics committee. All subjects had normal or corrected-to-normal vision. No subject had a history of neurological, major medical, or psychiatric disorder (according to personal interviews with the Mini-International Neuropsychiatric Interview, Lecrubier et al. 1997). All participants were right-handed as assessed by the Edinburgh handedness questionnaire (mean score = 85; Oldfield 1971).

Materials

We selected 90 pictures of the International Affective Picture System (IAPS; Lang et al. 2005) with mean arousal values >6 and mean valence ratings <4 based on the normative ratings of female participants. We selected pictures with threat-related content (e.g. frightening animals, weapons) to exclude pictures associated with other emotions such as disgust or sadness.

Behavioural task

During the experiment participants were confronted with pictures of high arousal and negative valence. Each trial started with presentation of one of the pictures for 2 s. This initial presentation before the instruction cue was designed to ensure a strong initial emotional processing of the stimulus, which would be followed by inhibition on some trials. Our logic was based on analogy with motor stopping tasks, in which participants first see a go stimulus, feel the strong urge to respond and only afterwards get the signal to inhibit the ongoing action. After initial presentation of the emotional picture, a brief colour flash of 200 ms duration instructed the participants to either (1) feel the emotion elicited by the picture if the colour was green (*exogenous feel condition*), (2) not to feel the emotion if the colour was red (*exogenous inhibition condition*) and (3) decide for themselves between feeling or not feeling the emotion when the colour was yellow (*endogenous feel condition*, *endogenous inhibition condition*) (Fig. 1). After the colour cue the picture was shown for another 10 s. After a jitter interval of 2–3.5 s (varied in steps of 500 ms) a 4-point

