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Individual differences in emotional reactivity moderate the strength of the relationship between attentional and implicit-memory biases towards threat-related stimuli

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The study investigated whether the strength of the relationship between attentional and implicit-memory biases for threat-related material can be moderated by individual differences in temperament and personality. A spatial cueing task, where task-irrelevant angry, happy, and neutral faces acted as spatial cues preceding a target, was immediately followed by an unexpected “old/new” task involving previously presented faces. Temperament-based emotional reactivity (ER; one’s typical response strength to emotional stimuli) predicted improved memory performance for angry faces in the “old/new” task. Critically, the relationship between the attentional bias towards threat (indexed by a cue validity index, i.e., a difference in response times on trials where cues with angry expression were presented in the same versus different location to the subsequent target) and enhanced implicit-memory for previously presented task-irrelevant threat-related information was found to be moderated by ER. The current findings provide the first evidence that temperament traits can offer novel insights into the mechanisms enhancing cognitive biases towards threat in the typical population.

Keywords: Attention–memory relationship; Cognitive biases; Emotional reactivity; Temperament; Threat processing.

An attentional bias towards threat, which can be visible in facilitated detection of a stimulus indicating danger in the external environment, bears obvious survival-related benefits. Preferential encoding of threat-related stimuli into memory (i.e., a memory bias) is also frequently beneficial

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but might be problematic in situations where threatening stimuli are not critical to the currently performed task. For example, spending time ruminating about having just spilled a coffee onto oneself is generally adaptive (avoiding pain in the future), but less so in a context where one has just started a time-limited exam.

Over the past 20 years, biases in attentional and memory processing of threat-related stimuli have received substantial interest—notably, as independently operating processes observed in individuals with specific personality types or disorders (see Mathews & MacLeod, 2005). However, there is little evidence for a direct link between attentional and memory biases towards threat, as well as for mechanisms that strengthen their relationship across individuals from the general population (see Blaut, Paulewicz, Szastok, Prochwicz, & Koster, 2013, for initial evidence in dysphoric individuals). In the present study, we demonstrate that the relationship between attentional and memory biases can be strengthened by temperament traits that regulate formal (i.e., related to magnitude and duration) aspects of emotional information processing.

Attentional and memory biases in anxious individuals

Previous studies suggested that information processing might be intrinsically biased towards threat. For example, LeDoux (1996) discovered a "quick and dirty" neural pathway between the thalamus and the amygdala that does not depend on the auditory cortex. In line with the existence of such pathways in different sensory modalities, multiple studies demonstrated preferential attentional processing of threat-related stimuli even when they were task-irrelevant (for a review, see Vuilleumier & Driver, 2007). Importantly, studies employing various paradigms have shown that such biased attentional processing is particularly pronounced in anxious individuals: These individuals respond more quickly to threat-related stimuli in the dot-probe task (for a review, see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van IJzendoorn, 2007) and are also slower to volitionally disengage attentional focus from the processing of "cues" (i.e., stimuli that indicate in a spatially predictive or non-predictive fashion the location of an upcoming target) in the spatial cueing paradigm (e.g., Fox, Russo, Bowles, & Dutton, 2001) if such cues are linked to threat. Fox et al. (2001) showed that in contexts where the location of an upcoming visual target is largely predictable by a face-cue, it takes these individuals more time to re-orient attentional focus on (a minority of) trials where cues provided incorrect spatial information, but only for face-cues with an angry, but not neutral or happy, expression. While some researchers (e.g., Rudaizky, Basanovic, & MacLeod, 2014) suggest that impaired attentional disengagement from and enhanced attentional engagement to threat-related stimuli might have been jointly responsible for the described results, such findings nevertheless provide converging evidence for an attentional bias towards threatening information in anxious individuals. Similarly, trait-anxiety (TA) is associated with preferential encoding of threatening stimuli into memory without an intention to do so ("implicit-memory bias"; Mathews & MacLeod, 2005): Anxious individuals show better memory for task-irrelevant threat-related words presented during a lexical (but not a semantic) task (Russo, Fox, Lynn, & Nguyen-Van-Tam, 2001), and for task-irrelevant fearful faces in a face-identity recognition task (Stout, Shackman, & Larson, 2013).

