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ORIGINAL ARTICLE

Neural plasticity in response to attention training in anxiety

S. Eldar* and Y. Bar-Haim

The Adler Center for Research in Child Developmental and Psychopathology, Department of Psychology, Tel Aviv University, Tel Aviv, Israel

Background. Behavioral studies show that attention training can alter threat bias, influence vulnerability to stress and reduce clinical anxiety symptoms. The aim of this study was to examine which cognitive functions of attention processing are modulated by attention training, and how *a priori* anxiety interacts with the attention training procedure. Specifically, we expected modulation in the P1/N1 event-related potential (ERP) complex if early spatial attention was to be affected by training and modulation in later ERP components (P2, N2, P3) had training affected top-down attentional processes.

Method. Thirty anxious and 30 non-anxious adults performed a modified probe detection task. Electroencephalograms (EEGs) were recorded throughout for later ERP analyses. Half the participants in each anxiety group were randomly assigned to undergo a training procedure designed to divert their attention away from threat and the other half received placebo training.

Results. Anxious participants who were trained to avoid threat showed a linear reduction in response time (RT) to targets replacing neutral faces with the progression of training. This change in RT was not observed among non-anxious participants or among anxious participants who were exposed to placebo training. Following training, the anxious participants who were trained to avoid threat showed a reduction in P2 and P3 mean amplitudes and an enhancement in N2 mean amplitude.

Conclusions. Attention training affects anxious participants whereas non-anxious participants seem not to respond to it. The ERP data suggest that attention training modulates top-down processes of attention control rather than processes of early attention orienting.

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Key words: Anxiety, attention-training, dot-probe, ERP.

Introduction

The attention system of anxious individuals is biased in favor of threat-related stimuli (Williams *et al*. 1996; Mogg & Bradley, 1998; Bar-Haim *et al*. 2007). Recently, expanding on this knowledge, researchers have explored the therapeutic potential of attention training for anxiety (Amir *et al*. 2008; Songwei *et al*. 2008; Amir, 2009; Pine *et al*. 2009; Schmidt *et al*. 2009). Preliminary studies with non-anxious participants have shown that attention biases can be manipulated by computerized attention tasks, and that such training has an effect on vulnerability to stress (MacLeod *et al*. 2002; Mathews & MacLeod, 2002; Eldar *et al*. 2008). Studies in anxious populations indicate that systematic training of attention away from threat reduces anxiety levels, whereas placebo training protocols do not (Mathews & MacLeod, 2002; Amir *et al*. 2008; Amir, 2009; Hazen *et al*. 2009; Schmidt *et al*. 2009).

We used a variant of the dot-probe task (MacLeod *et al*. 1986; Bradley *et al*. 1997), in combination with online recordings of event-related potentials (ERPs), to identify the stages of processing that are being modulated by attention training. These could be bottom-up and automatic or top-down and strategic; related to pre-attentive processes, capture of attention, attention orienting or attention control, each of which is indexed differentially by specific ERP components. We also assessed whether an *a priori* trait anxiety level interacts with the attention training procedure in modifying these markers of neurocognitive function.

Four lines of ERP research are relevant for the present study: first, the fine-grained temporal resolution of ERPs allows examination of the processing resources allocated to stimulus evaluation during different stages of information processing (Hillyard & Kutas, 1983). The P1 and N1 components represent

* Address for correspondence: S. Eldar, M.A., The Adler Center for Research in Child Developmental and Psychopathology, Department of Psychology, Tel Aviv University, Tel Aviv 69978, Israel.
(Email: nitzansh@post.tau.ac.il)

early visuospatial orienting of attention (Luck *et al*. 1990; Hillyard *et al*. 1995; Mangun, 1995; Yamaguchi *et al*. 1995; Clark & Hillyard, 1996; Hillyard & Anllo-Vento, 1998; Mangun & Buck, 1998; Fichtenholtz *et al*. 2007), whereas the P2, N2 and P3 components typically reflect top-down and more elaborate processing. Specifically, the P2 component has been associated with emotion evaluation (Carretie *et al*. 2001*a*, *b*) and attention disengagement (Bar-Haim *et al*. 2005), the N2 component reflects attention control and inhibition mechanisms (Falkenstein *et al*. 1999; Dennis & Chen, 2007*a*, *b*; Folstein & Van Petten, 2008), and the P3 has been associated with strategic orienting of attention (Friedman *et al*. 2001; Fichtenholtz *et al*. 2007; Polich, 2007). Second, threatening stimuli have been shown to elicit higher P1 (Xinying *et al*. 2005), P2 (Bar-Haim *et al*. 2005) and P3 (Kotchoubey *et al*. 1997; Bruin *et al*. 2000; Segalowitz *et al*. 2001; Carretie *et al*. 2003) amplitudes in anxious relative to non-anxious participants. Third, studies on the plasticity of these ERP components indicate that the amplitudes of the N1, P2 and P3 components decrease with repeated stimulus exposure (Kotchoubey *et al*. 1997; Bruin *et al*. 2000; Segalowitz *et al*. 2001; Carretie *et al*. 2003), whereas the amplitude of the N2 typically increases (Kotchoubey *et al*. 1997). Finally, recent studies in other research domains have started to use ERP measurements to track neural plasticity in response to visual training (Shoji & Skrandies, 2006; Tanaka & Pierce, 2009). However, the present study is the first to apply this strategy to the field of threat bias modification.