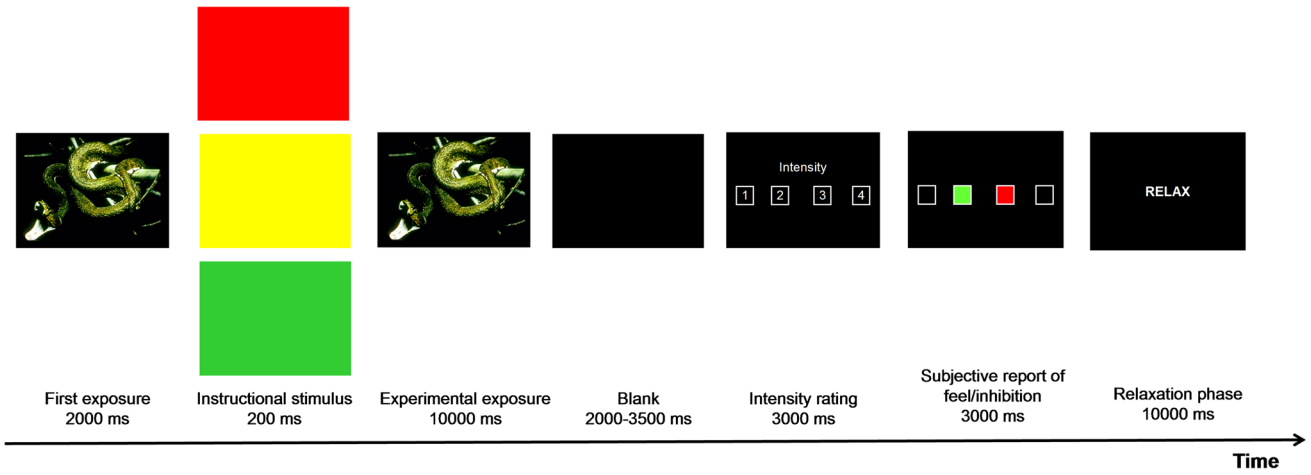

Fig. 1 Schematic drawing of the paradigm

rating scale was presented prompting a report of the intensity of the emotion felt after the regulation instruction. Participants responded by means of two hand held button boxes operated with the right and left index and middle finger. The intensity rating scale was randomly presented, so that '1' was on the left and '4' on the right in some trials, while other trials used a reversed scale with '4' on the left and '1' on the right side of the screen. This was done to prevent movement preparation during exposure to the emotional picture. After the intensity rating participants had to indicate whether the current trial was a *feel* or *inhibition* trial by pressing the right or left index finger. In the case of a yellow colour flash, the response allowed the participants to indicate whether they had chosen to feel or inhibit the emotion. After that participants were asked to relax for 10 s. The following inter-trial-interval varied between 0 and 1.5 s (in steps of 500 ms). The three conditions (exogenous feel, exogenous inhibit, endogenous) were randomly intermixed across the experiment. The experiment consisted of 4 runs, each containing 20 trials, with an overall duration of approximately 35 min.

Before the experiment started, participants were instructed to naturally experience the emotional response the picture might elicit in *feel* trials. In order to decrease their negative emotions in *inhibition* trials there were instructed to use a variant of reappraisal, namely distancing (Gross 1998). They were asked to increase their sense of objective distance and to view the image in a detached way (Eifert and Heffner 2003; Levesque et al. 2003; Beauregard et al. 2001; Ochsner et al. 2004). One example we used to explain this strategy is to imagine being a doctor when a picture of a wounded person is being shown. Participants were instructed not to look away, blur their vision or to distract themselves with irrelevant thoughts. After the instruction they received a brief training session comprising 10 pictures that were not part of the later stimulus set.

Scanning procedure

Images were collected with a 3T Magnetom Trio MRI scanner system (Siemens Medical Systems, Erlangen, Germany) using an 8-channel radiofrequency head coil. First, high-resolution anatomical images were acquired using a T1-weighted 3D MPRAGE sequence (TR = 2,530 ms, TE = 2.58 ms, TI = 1,100 ms, acquisition matrix = 256 × 256 × 176, sagittal FOV = 220 mm, flip angle = 7°, voxel size = 0.86 × 0.86 × 0.9 mm^3). Functional images were collected using a T2*-weighted EPI sequence sensitive to BOLD contrast (TR = 2,000 ms, TE = 35 ms, image matrix = 64 × 64, FOV = 224 mm, flip angle = 80°, slice thickness = 3.0 mm, distance factor = 17 %, voxel size 3.5 × 3.5 × 3 mm^3, 30 axial slices). 260 image volumes aligned to AC-PC were acquired per run.

Behavioural analysis

We excluded those few trials in which participants were instructed to feel or not to feel the emotion, but volunteered at the end of the trial that they had responded incorrectly (0.7 %). To investigate whether the valence and arousal value of pictures where participants chose to feel differed from that of pictures where participants chose to inhibit we computed a repeated measure ANOVA with the factors source of control (endogenous vs. exogenous) and feel/inhibition using IAPS valence and arousal norms for each stimulus as the dependent variable. The same analysis strategy was applied to the participants' ratings of the intensity of experienced emotion.

fMRI data pre-processing and main analysis

The fMRI data were analysed using SPM5 software (Wellcome Department of Cognitive Neurology, London,

UK). The first four volumes of all EPI series were excluded from the analysis to allow the magnetization to approach a dynamic equilibrium. Data processing started with slice time correction and realignment of the EPI datasets. A mean image for all EPI volumes was created, to which individual volumes were spatially realigned by means of rigid body transformations. The structural image was co-registered with the mean image of the EPI series. Then the structural image was normalised to the Montreal Neurological Institute (MNI) template, and the normalisation parameters were applied to the EPI images to ensure an anatomically informed normalisation. A commonly applied filter of 8 mm FWHM (full-width at half maximum) was used. Low-frequency drifts in the time domain were removed by modelling the time series for each voxel by a set of discrete cosine functions to which a cut-off of 128 s was applied. The statistical analyses were performed using the general linear model (GLM). We modelled the picture at the beginning of each trial (first exposure) as an event. Moreover, we modelled each trial starting with the colour flash as a boxcar function with the duration of the picture presentation separately for the conditions: exogenous feel, exogenous inhibition, endogenous feel, endogenous inhibition. The request phase (containing the intensity rating and the subjective report whether the trial was a feel or inhibition trial) and the relaxation phase were modelled as separate blocks. These vectors were convolved with a canonical hemodynamic response function (HRF) and its temporal derivatives to form regressors in a design matrix. The parameters of the ensuing general linear model were estimated in the usual way and used to form contrasts, testing for main effects and interactions. The resulting contrast images were then entered into a series of one sample t tests at the second (between subject) level. This is the usual summary statistic approach to random effect analyses. For display purposes the resulting SPMs were thresholded at $p < 0.001$ (uncorrected) with an extent of threshold of five voxels. However, we only report effects that survive small volume correction within the brain regions identified in the main effect of source of control (F contrast). The resulting maps were overlaid onto a normalised T1 weighted MNI template (colin27) and the coordinates reported correspond to the MNI coordinate system.

