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Current Opinion in Psychology

Neural mechanisms associated with reappraisal and attentional deployment

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Attentional deployment is an emotion regulation strategy that involves shifting attentional focus within an emotional scene in order to modulate emotional experience. Attentional deployment is widely used and effective at reducing negative affect, yet the supporting neural mechanisms are poorly understood. The rich literature on the neural correlates of reappraisal may help inform our understanding of attentional deployment, as reappraisal recruits common control regions associated with emotion regulation and may tap into specific mechanisms associated with directing attention. We highlight commonalities between reappraisal and attentional deployment and then focus on potentially unique aspects of attentional deployment, including the importance of parietal regions and implications for understanding the normative development of emotion regulation, as well as both well-being and psychopathology.

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Current Opinion in Psychology 2015, **3**:17–21

This review comes from a themed issue on **Emotion regulation**

Edited by **Amelia Aldao** and **Matthew T Tull**

For a complete overview see the Issue and the Editorial

Available online 19th January 2015

http://dx.doi.org/10.1016/j.copsyc.2015.01.010

Attention and emotion

Emotion captivates and sustains attention [1]. A prototypical example of this is driving past a car accident — traffic comes to a crawl as everyone slows to look at the event. The seemingly automatic capture of attention by emotional content has been referred to as motivated attention [2]. Attention to emotion facilitates information processing, including altering perception and memory [3,4]. While initial attention to emotion may occur in a reflexive fashion, an individual's goals and motivation determine how attention is allocated in a top-down fashion [5]. In this way, attention and emotion interact dynamically over time to influence affect and behavior.

Individuals can control attention to emotion by employing attentional deployment (AD), an emotion regulation (ER) strategy that typically involves shifting attention away from emotional information in the service of reducing emotional impact [6]. For instance, although attention may be initially captivated by the car accident, an individual may choose to redirect attention away from the accident and toward more mundane aspects of the scene in order to feel less distress. AD is used across the lifespan, from young children [7,8] to older adults [9–11] and it is effective at reducing negative affect [9,12•]. Deficits in AD are also present in psychopathologies such as anxiety and depression [13,14]. Thus, understanding mechanisms associated with this strategy is important for developing comprehensive theories of ER and has potential clinical utility.

Current understanding of neural mechanisms supporting ER stems primarily from studies of reappraisal — a strategy that involves changing emotional impact by changing the meaning of a stimulus or event [6]. Reappraisal is a complex strategy that involves several subprocesses, including constructing appraisals, holding information in working memory, and deploying attention to relevant features of stimuli. Accordingly, reappraisal may reflect features common across many ER strategies, such as cognitive control, and may actually encompass more specific strategies like AD. For example, eye-tracking studies have demonstrated that people fixate away from arousing information when using reappraisal to down-regulate emotion [15•,16]. Further, gaze accounts for a significant proportion of activation changes in reappraisal-related brain regions [16], suggesting that neural activation during reappraisal may, to some degree, reflect AD.

We begin with an overview of the large functional magnetic resonance imaging (fMRI) literature on reappraisal. We will then compare reappraisal findings to those from the more limited literature on the neural mechanisms of visual AD, highlighting the key role of parietal regions during AD. We will conclude with potential applications for utilizing AD studies to examine ER across the lifespan and to inform interventions for individuals with psychopathology.

Neural mechanisms of reappraisal

Reduced amygdala activation is often considered a hallmark of reappraisal success, and is typically assumed to represent changes in emotional reactivity. The amygdala reflects bottom-up detection and processing of emotional stimuli [17], but amygdala activation can also be modified by an individual's goals, competing attentional demands, and willful efforts to regulate emotion [18,19]. Meta-analyses demonstrate that amygdala activity is reduced when individuals use reappraisal to down-regulate negative affect [20•,21].

