



Spatiotemporal brain dynamics underlying attentional bias modifications

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ABSTRACT

Exaggerated attentional biases toward specific elements of the environment contribute to the maintenance of several psychiatric conditions, such as biases to threatening faces in social anxiety. Although recent literature indicates that attentional bias modification may constitute an effective approach for psychiatric remediation, the underlying neurophysiological mechanisms remain unclear. We addressed this question by recording EEG in 24 healthy participants performing a modified dot-probe task in which pairs of neutral cues (colored shapes) were replaced by probe stimuli requiring a discrimination judgment. To induce an attentional bias toward or away from the cues, the probes were systematically presented either at the same or at the opposite position of a specific cue color. This paradigm enabled participants to spontaneously develop biases to initially unbiased, neutral cues, as measured by the response speed to the probe presented after the cues. Behavioral result indicated that the ABM procedure induced approach and avoidance biases. The influence of ABM on inhibitory control was assessed in a separated Go/NoGo task: changes in AB did not influence participants' capacity to inhibit their responses to the cues. Attentional bias modification was associated with a topographic modulation of event-related potentials already 50–84 ms following the onset of the cues. Statistical analyses of distributed electrical source estimations revealed that the development of attentional biases was associated with decreased activity in the left temporo-parieto-occipital junction. These findings suggest that attentional bias modification affects early sensory processing phases related to the extraction of information based on stimulus saliency.

1. Introduction

Whether an object attracts attention depends on its relevance to the current goals (i.e. attentional set) and its physical features (i.e. stimulus saliency Koch and Ullman, 1985; Wolfe, 1994; Wolfe et al., 1989). For example, people dressed in blue will attract attention when one is looking for a friend with a blue t-shirt, while an unexpected, loud sound may capture attention independently of one's current behavioral goals. “Attentional bias” (AB) refers to the tendency to allocate more attentional resources to specific objects, such as toward food when one is hungry. ABs often have an obvious adaptive value (e.g. a bias toward food items may facilitate foraging), but may become maladaptive when expanding beyond the normal range or to irrelevant objects. For example, exaggerated biases toward emotionally negative stimuli could participate in intensifying anxiety (e.g. Amir et al., 2008; Britton et al., 2015; Heeren et al., 2015). Based on the evidence that abnormal AB contributes to the development and maintenance of many psychiatric disorders, important efforts have been invested into the development of behavioral interventions aiming to reduce ABs (Hakamata et al., 2010;

Lopes et al., 2015; MacLeod and Clarke, 2014). However, while attentional bias modification (ABM) procedures have shown promising behavioral effects, their underlying neurocognitive mechanisms remain unclear. The present study addresses this question by investigating the spatiotemporal brain dynamics of ABM to initially neutral stimuli in healthy adults.

ABM procedures typically involve practicing so-called “modified dot-probe tasks” (MacLeod et al., 1986; MacLeod and Mathews, 2012). In such tasks, pairs of visual cues differing along a given dimension (e.g. emotionally positive vs. negative faces) are briefly presented at one of two positions on the screen. Participants are asked to make a visual discrimination judgment of a probe stimulus appearing at the location of the cue or at the opposite location. ABs are expressed as faster responses to the probes appearing at the location of cues attracting attention (e.g. an angry face) compared to the alternative location. Critically, ABs can be modified by modulating the probability of the association between the location of a given cue and the location of the probe: if the probe is systematically presented on the same side as a specific type of cue, attention will progressively become attracted by

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this cue. Conversely, if the probe is always presented opposite to a given cue, subjects will develop an attentional bias away from the cue.

While many studies investigated ABMs using dot-probe tasks in healthy (e.g. Amir et al., 2008; Suway et al., 2013) and clinical populations (e.g. Attwood et al., 2008; Eldar and Bar-Haim, 2010; Field et al., 2009; Lopes et al., 2014; Schoenmakers et al., 2010; Shafraan et al., 2008), only few examined the neural underpinnings of ABM (Britton et al., 2015; Browning et al., 2010; Eldar and Bar-Haim, 2010; Li et al., 2016; Nelson et al., 2015; O'Toole and Dennis, 2012; Osinsky et al., 2014; Suway et al., 2013).

This literature suggests that ABM procedures may influence different functional processing stages by showing effects at both late-latency high-order top-down control mechanisms, and at the level of early latency in brain areas involved in low-level processing.

Functional magnetic resonance imaging (fMRI) studies for instance showed associations between the modification of ABs toward emotional stimuli (threat-related vs. neutral or positive stimuli) and changes in activity within right lateral prefrontal cortices (rLPFC; Browning et al., 2010), middle frontal gyri (rMFG) and anterior insula (rAI; Li et al., 2016). Based on previous evidence for associations between these regions and voluntary control of attention, ABM procedures have been advanced to influence behavioral responses to the biased stimuli by modifying top-down attentional set. In contrast, other neuroimaging studies have suggested that the effects of ABM may also be influenced by low-level subcortical structures. Britton et al., 2015 for instance showed an increased activity in bilateral amygdala following an ABM training away from threatening faces in adults with high social anxiety symptoms.