Percent signal change analysis

For the signal change analysis we used a sphere with a radius of 6 mm around the peak coordinate of interest. In order to explore effects of emotion inhibition on specific brain structures linked to emotion processing, we used predefined masks for right and left amygdala from the WFU pickatlas (Maldjian et al. 2003, 2004). For each subject, region and condition, the mean percent signal change over a time window of 4–6 s after stimulus onset was computed (http://marsbar.sourceforge.net/; Brett et al. 2002).

Functional connectivity analysis

Psychophysiological interaction (PPI, Friston et al. 1997) analysis assesses whether the connectivity between a seed region and all other voxels in the brain is changed by an experimental condition. We explored PPIs for a volume of interest (VOI) in the dmPFC and right middle frontal gyrus. Individual VOIs were defined as 6-mm radius spheres, around the local maximum in appropriate contrasts, as follows. For the dmPFC the individuals' voxel closest to the peak voxel of the group analysis (4, 63, 18) was selected on the contrast endogenous vs. exogenous inhibition. For the right middle frontal gyrus, the individuals' voxel closest to the peak voxel of the group analysis (46, 28, 39) was selected on the contrast exogenous vs. endogenous inhibition. The significance for the VOI extraction was set to $p < 0.005$, $k > 5$ (uncorrected).

The time series data of the first eigenvariate of the prefrontal VOI formed the physiological variable. A psychological variable was constructed, which encoded the effect of inhibition (separate analysis for the endogenous and exogenous condition). The PPI regressor is the interaction (multiplication) of these physiological and psychological effects. Note that the physiological variable encodes an effect of endogenous versus exogenous regulation, while the psychological variable reflects endogenous inhibition versus endogenous feel. The design matrix for the PPI analysis contains the psychological and physiological variables and their interaction (the PPI). Crucially, a significant PPI accounts for evoked responses that cannot be explained by the direct physiological or psychological variables per se.

A similar analysis was performed for brain regions influenced by right middle frontal gyrus. Here the physiological variable encoded the effects of exogenous versus endogenous regulation, while the psychological variable reflects exogenous inhibition versus exogenous feel. In addition, we conducted a PPI for dmPFC and right middle frontal gyrus exploring the effects on exogenous versus endogenous inhibition. The second-level random effects for both PPI analyses were thresholded at a more lenient threshold of $p < 0.005$, $k = 5$ (uncorrected), because this analysis was of exploratory nature.

Results

Behavioural results

The number of *endogenous feel* (mean = 20.1; SD = 2.17) and *endogenous inhibition* (mean = 19.9; SD = 2.17) trials

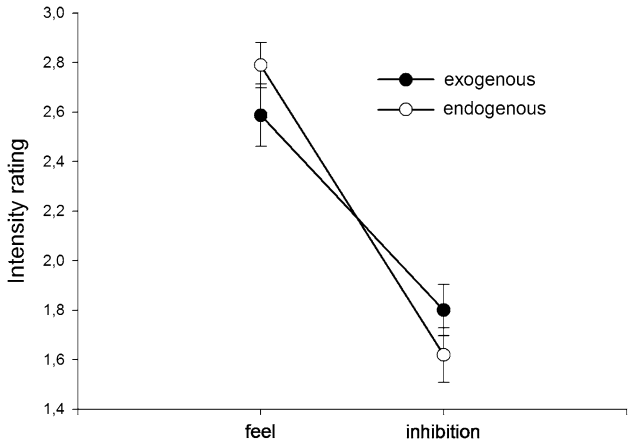

Fig. 2 Subjective intensity ratings. Note the more pronounced modulation of emotion in the endogenous compared to the exogenous condition