Attentional and memory processes are strongly linked with each other. Encoding of a stimulus into memory depends on attention, and emotion-laden stimuli are not an exception (Pottage & Schaefer, 2012). This contingence should extend to contexts where attentional resources are consciously deployed to stimuli but there is no pre-existing intention for memory encoding: In such situations, one's attentional bias towards threatening stimuli should result in their stronger encoding into memory even if such stimuli are irrelevant to the task. Notably, individual differences in personality and temperament might strengthen the relationship between the attentional bias towards threat-related stimuli and their subsequent-enhanced memory encoding.

The role of individual differences in personality and temperament in the processing of threat-related information

Could the memory bias that is driven by an attentional bias be observed in a typical, non-anxious population? The individual differences approach in the research on the attentional and/or memory bias has been typically focused on the previously mentioned TA, as measured by

State-Trait Anxiety Inventory (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). In many studies of this kind, individuals with low versus high TA scores are selected from the general population to study the effect of biases towards threat on information processing (e.g., Fox et al., 2001; for exception see Stout et al., 2013). Importantly, a recent meta-analysis (Bar-Haim et al., 2007) suggested that only clinically and subclinically anxious individuals exhibit the attentional bias towards negative information, with low-anxiety individuals showing no bias whatsoever. However, such a dichotomous picture might be driven partly by the chosen method. Using an arbitrary cutoff point (e.g., median) that divides a continuous variable into separate groups (i.e., a division between high- versus low-anxiety groups) may lead to a reduction in statistical power when searching for moderating effects of individual differences on biased processing of threatening information. Moreover, comparing high- and low-anxiety groups may be severely limiting the understanding of the psychological mechanisms that underlie biased information processing.

It is possible that factors strengthening the attention-based memory bias (i.e., memory bias that results from enhanced allocation of attentional resources towards threat-related stimuli) might also be revealed by studying individual differences in characteristics related to temperament. Temperament traits should characterise, to a certain degree, the whole population, i.e., both anxious and non-anxious individuals alike, and thus could reveal a realistic picture on the frequency of the cognitive biases. The importance of temperament characteristics for shaping individual differences in cognition and behaviour is supported by the fact that temperament traits can be observed even in animals or infants, and as such they could be regarded as more biologically determined than more socially determined personality traits (Strelau, 2006). In spite of this, to our knowledge, there is little research linking specific dimensions from major temperament theories with biased cognitive processing of threat-related information (but see Derryberry & Reed, 1998; Lonigan, Vasey, Phillips, & Hazen, 2004, Mauer & Borkenau, 2007, for notable exceptions), which leaves unclear the importance of temperament characteristics in modulating the interactions between different cognitive biases.

Present study

In the current study, the role of individual differences in strengthening the relationship between the attentional and memory bias was investigated by focusing on personality and temperament traits. The temperament traits we focused on were drawn from the Regulative Theory of Temperament (RTT, Strelau, 2006), which proposes the existence of six temperament dimensions reflecting various energetic and temporal aspects of information processing and behaviour. Critically, two of the RTT dimensions have been repeatedly shown to moderate the processing of aversive material: Emotional reactivity (ER; tendency to react intensively to emotional stimuli) modulates brain activity evoked by processing threat-related faces (e.g., Fajkowska, Zagórska, Strelau, & Jaśkowski, 2012), and perseveration (PE; typical duration of one's reaction after stimulus disappearance) increases event-related potential amplitude in response to enhanced semantic processing of emotional words (e.g., De Pascalis, Strelau, & Zawadzki, 1999). Importantly, Strelau and Zawadzki (2011) have recently demonstrated that these temperament traits are strongly related to "fearfulness", a characteristic that they consider a symptom of TA. This poses a question as to whether studying the described temperament traits could also help to advance our understanding of cognitive biases towards threat-related information and their interplay in the healthy population. It is possible that the temperament traits, those regulating the strength- and time-related aspects of information processing, might both significantly enhance one's preferential encoding of threatening stimuli into memory by influencing the allocation of attentional resources to such information. Interestingly, RTT could offer an important advantage over other models of temperament in the understanding of the attention-based memory bias: ER and PE reflect traits regulating different aspects of information processing and, thus, they afford specific predictions as to whether an energy- or a time-based regulatory mechanism is more important for enhancing memory for previously selected irrelevant threatening material in some individuals, while reducing the likelihood of such a transfer in others. As traits describing the strength and duration of one's typical processing of emotional information, ER and PE, respectively, might reveal the mechanism that determines involuntarily stronger assignment of attentional resources to threatening material and subsequently triggers enhanced memory for it (see below). Importantly, if these temperament traits were shown to be moderators of the discussed relationship, this would also provide further behavioural validation of these dimensions.