Drawing on the above-reviewed literature we expected to unveil which processing stages are affected by attention training, by examining the differential effect of training *versus* placebo on the amplitudes of specific ERP components. We expected to detect modulation in the P1/N1 component if early spatial attention was to be affected by training, and modulation in later components (P2, N2, P3) had training affected top-down attentional processes. Additionally, because threat bias is more prevalent among anxious than non-anxious individuals, we expected selective training effects to manifest more clearly in anxious participants, whereas in non-anxious participants these measurements might be diluted due to threat bias 'floor effects'.

Method

Participants

Participants were selected from a pool of 250 undergraduate students based on their scores on the State–Trait Anxiety Inventory (STAI) trait scale (Spielberger *et al*. 1983). The anxious ($n=30$) and the non-anxious ($n=30$) groups were sampled from the top and bottom quartiles of the distribution respectively. The groups differed significantly on trait anxiety [anxious: mean = 56.24, S.D. = 5.18; non-anxious: mean = 27.12, S.D. = 2.61, $t(58)=27.47$, $p<0.001$]. Half the anxious group [13 females, mean age = 23.30 (S.D. = 2.39) years] and half the non-anxious group [11 females, mean age = 22.20 (S.D. = 2.36) years] were exposed to a training condition designed to induce an attentional bias away from threat. The rest of the participants [anxious: 13 females, mean age = 22.14 (S.D. = 1.74) years; non-anxious: 11 females, mean age = 23.07 (S.D. = 1.07) years] were exposed to a placebo training condition.

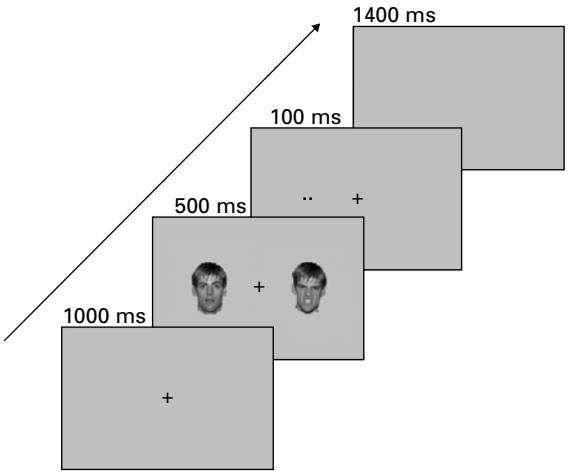

Fig. 1. Sequence of events in the dot-probe task.

The dot-probe task

In the dot-probe task two stimuli, one threat-related (angry face) and one neutral (neutral face), were shown on each trial. Their offset was followed by a target replacing one of them. Participants were asked to respond to the target as fast as possible without compromising accuracy (Fig. 1). Response latencies provide a 'snapshot' of the distribution of participants' attention, with faster responses to targets evident of the attended relative to the unattended location (Navon & Margalit, 1983). Attention bias towards threat is inferred when participants respond faster to targets replacing threat-related stimuli. The opposite pattern indicates avoidance of threat.

Stimuli consisted of chromatic photographs of 12 actors (six males) taken from the NimStim set (www.macbrain.org), presented in pairs of Angry–Neutral and Neutral–Neutral faces of the same actor. The task consisted of seven blocks. The first and last blocks (pre- and post-training/placebo) were the same

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for all participants. The five central blocks served for attention manipulation. Participants were exposed either to five blocks of attention training to avoid threat or to five blocks of a placebo condition, not intended to train attention. Across all blocks the basic trial format was the same. Following a 1000-ms presentation of a fixation cross (2 cm × 2 cm) at the center of the screen, a face pair was presented for 500 ms. Face photographs subtended 55 mm × 80 mm, and were presented with equal distance to the right and left of the fixation cross (16.5 cm center-to-center). Upon removal of the faces, a target display appeared for 100 ms, after which the screen went blank. The target display consisted of two dots, 2 mm in diameter, distant from each other by 5 mm center-to-center. The dot pair was oriented either horizontally (..) or vertically (:) and appeared at a distance of 8.5 cm either to the left or to the right of fixation at the location of the center of either the left or the right face photograph. Participants had to determine the orientation of the dots by pressing one of two prespecified buttons. A new trial began 1400 ms after target offset.

The pre- and post-training/placebo blocks consisted of 144 trials each, with 48 Neutral–Neutral trials and 96 Angry–Neutral trials. Angry faces were equally likely to appear on the left or the right side of the screen. Targets were equally likely to appear at the location of the right or the left face, and their orientation was equally likely to be horizontal or vertical. These variables were randomly mixed in presentation.