did not differ significantly [$t\,(14) = -0.24, p = 0.82$]. Since participants freely chose whether to feel or inhibit emotion for each picture, emotional responses could, in principle, be confounded with stimulus features. We therefore investigated whether the valence and arousal value of pictures where participants chose to feel differed from that of pictures where participants chose to inhibit. We found no significant effect, main effects or interactions, either for valence ($p > 0.40$) or for arousal ($p > 0.55$). A further planned comparison of valence and arousal between the endogenous feel and inhibition trials also revealed no difference (valence $p > 0.18$, arousal $p > 0.45$), suggesting the endogenous choice was not, in fact, an exogenous reaction to particular stimulus features.

The analysis of the participants' ratings of the intensity of experienced emotion showed a main effect of feel/inhibition [$F\ (1.14) = 64.27,\ p < 0.001$] with higher affective intensity for the *feel* compared to the *inhibition* condition. There was no main effect of source of control (endogenous/exogenous), but a highly significant interaction between source of control and feel/inhibition [$F\ (1.14) = 21.32,\ p < 0.001$] based on stronger intensity modulation between *feel* and *inhibition* for the *endogenous* compared to the *exogenous* condition (Fig. 2). Paired *t* tests show a significant difference between inhibit and feel intensity ratings for the exogenous [$t\ (14) = -5.67,\ p < 0.001$] and endogenous [$t\ (14) = -9.92,\ p < 0.001$] condition.

fMRI results

The whole brain interaction of the factors source of control (endogenous vs. exogenous) and feel/inhibition did not yield any significant effects (with a threshold of $p < 0.001$, $k > 5$).

To ensure that our paradigm produced the usual main effects of emotional feelings on the amygdala, we first looked at the significance of the contrast feel vs. inhibition testing for this main effect in, and only in, the amygdala, since this is the paradigmatic brain structure underlying evaluation of the emotional significance of stimuli (for review see Lane and Nadel 2000). In order to do so we used an anatomical ROI of bilateral amygdala (created by means of the WFU pickatlas) for small volume correction. We found significantly greater activation when emotions were felt rather than inhibited, (coordinates −16, −4, −17, cluster corrected *p* value 0.043), neither source of control (endogenous/exogenous) nor the interaction between feel/inhibition and source of control was significant ($p > 0.3$).

The main effect of source of control (F contrast) resulted in activation in right MFG, dmPFC, mid cingulate cortex, left IPL, bilateral postcentral gyrus, right superior temporal gyrus, supplementary motor area (SMA) and precuneus ($p < 0.001$, $k > 5$).

To investigate the contrast of interest, namely differences between intentionally inhibiting an emotion and being instructed to inhibit an emotion we contrasted the *endogenous inhibition* with the *exogenous inhibition* condition. In a whole brain analysis we found higher activity in dmPFC, bilateral posterior superior temporal gyrus (STG) and left middle occipital gyrus for the *endogenous inhibition* condition; and higher activity in right middle frontal gyrus (MFG) and left inferior parietal lobule (IPL) for the *exogenous inhibition* condition (Fig. 3a; Tables 1, 2). We performed a small volume correction within those brain regions that survived multiple comparison correction within the regions involved in the main effect contrast of source of control. These areas were dmPFC, STG, MFG and IPL.

Then we explored the BOLD signal change in the brain regions identified within the contrast of *endogenous inhibition* and *exogenous inhibition* for interactions of the source of control (endogenous/exogenous) and condition (feel/inhibition). We found significant interaction effects in dmPFC [$F\ (1.14) = 5.68,\ p < 0.05$] and right MFG [$F\ (1.14) = 14.32,\ p < 0.01$] (Fig. 4).