To examine whether the strength of the relationship between attentional bias towards threat and memory for incidentally encoded threatening stimuli is moderated by TA, ER, or PE, we used a spatial cueing task that was immediately followed by an unexpected "old/new" memory task. In the spatial cueing task, a target triangle was always preceded by a task-irrelevant face stimulus that had one of three different emotional expressions (angry, happy, or neutral) and acted as spatial "cues" that predicted the upcoming target's location. A similar attentional paradigm was originally employed by Fox et al. (2001) to study how individual differences in anxiety affect the amount of attentional resources that participants allocate to threatening stimuli.

Overall, we expected that a greater attentional bias for angry versus neutral or positive face-cues (Fox et al., 2001; Rudaizky et al., 2014) would predict better memory performance for the same face identities when presented with angry expressions, as measured by d' (the sensitivity index used in signal detection theory), thus providing evidence for a link between the attentional bias and the memory bias. The critical question was whether the strength of the relationship between attentional and memory biases for threat-related material would be enhanced by TA, typically associated with biased processing of threat, as well as ER and PE. While TA has been linked to both atypical disengagement as well as engagement of attentional focus in the context of threatening stimuli (Rudaizky et al., 2014), the effects of specific temperament dimensions on the processing of threatening stimuli are far less understood. Based on the limited existing literature (De Pascalis et al., 1999; Fajkowska et al., 2012), we expected to observe both the effects of ER and, possibly, also PE in the current paradigm, as they both led to the reported effects likely by affecting attention allocation, but probably via different mechanisms. ER might predominantly affect the amount of attentional resources allocated initially to threatening stimuli upon presentation. Thus, it should lead to faster engagement with such stimuli as well as slower disengagement (from the short-duration cues employed here) affecting reaction times (RTs) on both valid as well as invalid trials, respectively. In other words, the longer a particular stimulus is processed across the two types of trial for, the stronger the effective memory trace should be. In turn, PE might be related to prolonged albeit relatively moderate allocation of attentional resources, thus affecting RTs predominantly on invalid trials, effectively having an overall weaker effect on RTs in the attentional task, and as a consequence the relationship between the two biases.

METHOD

Participants

Forty-three undergraduate students (mean age 23.4 years, age range 19–31 years) with normal or corrected-to-normal vision took part in the experiment in exchange for course credit. Critically, with the conventionally used statistical power level of .8 and a p value of .05, the current sample size was revealed (using the G*Power 3.17 software; Faul, Erdfelder, Lang, & Buchner, 2007) to be sufficient to detect a medium-sized effect of an addition of the interaction term between attentional bias and temperament differences to a moderated hierarchical regression analysis. Thus, the current sample size was sufficient to evaluate the importance of specific individual differences as moderators of the relationship between attention and memory biases for threat-related stimuli (notably, in our previous study on a similar topic we found this interaction had a large effect size, Cohen's $f^2 = .35$; Traczyk, Matusz, & Sobków, 2010). The study was approved by Ethics Committee and all participants gave informed consent to participate in this experiment. None of the participants were excluded from the experiment.

Procedure, stimuli, and design

Participants were seated in a dimly lit room 50 cm from a monitor (1,280 × 1,024; 50 Hz). The experiment consisted of a spatial attention task followed by an unexpected "old/new" memory task.

Cueing task. On each trial, a grey central fixation cross (500 ms) was immediately followed by a cue (250 ms), an interstimulus interval of 50 ms, and a