The five attention training/placebo blocks (480 trials in total) consisted of pairs of Angry–Neutral faces. Participants trained to avoid threat were presented with trials in which targets always replaced neutral faces. Participants in the placebo condition were exposed to trials in which targets were equally likely to replace angry or neutral faces. For both conditions the neutral face was equally likely to appear on the left or on the right, and orientation of the target was equally likely to be horizontal or vertical. These variables were randomly mixed in presentation.

The primary behavioral index of a training effect was derived by assessing change in response time (RT) over the five training/placebo blocks. Such changes reflect the effects of training during its implementation. Mean RTs for targets replacing neutral faces were calculated separately for each training/placebo block, enabling examination of changes in RT over time as a function of anxiety and training condition. In addition, we compared the pre- and post-training/placebo attention bias scores (mean RT for targets replacing neutral faces – mean RT for targets replacing angry faces). Positive bias values reflect attention bias towards threat; negative values reflect avoidance of threat (Bradley *et al*. 1998).

Electrophysiological recording and analysis

Electroencephalogram (EEG) recording and artifact scoring

Continuous EEGs were recorded from 25 scalp sites while participants performed the dot-probe task. Electrodes were located according to the international 10/20 system (Jasper, 1958). EEG channels were collected with reference to the chin. Vertical and horizontal electro-oculograms (EOGs) were recorded from above and below the left eye, and at the right and left outer canthi. Impedances were kept below 5 kΩ. The sampling rate was 256 Hz, and the bioamplifier filter settings were 0.1–100 Hz. Processing and analysis of the EEG signal was carried out offline. EEG data exceeding $\pm 100\,\mu$V were removed from further analysis. Eye blinks that appeared in the EOG signal were regressed out of the EEG using methods described in the literature (e.g. Lins *et al*. 1993; Miller & Tomarken, 2001). Trials containing horizontal eye movements were eliminated from further analysis, as were trials with incorrect responses. Mean ERP amplitudes to the faces and the targets were measured within preset latency windows, and relative to a 100-ms pre-stimulus baseline. Once selected, latency windows were the same for all participants.

Faces-evoked ERP components

Based on previous reports and inspection of the grand mean ERPs, mean ERP amplitudes were assessed in five separate time windows and preselected electrode sites. The P1 (90–140 ms) and N1 (140–190 ms) components were analyzed over the O1 and O2 electrode sites (e.g. Clark & Hillyard, 1996). The P2 (190–270 ms) and N2 (250–330 ms) were analyzed over central (C3, Cz, C4) electrodes sites (e.g. Bar-Haim *et al*. 2005; Dennis & Chen, 2007*a*). The P3 component (330–400 ms) was analyzed over frontal (Fp1, Fp2, F3, F4, Fz, F7, F8) electrodes sites (e.g. Naumann *et al*. 1992; De Pascalis *et al*. 2004; Folstein & Van Petten, 2008).

Target-evoked ERP components

Target evaluation (Kutas *et al*. 1977; McCarthy & Donchin, 1981; Magliero *et al*. 1984) and response selection (Falkenstein *et al*. 1997) in choice reaction time tasks are known to modulate the frontal P3 component (~300–950 ms following target onset). Thus, these analyses were conducted for P3 over frontal (Fp1, Fp2, F3, F4, Fz, F7, F8) electrode sites.

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General procedure

Participants who met inclusion criteria were invited to the laboratory. They were seated in a comfortable chair 100 cm from a computer screen. Following EEG preparation, state anxiety was measured (STAI-S). Participants then received 32 practice trials, followed by the pre-training/placebo block and the five training/placebo blocks. STAI-S was again measured before the final post-training/placebo block was delivered. Short breaks were allowed at the end of each block. EEGs were recorded throughout the experiment.

Data analyses

RT data

Trials with RTs that exceeded ± 2 standard deviations (S.D.) of a subject's mean RT (calculated separately for each condition) were rejected, as were trials with incorrect responses or with responses that were faster than 200 ms.

To examine the efficacy of training (targets always at the neutral face location), we calculated mean RTs for targets replacing neutral faces separately for each training/placebo block.† A $5 \times 2 \times 2$ MANOVA was conducted with blocks (five) as a within-subject factor, and anxiety (anxious, non-anxious) and training condition (training, placebo) as between-subjects factors. For the participants assigned to the placebo condition, an additional 5×2 MANOVA on mean RTs to targets replacing angry faces was conducted with blocks (five) as a within-subject factor and anxiety (anxious, non-anxious) as a between-subjects factor.

To assess changes in threat bias scores from pre- to post-training/placebo, a $2 \times 2 \times 2$ ANOVA was conducted with time (pre-training/placebo, post-training/placebo) as a within-subject factor, and anxiety (anxious, non-anxious) and training condition (training, placebo) as between-subjects factors.

ERP data

Faces-evoked ERP analysis. For each ERP component (P1, N1, P2, N2, P3) the mean amplitude averaged across the selected electrode sites was subjected to a $2 \times 2 \times 2 \times 2$ MANOVA with Time (pre-training/placebo, post-training/placebo) and stimulus type (Angry–Neutral face pairs, Neutral–Neutral face pairs) as within-subject factors, and anxiety (anxious, non-anxious) and training condition (training, placebo) as between-subjects factors.