During reappraisal, reduced amygdala activation is typically accompanied by increased frontoparietal activation associated with cognitive control [19]. Meta-analyses report that reappraisal is consistently associated with increased activation in dorsolateral prefrontal cortex (DLPFC), dorsomedial prefrontal cortex (DMPFC), ventrolateral prefrontal cortex (VLPFC), parietal, and temporal regions [20•,21], and less consistently in the ventromedial prefrontal cortex (VMPFC) [22]. The majority of these regions are considered cognitive control regions because of their activation in nonaffective studies involving cognitive processes such as working memory [23] or attentional control [24]. Prefrontal regions such as the DMPFC and DLPFC, and parietal regions are specifically implicated in attentional or oculomotor control [24], and are particularly relevant to studies of AD.

Connectivity analyses have also supported a role of these cognitive control regions in the down-regulation of amygdala activation and negative affect. During reappraisal, inverse correlations between the amygdala and regions of the prefrontal cortex, including the lateral PFC [25] and the VMPFC [26] have been reported. Greater coupling between the amygdala and prefrontal regions and the DMPFC has also been associated with reduced negative affect [27]. Connections between the amygdala and a subset of prefrontal regions (particularly the medial PFC) [28], and some parietal regions [29] provide anatomical feasibility for these findings. Control regions lacking direct connections to the amygdala may exert indirect regulatory effects on the amygdala through anatomical connections with prefrontal and parietal regions that have direct connections to the amygdala [30].

Reappraisal studies provide a foundation for understanding control mechanisms associated with ER, which may inform our understanding of more specific strategies like AD. Most notably, DLPFC and parietal regions can reflect *attentional control*, which is common to both reappraisal and AD. Despite evidence that AD is a powerful means to regulate emotion, investigations into the neural mechanisms supporting AD are largely lacking. Our lab conducted a series of event-related potential (ERP) and fMRI studies asking participants to direct visual attention within the context of an unpleasant image in order to interrogate the neural correlates of AD, more specifically.

Neural mechanisms of attentional deployment

We first investigated AD through a series of studies measuring the late positive potential (LPP) — a central-parietal ERP component that is larger for emotional than neutral stimuli [31]. In the first of these studies, participants passively viewed unpleasant and neutral images for 3 s, after which a circle directed attention to either an arousing or a nonarousing portion of the unpleasant image [32]. The LPP was enhanced in response to emotional images during passive viewing and when attention was directed to an arousing region, but not when attention was directed to a nonarousing region. Similarly, initially directing attention to a nonarousing region also reduced the LPP, suggesting AD can impact neural response even before full awareness of unpleasant content [37]. Using a tone, rather than a visual cue, to direct attention to arousing or nonarousing regions of unpleasant images produced an analogous effect [33]. These findings are in concert with reports of reduced LPP magnitude during reappraisal [34], and suggest that AD impacts the LPP in an equally dramatic fashion. Nonetheless, ERP studies using the LPP were unable to differentiate mechanisms associated with AD versus reappraisal.

Using a modified version of the same paradigm, we investigated specific brain regions associated with AD in two independent fMRI studies, one of which involved simultaneously collecting eye-tracking data [12•]. In both studies, we made direct comparisons between focusing on an arousing region and focusing on a nonarousing region of unpleasant visual stimuli in order to isolate the effect of AD while controlling for the general demand of focusing attention. Across both studies, focusing attention on nonarousing, compared to arousing, content activated prefrontal (including DLPFC and DMPFC) and parietal regions, despite similar task demands across conditions. Across both studies, directing attention away from unpleasant content was associated with reduced negative affect, however directing attention away from unpleasant content was only associated with reduced amygdala activation when task compliance was monitored with eye-tracking [12•]. These findings suggested that, like reappraisal, AD may down-regulate amygdala activation via prefrontal and parietal control regions. Considering the reflexive way in which attention is directed to emotional content, activation in these control regions during AD might reflect the increased effort required to disengage attention from emotional content and hold attention elsewhere.