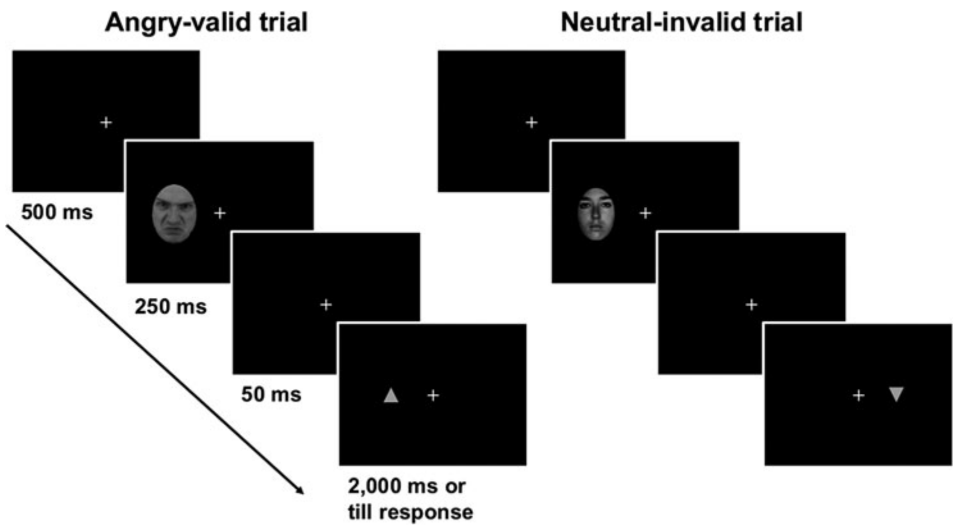

Figure 1. Schematic illustration of the sequence of events on each trial, shown separately for valid-angry trials (left panel) and invalid-neutral trials (right panel).

target (duration of 2,000 ms or until response recorded; see Figure 1). The intertrial interval was 1,000 ms. Participants discriminated the orientation (up/down) of an apex of a blue triangle target by pressing the up-arrow or the down-arrow keyboard button with their left- and right-hand finger, respectively. Target triangle (1.5° × 5.2°) was presented randomly and equiprobably to the left or right from the central fixation point (2.3° distance).

Cues preceding the triangle targets were task-irrelevant faces of three different emotional expressions (angry, happy, neutral). Faces of 10 identities (5 females), each showing all three emotions, were selected from a standardised emotional expressions pool (Lundqvist, Flykt, & Öhman, 1998), resulting in a set of 30 emotional stimuli. All faces were equal-size ovals (3.2° × 4.3°) presented in grayscale. Cues appeared at the same location as the subsequent target on 60% of all trials and on the opposite side on 20% of all trials. On the remaining 20% of trials, included to maintain participants' alertness, no target was presented ("catch trials").

Six blocks of 90 trials were performed, giving a total of 540 experimental trials. A short practice block (10 trials) with schematic faces as cues preceded the experiment. The assignment of the left and right hand to the up- and down-arrow response key was counterbalanced across participants.

Memory task. Thirty facial expressions from the cueing task and 30 new faces from the same set were presented centrally (2,000 ms) against a black background in a randomised order. Participants were instructed to decide whether the presented expression was shown in the previous task (yes/no).

Questionnaires. A few days before the experiment each participant completed STAI-T (Spielberger et al., 1983) and the Formal Characteristics of Behaviour-Temperament Inventory (Strelau & Zawadzki, 1993) that provided the TA, ER, and PE measures.

General data analysis approach

To investigate whether the strength of the relationship between attentional and implicit-memory biases for threat-related material can be moderated by individual differences in temperament and personality, we carried out the following analytical steps:

First, we evaluated whether angry faces produce an attentional and a memory bias. The attentional bias was assessed using a relative measure of attentional resources allocation, the cue validity index (CVI) that is calculated by subtracting RTs on trials where cues appeared in the same location (valid trials) from reaction times on trials where cues and targets appeared in different locations (invalid trials). In our experimental design, a larger CVI indicates that more attentional resources were allocated towards a face-cue. In turn, the memory bias in the memory task was evaluated by calculating d' as a difference between z-transforms of the hit rate and the false alarm rate for each of the three facial expressions. The hit rate was defined as a probability of reporting an “old” facial expression as presented in the cueing task, while the false alarm rate was defined as a probability of reporting a “new” facial expression as appearing in the previous task. Higher values of d' indicated higher sensitivity to detect old faces among new ones, and hence stronger memory encoding. To allow d' estimates to accommodate zero-frequency false alarm categories, 0.5 observation was arbitrary assigned in such cases.

Second, moderation analyses based on hierarchical regressions using PROCESS macro (Hayes, 2013) were carried out, where the role of each of the three individual difference measures (TA, ER, and PE) in moderating the relationship between the attentional bias in the cueing task and the memory bias for the “old” faces was investigated separately for each of the three emotional expressions of these faces (angry, happy, neutral). Because of the risk of violation of the multicollinearity assumption, nine moderation analyses (instead of one complex model) including different uncorrelated predictors were performed. In order to control for Type 1 error produced by comparing these nine models, the sequential step-wise Bonferroni–Holm correction (Holm, 1979) was employed. Specifically, p values were adjusted considering presence of nine interaction terms across the tested models. This allowed us to control for the family-wise error at the standard p value of .05.