Based on our finding that dmPFC is involved in intentional inhibition of emotion, we wanted to explore what functional connectivity might underlie this control. Therefore, we conducted a PPI analysis with a seed voxel in dmPFC (4, 63, 18) searching for brain regions that show a higher connectivity with dmPFC during endogenous inhibition compared to endogenous feel. The results show that dmPFC is more strongly connected to pre-supplementary motor cortex (preSMA; −4, 14, 49) during the *endogenous inhibition* compared to the *endogenous feel* condition ($p < 0.005$, $k > 5$, Fig. 3b). We also explored functional connectivity with a seed in the middle frontal

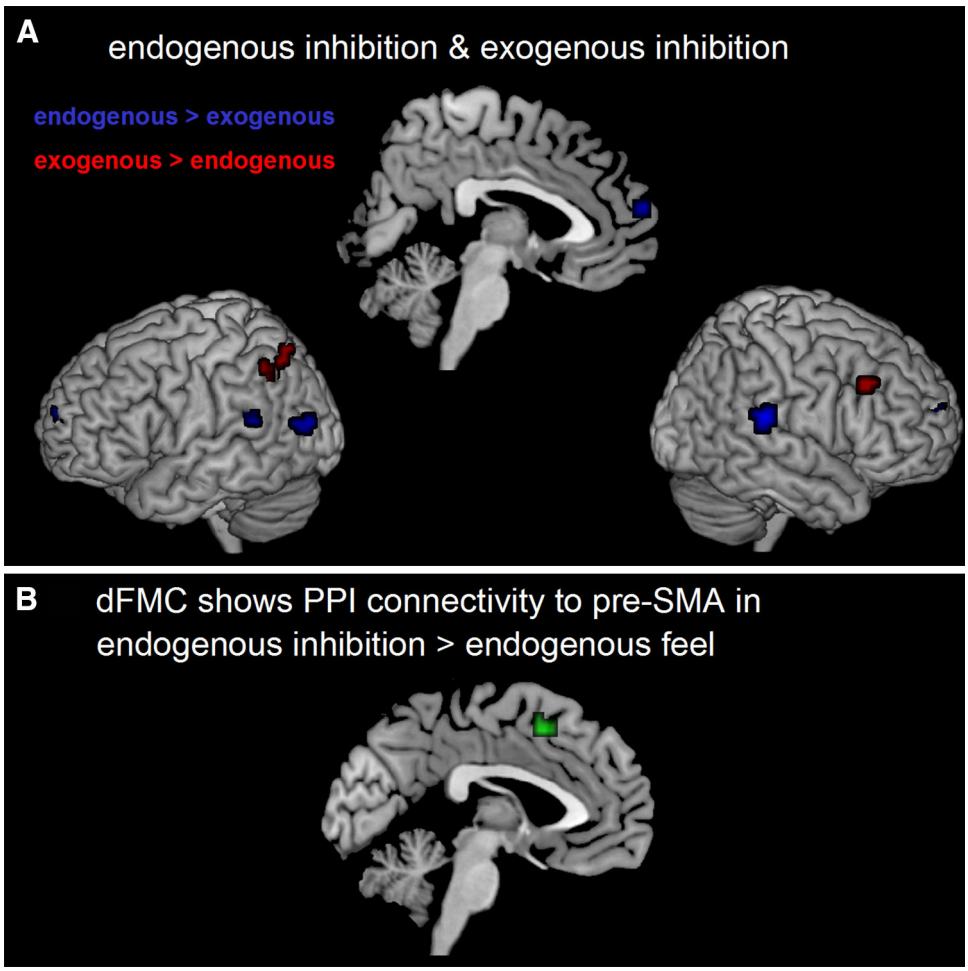

Fig. 3 **a** Main contrast of the endogenous inhibition vs. exogenous inhibition condition. SPMs averaged over 15 subjects ($p < 0.001$, 5 adjacent voxels, uncorrected) mapped onto an MNI template. *Blue* endogenous inhibition > exogenous inhibition, *red* exogenous inhibition > endogenous inhibition. **b** Differences in functional connectivity (endogenous inhibition vs. endogenous feel) between the seed region in dorsal frontomedial cortex (dmPFC; 4, 63, 18) and the pre-supplementary motor area (preSMA; −4, 14, 49) ($p < 0.005$, 5 adjacent voxels, uncorrected)