In line with these fMRI literature, event-related potential (ERP) studies indicate that ABM training influences both late latency attentional control and error-related frontal N2 and conflict resolution P3 components (Eldar and Bar-Haim, 2010; Nelson et al., 2015; O'Toole and Dennis, 2012; Suway et al., 2013). Attentional allocation is typically indexed by the N2pc ERP component, an occipital negativity contralateral to the side of an attended stimulus and manifesting between 180 and 300 ms post stimulus onset (Eimer and Kiss, 2008; Holmes et al., 2014; Kappenman et al., 2015; Kappenman et al., 2014; Osinsky et al., 2014; Reutter et al., 2017; Weymar et al., 2011). The N2pc is notably assumed to reflect the attentional selection of a target stimulus among distractors. Further ERP studies revealed effects of ABM on even earlier latency parieto-occipital P1 sensory components, from 100 ms onwards. O'Toole and Dennis (2012) for instance showed that an ABM training toward or away from threat pictures modifies P1 amplitude to the emotional faces cues of the dot-probe task, suggesting that the procedure influenced early spatial attention.

Critically, the hypothesis for ABM influencing prefrontal control and lower-level bottom-up mechanisms are most likely complementary; top-down influence has indeed repeatedly been shown to alter long-term activity of low-level structure, with e.g. frontal cortices modulating amygdala responses and in turn attentional biases (Britton et al., 2015; Taylor et al., 2013; see Gilbert and Li, 2013 for review).

A limitation of these previous investigations of ABM is that they focused on emotional stimuli and were thus potentially confounded by individual variations in the initial biases to the stimuli. Pre-existing 'natural' biases to emotional stimuli may likewise influence the effects of ABM, limiting the generalizability of studies based on non-neutral stimuli. In addition, previous ABM paradigms were designed to have single-direction effects by either focusing on developing approach or avoidance biases (e.g. Amir et al., 2008; Britton et al., 2015; Browning et al., 2010; Osinsky et al., 2014), preventing the comparison between the neurophysiological mechanisms supporting the developments of approach vs. avoidance biases. For these reasons, it is important to study ABM with initially neutral stimuli that only obtain significance through practice, leaving open the possibility to spontaneously develop approach or avoidance biases. On this basis, the neural underpinnings of the development of approach vs. avoidance AB could then be compared.

To further characterize the nature of the biases induced by ABM procedures we investigated whether the development of biases influenced the executive control of the responses to the biased stimuli. Dual-process models posit that behavioral outcomes depend on interactions between bottom-up, implicit motivational responses to stimuli (as those putatively manipulated by ABM procedures), and top-down controlled, effortful actions such as response inhibition (e.g. Strack and Deutsch, 2004). While growing evidence indicate that maladaptive behaviors indeed depend on the relative strength of automatic approach biases and inhibitory control capacity (e.g. Kakoschke et al., 2015), to our knowledge no study so far directly tested whether modifying attentional biases actually modulates inhibitory control performance. Results for an influence of the ABM procedure on inhibitory control performance would enable linking the processes involved in each system. For instance, if the development of an approach bias to a given stimulus with the ABM procedure leads to more inhibition failures to this stimulus, it would suggest that at least part of the cognitive processes inhibited during the control task are those modified when an attentional bias develops (Kakoschke et al., 2015; Meule and Platte, 2016).

To address these questions, we examined the spatiotemporal brain mechanisms underlying attentional bias modification toward and away from initially neutral stimuli using a modified dot-probe task. We investigated when and where in the brain the ABM training modulates the processing of task-relevant stimuli by comparing ERPs to the cues measured at the beginning vs. the end of the ABM training. We analyzed the ERPs within the electrical neuroimaging framework, in which modulations in the strength and the topography of the electric field at the scalp are analyzed with robust randomization statistics and combined with intracranial source estimations (Michel and Murray, 2012; Murray et al., 2008a). Because changes in ERP topography necessarily follow from changes in the configuration of the underlying neural generators and changes in the global field power index modulation in the strength of the generator activity, our analyses could help disentangling the neurophysiological mechanisms underlying ABM (Murray et al., 2008a; Tzovara et al., 2012). Following the ERP analyses, distributed source estimations were statistically analyzed over the periods showing strength and/or topographic ERP modulations. Since this approach is data-driven and applied to the whole ERP epoch, it further overcomes the limitations of classical local ERP analyses focusing only on a priori determined electrodes and periods of interest, and allows identifying both when and where in the brain modifications of cortical processing are associated with the development of AB. This later methodological advantage is particularly important in the study of ABM because it may help better characterizing the interaction between late frontal and early low-level processing stage thought to underlie this phenomenon.

We hypothesized that ABM would affect both early stages of electrocortical processing reflecting gating mechanisms (latencies between 50–100 ms) or bottom-up capture of attention (50 and 200 ms, notably on the P1 parieto-occipital and N2pc ERP component; Fellrath et al., 2014; Hickey et al., 2006) and later, top-down attentional mechanisms (latencies after 150 ms within parietal and frontal sites corresponding to the N2 (Eldar and Bar-Haim, 2010; Osinsky et al., 2014), P2 (Eldar and Bar-Haim, 2010; Suway et al., 2013) and/or P3 components (Eldar and Bar-Haim, 2010)). We further assessed whether modulating attentional biases influenced inhibitory control to the biased stimuli by testing participants in a Go/NoGo task in which they had to withhold responses to the cues biased during ABM training. We predicted that increases in approach biases would decrease the ability to withhold responses to the cues (and the reverse effect with avoidance biases).

2. Material and methods

2.1. Participants

Thirty-two right-handed volunteers participated in this study.

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