Target-evoked ERP analysis. The mean amplitude of the P3 component was subjected to a $3 \times 2 \times 2 \times 2$ MANOVA with target location (angry face location, neutral face location, neutral–neutral trials) and time (pre-training/placebo, post-training/placebo) as within-subject factors, and anxiety (anxious, non-anxious) and training condition (training, placebo) as between-subject factors.

State anxiety

Scores on the STAI-S were subjected to $2 \times 2 \times 2$ ANOVA with time (pre-experiment, post-training/placebo) as a within subject factor, and anxiety (anxious, non-anxious) and training condition (training, placebo) as between-subject factors. In addition, correlations between bias score changes as a function of training and trait anxiety level and state anxiety post-training/placebo were computed.

Results

Behavioral RT data

Fig. 2 presents mean RTs for the five training/placebo blocks for each of the four anxiety × condition groups. In these blocks accuracy ranged from 90% to 96% with no differences between the groups. Analysis with mean RTs at the neutral face location as the dependent variable revealed a main effect of blocks [$F(4, 53) = 3.91$, $p < 0.01$] that was subsumed under a three-way block × anxiety × training condition interaction effect [$F(4, 53) = 3.00$, $p < 0.05$]. Four follow-up repeated-measures ANOVAs for each group revealed a significant blocks effect only among trained anxious participants [$F(4, 56) = 5.65$ $p < 0.01$]. Only in this group did the RT to targets appearing at the neutral faces location decrease as the training procedure progressed (Fig. 2*a*). Follow-up t tests within each block revealed that RTs of trained anxious participants were faster than RTs of trained non-anxious participants in blocks 3, 4 and 5 [t's(28) = 2.05, 1.97 and 2.17, p's < 0.05, 0.058 and 0.05 respectively], indicating that trained anxious participants showed a gradual reduction in RT as training progressed, whereas RTs of trained non-anxious participants remained unchanged. Anxious and non-anxious participants exposed to the placebo condition did not differ in RTs to targets at neutral face locations and their RTs across blocks remained unchanged. Analysis of mean RTs to targets appearing at angry face locations (available only for the placebo groups) revealed no change among both anxiety groups.

† Participants in the training condition were exposed only to trials in which the targets were at the neutral face location. For the placebo groups, mean RTs by block for targets appearing at the angry face location were calculated as well.

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Table 1. *Mean response times, bias scores and standard deviations (in parentheses) for the pre- and post-training/placebo phases in each anxiety × training condition group*

		Angry–Neutral			
		Target at Angry	Target at Neutral	Neutral–Neutral	Bias score
Non-anxious					
Training	Pre	602 (85)	608 (79)	604 (87)	6 (21)
	Post	552 (80)	558 (78)	565 (77)	6 (17)
Placebo	Pre	607 (60)	612 (60)	604 (68)	5 (26)
	Post	549 (75)	554 (59)	563(73)	5 (24)
Anxious					
Training	Pre	561 (62)	563 (65)	558 (65)	2 (19)
	Post	521 (70)	516 (65)	518 (61)	−5 (19)
Placebo	Pre	634 (96)	639 (106)	638 (113)	5 (23)
	Post	568 (66)	572 (67)	572 (69)	4 (15)

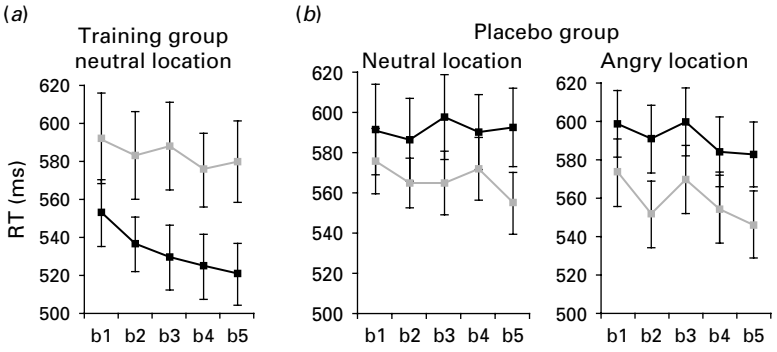

Fig. 2. Mean response times (RTs) and standard error bars for target probes replacing neutral and angry faces in the five training/placebo blocks, separate for (*a*) the training group and (*b*) the placebo groups. ■, Anxious; □, non-anxious.

Table 1 presents mean RTs and attention bias scores in the pre- and post-training/placebo blocks. In these blocks accuracy across groups ranged from 94% to 96%. ANOVA on attention bias scores revealed no significant findings. However, inspection of Table 1 suggests that only among the trained anxious participants was there a numeric trend indicating a change from a bias towards threat before training, to a bias away from threat post-training.

ERPs to face-pairs onset

A table summarizing change trends in ERP components as function of training/placebo and anxiety group is presented in the Supplementary online material.

P1

No significant findings were found for the P1 component.