Table 1 Areas showing significant activation in whole brain contrast *endogenous inhibition* vs. *exogenous inhibition* (*p* values are cluster corrected based on a small volume correction of regions of the main effect of source of control)

Area	BA	Peak coordinates (MNI)	*Z*-score	Extent	Cluster-level corrected *p* values
Right superior temporal gyrus	42/22	67, −28, 21	4.62	18	0.01
Dorsal frontomedial cortex (dmPFC)	10	4, 63, 18	3.74	14	0.02
Left middle occipital gyrus	19	−49, −77, 14	3.56	13	
Left superior temporal gyrus	42/22	−49, −46, 18	3.54	9	

Table 2 Areas showing significant activation in whole brain contrast *exogenous inhibition* vs. *endogenous inhibition* (*p* values are cluster corrected based on a small volume correction of regions of the main effect of source of control)

Area	BA	Peak coordinates (MNI)	*Z*-score	Extent	Cluster-level corrected *p* values
Left inferior parietal lobe	40	−35, −56, 42	4.56	27	0.015
Right middle frontal gyrus	9	46, 28, 39	3.32	8	0.020

gyrus (46, 28, 39) between the exogenous inhibition compared to the exogenous feel condition. Where we also identified a cluster in preSMA/SMA (−2, 2, 73), which was posterior to the preSMA cluster found to be connected to dmPFC.

No significant effects were observed for the connectivity of dmPFC and middle frontal gyrus when comparing the endogenous and exogenous inhibition condition.

Discussion

Our results demonstrate a neural dissociation between endogenous and exogenous inhibition of emotions. In line

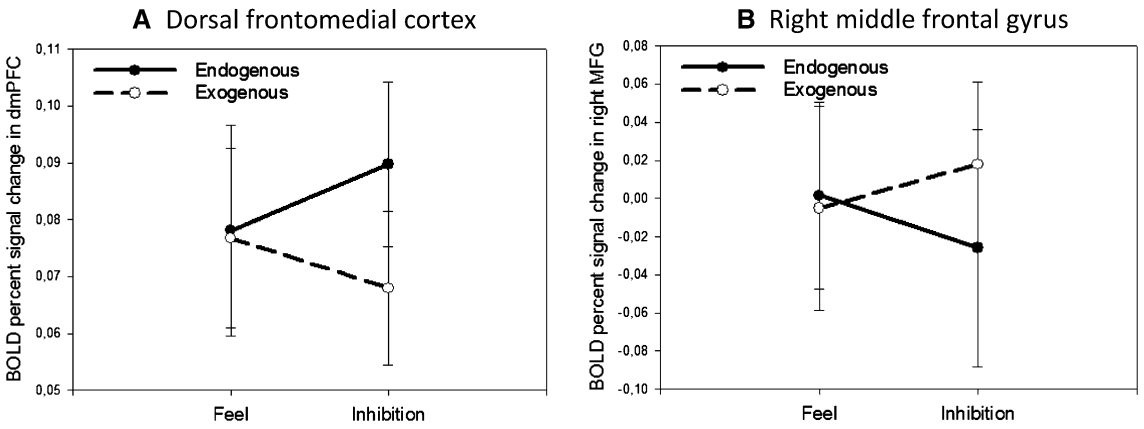

Fig. 4 Percent signal change within the significant cluster in dorsal frontomedial cortex and *right middle* frontal gyrus. *Errors* depict standard error of the mean

with previous studies on exogenous inhibition of action (Aron and Poldrack 2005), exogenous inhibition of negative emotion was associated with brain activity in lateral prefrontal cortex, namely middle and inferior frontal gyrus. The location of our coordinate is within the range of previous Go-NoGo studies (Aron and Poldrack 2005). We also found activation associated with exogenous inhibition in parietal cortex that has been reported previously in context reappraisal (Drabant et al. 2009; Staudinger et al. 2009) as well as in studies exploring stop signal and Go/NoGo tasks (Aron and Poldrack 2006; Menon et al. 2001).