In each of these nine regressions, in the first step the mean-centred CVIs for each of the three emotional expressions (e.g., angry) and scores on three individual differences measures (e.g., ER) were entered simultaneously as predictors into the regression analysis, in which d' for the respective facial expression served as the outcome variable (see Table 1). In the second step, an interaction between the two predictors (e.g., CVIs on trials with angry faces × ER) was added. A moderation effect was defined as a significant increase in the explained variation following inclusion of the interaction term (measured by F-test).

RESULTS

Extreme RTs (defined as ± 2.5 of individual SD on a z-scale) were excluded for each participant from further analyses. Only RTs from correct

TABLE 1

Unstandardised beta coefficients for regression models where the CVI for angry, happy, and neutral faces with ER, PE, and trait-anxiety scales (TA), respectively, were tested as predictors for memory for faces presented in the “old/new” task as indexed by d'.

		Angry					*Happy*					*Neutral*				
Step	*Predictors*	*b*	*t*	*p*	R^2	ΔR^2	*b*	*t*	*p*	R^2	ΔR^2	*b*	*t*	*p*	R^2	ΔR^2
1	CVI	0.48	0.12	.905			−0.57	−0.12	.907			1.14	0.36	.718		
	ER scale	0.05	2.32	.025			0.02	0.95	.343			0.04	1.87	.069		
2	CVI × ER	**2.19**	**2.81**	**.008 (.035)**	**.26****	**.13***	0.81	1.33	.548 (1.00)	.05	.02	0.64	0.73	.470 (1.00)	.08	.01
1	CVI	1.39	0.35	.731			3.39	0.59	.553			0.09	0.03	.979		
	PE scale	0.05	1.87	.069			−0.04	−1.50	.142			0.02	0.68	.498		
2	CVI × PE	1.71	2.01	.052 (.206)	.16	.08	−1.38	−0.79	.435 (1.00)	.10	.03	0.61	0.63	.532 (1.00)	.02	.01
1	CVI	0.82	0.18	.854			−1.09	−0.32	.753			0.04	0.01	.993		
	TA scale	0.02	1.60	.116			0.02	1.69	.097			0.03	1.65	.108		
2	CVI × TA	0.45	1.59	.121 (.422)	.10	.04	0.65	1.54	.130 (.422)	.14	.06	0.26	0.39	.693 (1.00)	.08	.01

Note: The significant interaction term for angry faces and ER ($b = 2.19$, $p = .035$, in bold) suggests that the strength of the relationship between attentional and memory bias is emotion-specific and is moderated by this temperament trait. P values of interaction terms adjusted for multiple comparisons using the Bonferroni–Holm correction are given in parentheses.
$^{**}p < .01$; $^{*}p < .05$ $r_{\text{ER-TA}}(42) = .63$; $r_{\text{ER-PE}}(42) = .56$; $r_{\text{TA-PE}}(42) = .38$, all $ps < .001$.

valid and invalid trials were analysed (average error rate: 2.5%; mean accuracy in catch trials 99.9%), resulting in a total loss of 5% of all trials. Inclusion of extreme RT trials did not influence the overall pattern of results.

Cuing task

Mean RTs were analysed in a 2 (cue validity: valid vs. invalid) × 3 (face expression: angry vs. happy vs. neutral) repeated-measures ANOVA. A main effect of cue validity, $F(1, 42) = 26.98$, $p < .001$, $\eta^2 = .39$, demonstrated faster responses to targets on valid versus invalid trials (430 ms, $SD = 45$ ms vs. 447 ms, $SD = 48$ ms). There was no main effect of face expression, $F(2, 41) = 3.01$; $p = .06$ ($M = 439$ ms, $SD = 46$ ms; $M = 436$ ms, $SD = 48$ ms; and $M = 439$ ms, $SD = 47$ ms for angry, happy, and neutral faces, respectively), or a two-way interaction between these factors ($F < 1$).

Three separate two-way ANOVAs were then carried out, with the CVIs for three emotional expressions as a within-subjects factor and median-split ER, PE, and TA (in three separate analyses) as between-subjects factors. We found a significant interaction effect, $F(2, 82) = 3.687$; $p = .029$, only for ER but not for PE, $F(2, 82) = 1.327$; $p = .271$, or TA, $F(2, 82) = 1.148$; $p = .322$. Further post-hoc analysis with Bonferroni correction showed that the only significant difference between high and low ER individuals was observed in the condition involving face-cues with angry expressions ($p = .041$), suggesting the existence of attentional bias towards threat.