N1

N1 amplitude decreased from the pre-training/placebo phase (mean = −3.00, S.D. = 2.94) to the post-training/placebo phase (mean = −1.00, S.D. = 2.86), regardless of anxiety level and training condition [$F(1, 56) = 41.23$, $p < 0.01$].

P2

A time × training condition interaction [$F(1, 56) = 4.69$, $p < 0.05$] was subsumed under a three-way time × anxiety × training condition interaction effect [$F(1, 56) = 4.99$, $p < 0.05$]. Follow-up ANOVAs for each anxiety group indicated that the time × training condition interaction was not significant among non-anxious participants but was significant among anxious participants [$F(1, 28) = 10.69$, $p < 0.01$]. Inspection of Fig. 3(*a*, *b*) reveals a reduction in P2 amplitude among trained anxious participants [pre: mean = −0.29, S.D. = 2.36; post: mean = −1.40, S.D. = 1.64,

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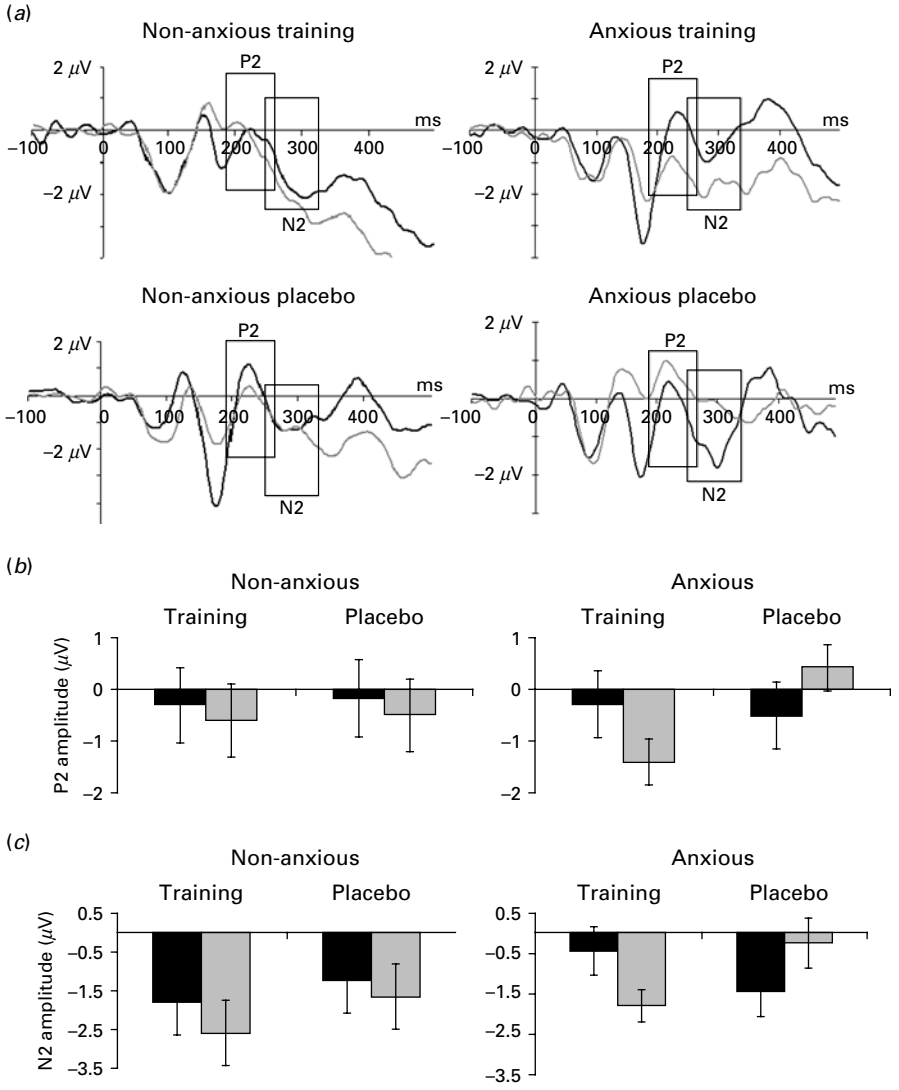

Fig. 3. Grand averaged event-related potentials (ERPs) over central electrode sites for the pre-training/placebo phase (black) and the post-training/placebo phase (gray), by anxiety and training condition. (*a*) ERP wave forms averaged over C3, Cz and C4; (*b*) mean amplitude and error bars for the P2 component; (*c*) mean amplitude and error bars for the N2 component.

$t(14) = 2.24$, $p < 0.05$] and an increased P2 amplitude among anxious participants in the placebo condition [pre: mean = −0.51, S.D. = 2.66; post: mean = 0.41, S.D. = 1.80, $t(14) = 2.38$, $p < 0.05$)].