The endogenous inhibition of negative emotion in the present study was associated with activity in medial frontal cortex, namely dmPFC. This is in line with previous studies on endogenous inhibition of action although the present coordinates are slightly more anterior (Brass and Haggard 2007; Kühn et al. 2009). Moreover we found activation in bilateral STG, a brain area that has previously been found in studies of reappraisal (Ochsner and Gross 2005). This brain area has also been associated with the self-other distinction (Spengler et al. 2009). In order to test onto which brain areas dmPFC exerts control we explored its functional connectivity. We found a stronger connectivity between dmPFC and preSMA during endogenous inhibition compared to endogenous feel trials.

Emotion regulation in previous research

In the past few years, models of emotion regulation have established that the prefrontal cortex plays a key role in cognitive regulation of emotion (Davidson 2002; Ochsner and Gross 2005). Several fMRI studies have reported increases in activity in the ventrolateral, dorsolateral, and dorsofrontomedial prefrontal cortices when participants were instructed to use various cognitive strategies to reduce negative emotional experience (Beauregard et al. 2001; Eippert et al. 2007; Goldin et al. 2008; Kalisch et al. 2006; Kim and Hamann 2007; Ochsner et al. 2004; Phan et al. 2005; van Reekum et al. 2007). These strategies include reinterpretation and detachment/distancing, but have in common the effect of inhibiting emotional experience. In this sense, the ends of emotion inhibition may be more important than the means by which it is achieved. Here we focussed on inhibition by distancing, which may be superior to study because it is not affected by the inter-individual differences or imaginativeness needed for reinterpretation. Crucially, the concept of detachment implies that the stimulus is still present and still perceived, but its emotional impact is inhibited. In this sense, distancing emphasises that the inhibition applies specifically to emotional content, and not for example to perception or imagery. Although many of the previous studies used the term "voluntary emotion regulation" (Beauregard et al. 2001; Eippert et al. 2007; Phan et al. 2005), the inhibition was instructed externally. It therefore reflects exogenous inhibition according to the definitions used here. Moreover, the contrast that those studies report (external inhibition vs. feel) introduces a possible confound with arousal, which is most likely greater during feeling than during inhibition of emotion.

In contrast, we focussed on emotion inhibition resulting from an endogenous or exogenous *origin*. The importance of distinguishing between endogenously and exogenously triggered emotion regulation is underlined by the interaction between source of control and feel vs. inhibit in reported intensity of emotion. We found a greater difference between feel and inhibit in the endogenous compared to the exogenous condition in intensity ratings. This suggests that the act of voluntarily choosing whether to feel or suppress facilitates the effects of experienced emotions. Volition seems to make emotional experience more intense, and suppression more efficient.

Intentional inhibition of action and inhibition of emotion

Many accounts of voluntary action distinguish between two routes (Passingham et al. 2010 for a review). Goldberg (1985) proposed a neuroanatomical dissociation of internally and externally guided *initiation* of action. According to his view, initiation of internally guided behaviour involves medial frontal cortex, notably the area now referred to as pre-supplementary motor area (preSMA), while initiation of externally triggered behaviour involves lateral frontal cortex, specifically the premotor cortex. A similar distinction appears to apply to *inhibition* of action: endogenous inhibition of action involves the medial prefrontal cortex (Brass and Haggard 2007; Kühn et al. 2009), while exogenous inhibition is located more laterally (Aron et al. 2004). The present study shows that this division between endogenous and exogenous inhibition, previously found for inhibition of actions, may apply to inhibition of emotions.

