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Using executive control training to suppress amygdala reactivity to aversive information

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ABSTRACT

The ability to regulate emotions is essential for adaptive behavior. This ability is suggested to be mediated by the connectivity between prefrontal brain regions and the amygdala. Yet, it is still unknown whether the ability to regulate emotions can be trained by using a non-emotional procedure, such as the recruitment of executive control (EC). Participants who were trained using a high-frequent executive control (EC) task (80% incongruent trials) showed reduced amygdala reactivity and behavioral interference of aversive pictures. These effects were observed only following multiple-session training and not following one training session. In addition, they were not observed for participants exposed to low-frequent EC training (20% incongruent trials). Resting-state functional connectivity analysis revealed a marginally significant interaction between training groups and change in the connectivity between the amygdala and the right inferior frontal gyrus (IFG). Amygdala–IFG connectivity was significantly increased following the training only in the high-frequent EC training group. These findings are the first to show that *non-emotional* training can induce changes in amygdala reactivity to aversive information and alter amygdala–prefrontal connectivity.

Introduction

Excessive emotional arousal can impair individuals' ability to achieve their goals (Ochsner et al., 2002). This is especially true when heightened arousal emerges from an encounter with task-irrelevant emotional stimuli. Although emotional processing was considered automatic for many years (Öhman et al., 2001), the prevalent notion among emotion scientists today posits that emotions can be down-regulated using voluntary (Goldin et al., 2008; Ochsner and Gross, 2008) and involuntary (Dolcos et al., 2006; Okon-Singer et al., 2007; van Dillen et al., 2009) emotion regulation strategies. These regulation mechanisms are associated with enhanced activation in prefrontal regions such as the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (DLPFC), and the right inferior frontal gyrus (IFG) and reduced activation in the amygdala, a key region in emotional processing (Dolcos et al., 2006; Iordan et al., 2013; Okon-Singer et al., 2014; Van Dillen et al., 2009; see reviews in Okon-Singer et al., 2013, 2015).

Importantly, the same prefrontal regions that are activated during emotion regulation tasks are also activated in tasks that recruit executive control (EC) (Aron et al., 2004; Fan et al., 2005; MacDonald et al., 2000). EC is a high-order cognitive operation that enables goal-directed behavior by suppressing irrelevant distraction (Banich, 2009; Fan et al., 2002; Miller and Cohen, 2001). Several studies reported that EC plays a role also in suppressing irrelevant emotional information (Blair et al., 2007; Cohen et al., 2011, 2012) and that there are functional and anatomical connections between EC-related regions and the amygdala (Quirk and Beer, 2006; Rohr et al., 2015; Roy et al., 2009). Thus, the inverse link between activation in prefrontal regions and the amygdala may be explained by EC activation.

Indeed, behavioral findings indicate that EC-based training can reduce emotional distraction and emotion dysregulation symptomatology (Cohen et al., 2015a, 2015b; Daches and Mor, 2014; Schweizer et al., 2011, 2013; Siegle et al., 2007). Specifically, training participants to exercise inhibition over emotional information was found to reduce state (Cohen et al., 2015a, 2015b) and trait (Daches and Mor, 2014) ruminations, a maladaptive coping strategy that is highly associated with depression and other psychopathologies (Nolen-Hoeksema et al., 2007). In addition, training participants with an emotional working memory task led to increased activation in frontal and parietal regions during an emotion regulation task (Schweizer et al., 2013). The findings regarding the effects of non-emotional EC training on emotional behavior

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are equivocal. While some studies have found that non-emotional EC training reduces psychopathological syndromes related to emotion dysregulation (Calkins et al., 2014; Siegle et al., 2007), contradicting evidence shows that only training consisting of emotional information alters emotional behavior (Schweizer et al., 2011). Thus, it is yet unknown whether non-emotional EC training can induce changes in emotion-related brain activity and in amygdala–prefrontal connectivity. The use of a non-emotional training is important for the understanding of cognition–emotion interactions and for clinical purposes. Specifically, in order to reveal the mechanisms involved in emotion regulation it is important to distinguish emotional from non-emotional effects. In previous studies in which emotional stimuli were embedded in the training it was hard to distinguish effects related to executive control from effects related to the emotional information. Therefore, using non-emotional training can uncover the specific cognitive mechanisms that subserve emotion regulation. Moreover, such training can be easily employed with different populations, such as children, elder adults, and individuals with neurological or psychiatric disorders.