N2

A time × training condition interaction [$F(1, 56) = 11.55$, $p < 0.01$] was again subsumed under a three-way interaction effect of time × anxiety × training condition [$F(1, 56) = 5.94$, $p < 0.05$]. Follow-up ANOVAs showed that the time × training condition interaction was significant only among anxious participants [$F(1, 28) = 17.59$, $p < 0.01$]. The N2 amplitude of anxious participants who were trained increased over time [pre: mean = −0.41, S.D. = 2.35; post: mean = −1.80, S.D. = 1.56, $t(14) = 3.00$, $p < 0.01$] whereas the N2 amplitude decreased among anxious participants in the placebo condition [pre: mean = −1.42, S.D. = 2.48; post: mean = −0.24, S.D. = 2.38, $t(14) = 2.93$, $p < 0.05$] (Fig. 3*a*, *c*).

P3

A trend level three-way interaction of time × training condition × anxiety was found [$F(1, 56) = 3.71$, $p = 0.059$]. ANOVAs for each anxiety group indicated that non-anxious participants showed a significant main effect of time [$F(1, 28) = 11.24$, $p < 0.05$] whereas anxious participants showed a significant time × training condition interaction effect [$F(1, 28) = 4.70$, $p < 0.05$]. Follow-up *t* tests revealed a reduced P3 amplitude for non-anxious participants in both the training [pre: mean = −0.97, S.D. = 2.18; post: mean = −2.28, S.D. = 2.45, $t(14) = 2.26$, $p < 0.05$] and the placebo

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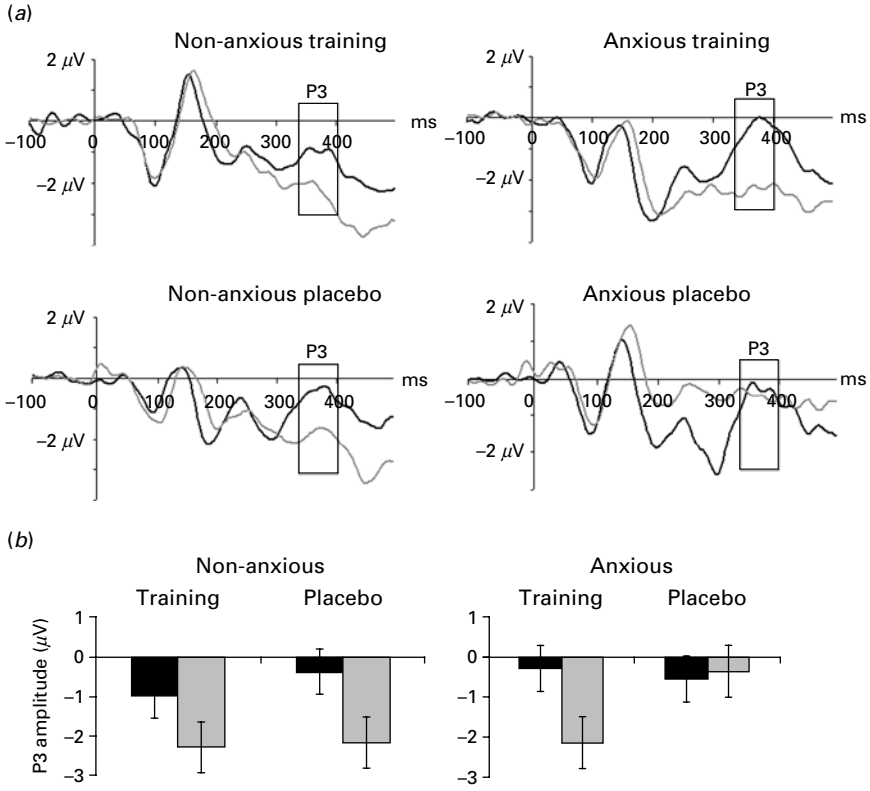

Fig. 4. Grand averaged event-related potentials (ERPs) for the pre-training/placebo phase (black) and the post-training/placebo phase (gray), by anxiety and training condition. (*a*) ERPs averaged over frontal electrode sites (Fp1, Fp2, F3, F4, Fz, F7, F8); (*b*) mean amplitude and error bars for the P3 component.

[pre: mean = −0.37, S.D. = 1.89; post: mean = −2.17, S.D. = 2.59, $t(14) = 2.48$, $p < 0.05$] conditions. A significant reduction in P3 amplitude was also observed in trained anxious participants [pre: mean = −0.27, S.D. = 2.35; post: mean = −2.14, S.D. = 2.57, $t(14) = 2.55$, $p < 0.05$]. Importantly, no change in P3 amplitude was noted for the anxious participants in the placebo condition [pre: mean = −0.54, S.D. = 2.49; post: mean = −0.35, S.D. = 2.51, $t(14) = 0.31$, $p = 0.75$] (Fig. 4).