The functional connectivity between dmPFC and preSMA in the endogenous inhibition compared to the endogenous feeling of emotions also recalls the results found previously in the context of action inhibition, in which the voluntary choice not to press a button was associated with fMRI activity in dmPFC and a functional connectivity analysis likewise revealed higher connectivity with preSMA during inhibition trials as compared to action trials (Kühn et al. 2009). The involvement of cognitive-motor structures such as preSMA in emotional inhibition is consistent with the general view that experiencing emotion is strongly linked to the motor expression of emotion (James 1884; Lange 1887). Relatively few studies have explicitly investigated the role of frontal motor areas in emotion processing. However, Oliveri et al. (2003) showed that negative emotional images increased SMA-motor connectivity, thus confirming an affective input to SMA.

We propose two possible interpretations of the dmPFC-PreSMA connectivity in our data. First, participants' experience of the emotional images might involve some motor component. This could be an overt motor response, such as a facial expression consistent with fear evoked by threatening images. Although participants were not explicitly instructed about the motor expression of emotions in our study, several theories of emotion suggest that facial expression is an automatic part of experiencing emotion (James 1884; Lange 1887; Dimberg 1982; Dimberg et al. 2002; Sato and Yoshikawa 2007; Wild et al. 2001). On this view, decisions to inhibit emotional experience might be associated with inhibition of facial or other motor actions, through a dmPFC-preSMA link, although the directionality of this link is not implied by the functional connectivity result in the present paper.

A second, weaker hypothesis suggests that preSMA may perform a covert simulation of affective motor responses, without actual motor output. This possibility is supported by findings of spatial-affective compatibility in simple reaction times. Painful stimuli facilitated simple reactions in an 'avoid' direction (button releases), relative to reactions in an 'approach' direction (button presses), while neutral stimuli showed no effect (Morrison et al. 2007). More generally, our connectivity analysis confirmed a dmPFC-preSMA functional connectivity previously seen for action inhibition (Kühn et al. 2009). This implies that the target of inhibitory processes may be similar no matter whether a motoric response or an emotional response is inhibited.

We also found connectivity of the right MFG with preSMA/SMA. Taken together this may suggest that the influence of the higher-level brain regions involved in endogenous and exogenous inhibition may both exert control onto the same brain region, namely preSMA/SMA. This finding parallels previous studies on the exogenous inhibition of action using Go/Nogo tasks that have frequently reported preSMA activation associated with inhibition (Simmonds et al. 2008). However, the results of a PPI analysis do not allow any conclusion on the directionality of connectivity and should therefore be treated with caution.

The commonality of inhibition of emotion and inhibition of action

We are tempted to speculate based on the similarity of the neural substrates for action and emotion inhibition that in fact intentional inhibition of action might be more cognitive than we have previously assumed. In our first study on voluntary action inhibition, we asked participants to decide to press a button but refrain from doing so in the last possible moment (Brass and Haggard 2007). This process of refraining from an action that was about to be made could likewise be interpreted as a (more cognitive) process of detaching from a previous choice rather then a mechanistic motoric braking process. This way the current finding might invite us to reinterpret the dmPFC involvement in the inhibition of action. Research is needed to develop this angle further, e.g. by comparing action inhibition, emotion inhibition as well as a purely cognitive detachment manipulation in a within-subject design.

Limitations

A limitation of the present study is that we did not observe the interaction between source of control (exogenous/endogenous) and the condition feel/inhibition in a whole

brain analysis. Moreover, the sample consisted of female students only. Therefore, further research is needed to extend the present findings to a broader population. Furthermore, future research focussing on the direct comparison between (endogenous/exogenous) inhibition of emotion and action should be conducted to explore the similarity between its neural correlates.

Conclusions

This study is the first to compare endogenous and exogenous inhibition of emotions directly. Endogenous inhibition of emotions was associated with dmPFC activation, while exogenous inhibition was associated with lateral prefrontal cortex activation. This dissociation recalls the distinction between the neural substrates for endogenous and exogenous inhibition of motor actions. Further, functional connectivity analyses revealed higher connectivity between dmPFC and preSMA during endogenous inhibition compared to endogenous feel. The inhibitory dmPFC module found in action inhibition (Brass and Haggard 2007; Kühn et al. 2009) and emotion inhibition may thus both target the same frontal motor areas.

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