The current work examined the effects of single-session and multiple-session EC training on emotional reactivity (Fig. 1A). Participants were randomly assigned to one of two training groups; a high-frequent EC group (H-EC) and a low-frequent EC group (L-EC). Each participant performed an initial training session, as well as additional 18 training sessions (over 6 days). Each training session contained an arrow-flanker task, which is commonly used to test EC (MacLeod et al., 2010). The arrow-flanker task consisted of congruent and incongruent stimuli. Incongruent stimuli necessitate the recruitment of EC (Gratton et al., 1988; Norman and Shallice, 1980). The proportion of incongruent trials was 80% in the H-EC group and 20% in the L-EC group. Functional magnetic resonance imaging (fMRI) was used to assess amygdala activation during an emotional interference task and resting-state functional connectivity between the amygdala and prefrontal regions implicated in the EC task. The emotional interference task consisted of negative and neutral pictures from a validated set (International Affective Pictures System: IAPS; Lang and Bradley, 2007). Negative pictures from the IAPS are commonly used to assess emotional reactions and are known to elicit amygdala activation (e.g., Hariri et al., 2002). On each trial a picture was followed by a simple discrimination task (deciding whether a presented square is blue or green). Previous studies that used similar tasks demonstrated that emotional distracters delay performance when irrelevant to the task at hand Q5 (Buodo et al., 2002; Hartikainen et al., 2000). Using this task enabled us to assess both behavioral and functional effects related to emotional processing. Importantly, we chose a very simple emotional interference task because we were interested in the effects of a "pure" executive control training on a "pure" emotional processing task. Choosing basic executive control and emotional interference tasks fits best our question whether a non-emotional training can alter emotion-related behavioral and functional reactions.

Compared to the L-EC group, the H-EC group was predicted to show reduced amygdala activation in response to distracting aversive pictures following training, associated with a reduction in behavioral interference by aversive pictures. Furthermore, we expected the H-EC group to show enhanced resting-state functional connectivity between the amygdala and prefrontal regions implicated in the flanker task. These predictions were based on previous findings showing that non-emotional EC training can reduce emotion dysregulation symptoms (Calkins et al., 2014; Siegle et al., 2007; although as noted contradicting evidence was shown by Schweizer et al., 2011), as well as on data from our lab showing that the behavioral (Cohen et al., 2011, 2012) and psychophysiological (Cohen et al., in press) reactions to aversive information are attenuated following EC activation.

Materials and methods

Subjects

Thirty-six healthy participants without any history of neurological or psychiatric diseases participated in the study in return for payment. The study was approved by the ethics committee of the University of Leipzig and all subjects gave informed consent prior to the experiment. All of the participants were right-handed, according to the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were randomly assigned to one of the two training groups. Three participants did not complete the training and thus did not participate in the second scanning session. The data of seven additional participants were excluded due to technical problems during the home training or the scanning sessions. The resultant sample included 26 participants, 13 in the L-EC

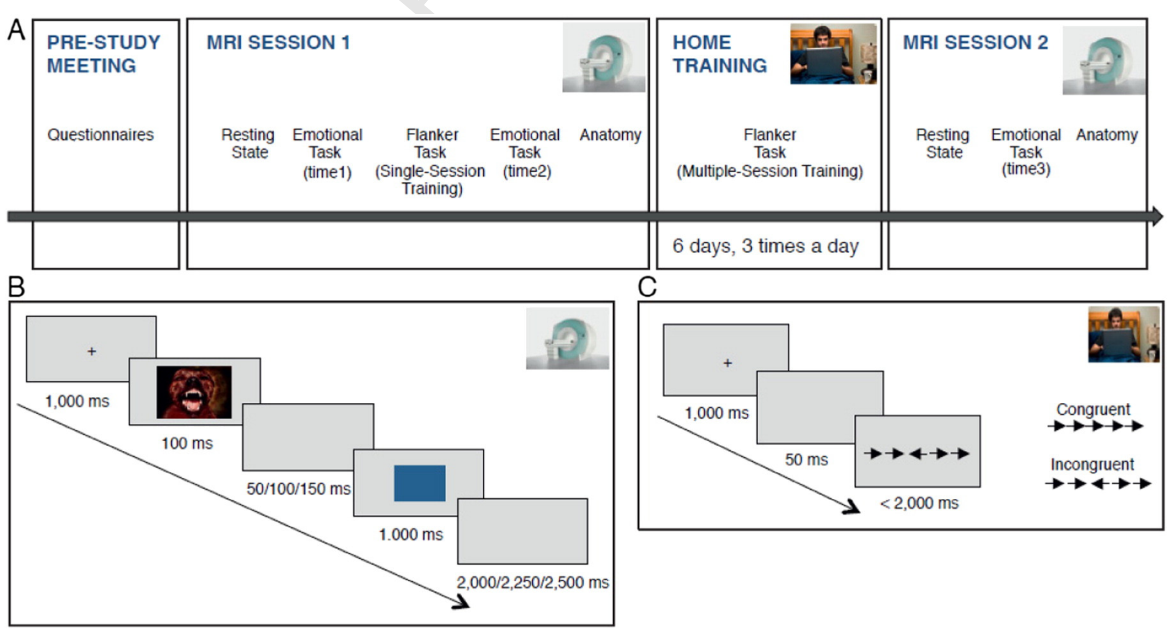

Fig. 1. A — general study timeline; B — emotional task procedure: negative and neutral pictures appeared before a choice reaction task; participants were asked to indicate whether a square was blue or green; C — home training procedure: arrow-flanker task; participants were asked to indicate the direction of the middle arrow and ignore the flanking arrows, which could be congruent or incongruent to the target arrow.

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