P3 to target onset

Significant enhancement of P3 amplitude over time was noted across participants at all target locations [$F(1, 56) = 4.45$, $p < 0.05$]. This main effect of time was subsumed under a significant three-way interaction of time × target location × training condition [$F(2, 56) = 2.97$, $p = 0.05$]. Follow-up ANOVAs within each training condition revealed a significant time × target location interaction effect only for participants who were trained [$F(2, 28) = 3.89$, $p < 0.05$]. Complementary *t* tests between pre- and post-training sessions were conducted for each of the three target locations (Angry, Neutral, Neutral–Neutral). As expected, P3 amplitude increased over time only for trials in which targets replaced neutral faces in Angry–Neutral trials [pre: mean = 5.41, S.D. = 4.30; post: mean = 8.70, S.D. = 5.30, $t(29) = 2.98$, $p < 0.05$]. No such change in P3 amplitude was observed when targets replaced angry faces in Angry–Neutral trials [pre: mean = 7.41, S.D. = 6.16; post: mean = 8.01 S.D. = 4.68, $t(29) = 0.77$, $p = 0.44$] or when targets appeared in Neutral–Neutral trials [pre: mean = 7.31, S.D. = 4.84; post: mean = 8.36 S.D. = 5.12, $t(29) = 1.21$, $p = 0.23$].

State anxiety

The results revealed three main effects: state anxiety was lower following training/placebo (mean = 34.88, S.D. = 6.79) compared to baseline (mean = 38.13, S.D. = 6.35) [$F(1, 55) = 4.27$, $p < 0.05$]; state anxiety was lower in the low trait-anxious group (mean = 27.74, S.D. = 7.12) relative to the high trait-anxious group (mean = 45.27, S.D. = 7.12) [$F(1, 55) = 92.93$, $p < 0.001$]; and state anxiety was lower overall in participants who were trained (mean = 34.60, S.D. = 7.12) relative to the placebo group (mean = 38.41, S.D. = 7.12) [$F(1, 55) = 4.90$, $p < 0.05$]. In addition, a trend towards a three-way interaction of time × anxiety × training condition emerged [$F(1, 55) = 3.78$, $p = 0.057$]. However,

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follow-up ANOVAs in each anxiety group did not reveal time × training condition interactions.

We further assessed whether state anxiety following training or placebo as a function of anxiety group was related to changes in threat bias scores. A significant correlation between state anxiety and change in bias score emerged only among the anxious participants who were trained ($r = 0.51$, $p < 0.05$) but not among the other three groups (all p's > 0.10). Further assessment of differences in the magnitude of these correlations indicated that the correlation in the anxious trained group was significantly higher than the correlations detected in the non-anxious groups, but not in the anxious placebo group ($r = 0.21$, $p = 0.45$).

Discussion

Behavioral studies show that attention training protocols using the dot-probe task can alter attention patterns and influence anxiety level (Mathews & MacLeod, 2002; Amir *et al*. 2008; Amir, 2009; Hazen *et al*. 2009; Pine *et al*. 2009; Schmidt *et al*. 2009). The aim of this study was to examine which cognitive functions of attention processing are influenced by attention modification, and how *a priori* anxiety might interact with attention training procedures in modifying these cognitive functions.

The behavioral findings suggest that the attempt at training attention away from threat has different effects on anxious and non-anxious individuals. Anxious individuals responded to the training procedure with a gradual reduction in RTs to the trained contingency. This suggests that they learned implicitly the correlation between target location and the emotion displayed in the facial stimuli, allowing them to direct attention away from threat and perform more efficiently with task progression. By contrast, non-anxious individuals did not show any change in RTs as the training session progressed, suggesting that they did not attribute a functional property to the faces displayed. This pattern is akin to the notion that non-anxious individuals ignore the displayed faces while performing a dot-probe task (Bar-Haim *et al*. 2007). As expected, participants who were exposed to the placebo condition did not show change in RTs over time.

The electrophysiological data revealed that, although early ERP components were neither affected by training nor affected in a similar manner across all experimental groups, the effect of training on later components manifested differently in each group. Specifically, the amplitude of the attention-modulated P1 component (Hillyard *et al*. 1995) to the face display did not vary across groups, and the amplitude of the N1 component, which has been associated with early discrimination of attended stimuli (e.g. Mangun, 1995; Mangun & Buck, 1998), decreased over time across all groups. This is in accord with previous reports (e.g. Itier & Taylor, 2002; Heisz *et al*. 2006) of a decrease in N1 amplitude with repeated exposures to face displays. Thus, our results suggest that neither attention training nor anxiety level influence early attention-orienting processes.

By contrast, the P2, N2 and P3 components to the face display revealed a systematic difference in the effects of attention training as a function of anxiety level. Specifically, P2 amplitude decreased among trained anxious participants, and increased among anxious participants in the placebo condition. P2 amplitude has been associated with processing of emotion in faces (Carretie *et al*. 2001*a*, *b*), and was shown to be higher in anxious relative to non-anxious individuals while processing angry faces (Bar-Haim *et al*. 2005). We therefore tentatively infer that the training procedure reduced the neurocognitive resources allocated to processing of emotional features of the faces display in trained anxious individuals.

In addition, anxious participants had a higher N2 amplitude following training, whereas the N2 amplitude diminished in anxious participants in the placebo condition. The N2 has been shown to be modulated by attention control processes (Falkenstein *et al*. 1999; Folstein & Van Petten, 2008), which may be attributed to increased efforts to divert attention away from threat (Dennis & Chen, 2007*a*, *b*). Our training procedure may have assisted anxious participants to gain better control over their attention resources, reflected in their increased ability to avoid threat.