To more closely compare AD findings to those from reappraisal studies, which typically contrast reappraisal against a passive viewing baseline [35], we then compared focusing on arousing or nonarousing content to passive viewing. Focusing on both arousing and nonarousing regions, compared to passive viewing, was associated with increases in prefrontal and parietal regions, reflecting the demand of directing attention within an emotional context. However, only directing attention to a nonarousing region was associated with changes in amygdala activation. These findings are similar to studies demonstrating prefrontal and parietal increases during up-regulation and down-regulation of emotional experiences via reappraisal [20•].

We subsequently explored relationships between the amygdala and control regions when directing attention to arousing or nonarousing regions relative to passive viewing by employing a psychophysiological interaction analysis (PPI) using the amygdala as a seed region. Directing attention away from unpleasant information was associated with increased connectivity only between the amygdala and the precuneus (Ferri *et al.*, unpublished). Further, increased amygdala–precuneus coupling was associated with increased eye-tracking measures of compliance (i.e., staying in the nonarousing region as instructed), and increased use of reappraisal in daily life, suggesting connectivity between these regions is important for successful implementation of AD, and ER more broadly. Amygdala–precuneus connectivity has been previously reported in other ER paradigms [36], and during resting state connectivity studies, which show negative connectivity between the amygdala and precuneus, and positive connectivity between the precuneus and prefrontal regions [37].

Considering all of these studies, directing attention away from unpleasant content was associated with a reduced LPP, reduced negative affect, reduced amygdala activation, increased fronto-parietal activation, and increased amygdala–precuneus connectivity. Although these findings are based on a small number of studies and further investigation is warranted, they suggest that, like reappraisal, successful AD may involve the down-regulation of negative affect and amygdala activation through the recruitment of cognitive control regions — perhaps the precuneus in particular.

Conclusions and implications

AD has strong potential for investigating neural mechanisms of ER: it can be assessed using multiple neural measures, compliance can be measured through eye-tracking, and difficulty can be equated across conditions. As AD is a common ER strategy, understating neural mechanisms supporting AD is important for refining general theories of ER. However, AD is also ideally suited to investigating ER in special populations, particularly in young children, older adults, and in clinical samples characterized by aberrant attention to emotion.

AD can be used to study the normative development of ER as very young children and the elderly utilize it to regulate affect and behavior. In contrast, reappraisal may be difficult or impossible for young children [38,39] as the ability to construct appraisals develops through adolescence, potentially mirroring the development of prefrontal regions [40]. Older adults also demonstrate difficulties employing reappraisal, which may be mediated by age-related decline in prefrontal function [41]. Conversely, AD is one of the first strategies to emerge in children: it is evident in 4 month old infants [42], and children begin to deliberately use it to regulate behavior between the ages of 3 and 5 [43], as orienting and executive control networks develop [44]. AD use continues through the lifespan, and older adults are adept at improving mood by redirecting attention [9,10], which may factor into increased well-being in older adulthood [11]. AD paradigms may be a plausible means to assess neural mechanisms of ER in children and older adults, which may inform developmental theories of ER and provide insight into adaptive ER and its relation to well-being across the lifespan.

Investigating AD may also be useful for designing and refining interventions for anxiety and depression, where aberrant attention to emotion is a core feature [13,14]. For example, a recent study showed that distraction is more effective at reducing negative affect in depression than reappraisal [45•]. Attentional training appears to have some impact on attention to affective stimuli, and on reductions in symptom severity in anxiety and depression [46,47]. Similarly, mindfulness training may target and lead to more flexible AD, improve anxiety symptoms [48] and strengthen connectivity between control regions [49]. Improvements in attentional control and associated connectivity may also influence functional relationships between parietal regions and the amygdala during affective processing. A simple AD paradigm might serve as a means to first assess deficits in neural activation and connectivity patterns during affective processing, and then to track the impact of training on neural function and emotional reactivity.

In conclusion, AD is a ubiquitous yet understudied ER strategy that demonstrates great promise for scientific investigations of ER. Future studies on AD hold the promise to advance both affective neuroscience and clinical science by elucidating neural mechanisms associated with the normative development of AD and as a targeted mechanism for better understanding well-being and psychopathology.

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