Finally, previous research has shown that frontal P3 decreases when participants are repeatedly exposed to stimuli (e.g. Bruin *et al*. 2000; Segalowitz *et al*. 2001). Indeed, frontal P3 amplitude was decreased among non-anxious participants. More importantly, P3 amplitude also decreased in trained anxious participants. These individuals exhibited P3 modulation patterns akin to those of non-anxious participants. By contrast, P3 amplitude did not change among the anxious participants in the placebo condition, suggesting that these participants failed to habituate high-level processes of attention orienting. Taken together, the results indicate that the training procedure facilitated normative neuronal habituation processes among anxious individuals by decreasing their overall processing efforts and increasing attentional control.

The lack of difference among the non-anxious participants in the P2 and N2 components pre- and post-training/placebo, along with the P3 habituation observed in this group, coincides with the behavioral

observation of no change in RTs over trials in this group, and strengthens our conclusion that non-anxious individuals are not influenced by the training procedures because they pay little attention to the emotional valance of the faces display. Indeed, allocation of processing resources to the faces display is not necessary for accurate performance on the dot-probe task.

Target-locked ERP results revealed an increase in frontal P3 exclusively on Angry–Neutral trials in which targets replaced the neutral face (i.e. trials akin to the attention training trials). This P3 enhancement was observed for all trained participants regardless of their *a priori* anxiety level. This may be taken as another indication for the effect of attention training on neural plasticity. Specifically, it seems that repeated exposure to the training trials facilitated recruitment of frontal activity, which has been associated with target evaluation (Kutas *et al*. 1977; McCarthy & Donchin, 1981; Magliero *et al*. 1984) and response selection (Falkenstein *et al*. 1997) processes in choice reaction time tasks. In addition, changes in attention bias away from threat were associated with lower state anxiety following training only in the anxious-trained group.

Overall, our findings suggest that attention training has an effect on anxious participants but not on non-anxious participants. This may be attributed to the possibility that anxious participants attend to the valence of the face stimuli whereas non-anxious participants ignore valance. The present training procedure influenced relatively late cognitive processes. It seems that by gaining greater control over attentional resources and by reducing resource investment in processing the emotional-face stimuli, attention training assists anxious individuals to perform the dot-probe task in a more adaptive way that resembles the neurobehavioral performance of non-anxious individuals.

This study provides novel data emphasizing the sensitivity of anxious individuals to attention training procedures at behavioral and electrophysiological levels. However, this study does not go without caveats and unresolved questions. First, ERP findings focused on the effects of training pre- and post-training/placebo phases whereas the behavioral effects were observed primarily during the training sessions themselves. This imperfect correspondence between behavioral and neuroimaging findings is fairly frequent and has been addressed on various occasions (e.g. Hillyard & Kutas, 1983; Monk *et al*. 2006; Santesso *et al*. 2008). Nevertheless, this still leaves some open question regarding the correspondence between behavior and neuroimaging data in the present study. Second, contrary to our assumption, anxious participants did not display attention bias towards threat in the pre-training/placebo phase. Although this lack of attention bias contradicts previous behavioral studies (Bar-Haim *et al*. 2007), it is possible that EEG preparation induced stress in the participants, thereby suppressing their attention bias. Indeed, several studies show that attention bias towards threat among anxious individuals tends to disappear under stressful circumstances (e.g. Mogg *et al*. 1993; Amir *et al*. 1996; Helfinstein *et al*. 2008). Third, as anticipated, trained anxious participants displayed a reduced threat bias score post-training. However, this effect was not statistically significant despite the significant reduction in RTs to the training trials during actual training. Previous studies that found a significant change in bias post-training used a considerably larger number of training trials over multiple sessions (e.g. Mathews & MacLeod, 2002; Amir, 2009; Hazen *et al*. 2009). Because of restrictions related to ERP recordings, we administered a relatively small number of training trials. Thus it seems plausible that the anxious participants learned to avoid threat, but that there was an insufficient number of trials to consolidate this learning for the post-training attention bias assessment, in which the target location–face emotion correlation is violated. Finally, an insufficient number of trials might also explain the lack of significant anxiety group × training condition interactions in overall state anxiety reduction.

In conclusion, this study shows that attention training is specifically effective with anxious individuals and can alter late top-down cognitive processes of attention. This study focused on training attention away from threat as the primary candidate for implementation in clinical work aimed at reduction of vulnerability to stress. However, it may be of interest for future neurophysiological studies to pursue investigation of the cognitive stages that might be modulated by this attention training towards threat in normative samples. Behavioral studies applying this strategy have proved to have important theoretical implications (e.g. MacLeod *et al*. 2002; Eldar *et al*. 2008). This newly emerging field of research on the efficacy of attention training can benefit from a better understanding of the neural substrates supporting the attention training process by identifying specific cognitive processes as targets for more refined intervention.

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Declaration of Interest

None.

Note

Supplementary material accompanies this paper on the Journal's website (http://journals.cambridge.org/psm).

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