Memory task

A one-way repeated-measures ANOVA on the d' scores suggested that implicit-memory performance for face identities differed on the basis of their emotional expression, $F(2, 41) = 9.12$, $p < .001$, $\eta^2 = .18$. Post-hoc tests with Bonferroni correction revealed higher d' values for angry faces ($M = 0.77$; $SD = 0.57$) when compared to both happy ($M = 0.33$; $SD = 0.58$), $p = .001$, as well as neutral faces ($M = 0.32$; $SD = 0.65$), $p = .001$. There was no difference in memory performance for faces with happy and neutral expressions.

The effect of individual differences and attention on implicit-memory

Out of the nine regression analyses performed to investigate the influence of interactions between specific individual differences and attention on incidental memory for identities with divergent emotional expressions, only the model including ER and CVI for angry faces significantly predicted memory performance for the previously presented material. We found a significant main effect of ER on d' for angry faces ($b = 0.05$, $p = .025$), which demonstrated that higher individual ER predicted a significant independent portion of variance in the memory performance for angry faces. There was no significant main effect of the CVI for angry faces alone on d' for angry faces ($b = 0.48$, $p = .905$). The critical novel finding was that this relationship between CVI for angry face-cues and memory performance for angry faces became significant when ER was included as a moderator, $b = 2.19$, $p = .035$: The inclusion of the interaction term between ER and CVI for angry face-cues into the model significantly increased the explained variance by a notable 13% (a medium-sized effect, $f^2 = .18$). Contrastingly, no similar interaction was found in models where TA ($b = 0.45$, $p = .422$) or PE ($b = 1.71$, $p = .206$) served as predictors for memory for angry faces. Importantly, no evidence of a similar interaction was found when d' for happy or neutral faces served as the dependent variable and interactions between CVIs for happy or neutral faces and the three individual differences scores separately served as predictors. In these cases, there was no evidence that addition of the interaction term improved the tested models (see Table 1). Thus, only ER (but not TA or PE) was a significant moderator of the relationship between the attentional bias for threatening information and memory performance for this information. Notably, this moderation effect was specific to threat-related material, rather than being specific to emotional material, or even valence-unspecific.

Subsequently, we used the Johnson–Neyman procedure (Hayes, 2013) to examine the conditional effect of ER on the relationship between attentional and memory biases. In this procedure, "regions of significance" are mathematically derived from the full spectrum of the moderator values, for which the relationship between a

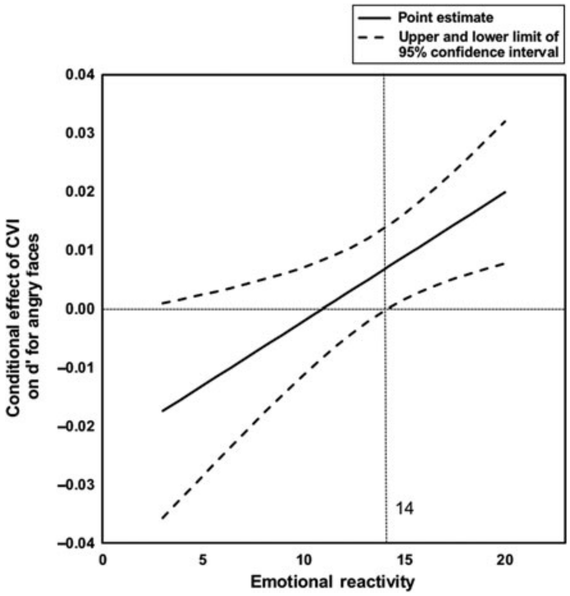

Figure 2. Johnson–Neyman regions of significance for the conditional effect of attentional bias for angry faces (as measured by the CVI) on the memory bias for this threat-related material (d' for angry faces). The solid line plots represent the conditional effect estimates of CVI for angry face-cues on d' for identities of these faces at different values of the ER. The dashed lines represent 95% of the upper and lower bounds of confidence interval. For the point at which the ER is above 14, the relationship between attentional and memory bias is significant.

predictor and a dependent variable is significant. If the confidence interval (CI) for the point estimate of the conditional effect does not contain a zero value, we can conclude that the predictor and the dependent variable are significantly related to each other. As Figure 2 illustrates, lower bound of 95% CI reached zero at the moderator value of 14, what suggests that CVI for angry face-cues predicts memory performance, as indexed by d', for these faces only for highly reactive individuals.

DISCUSSION

The aim of the present study was to investigate whether the strength of the direct relationship between the attentional bias and implicit-memory for threat-related material could be better predicted by including individual differences in TA, ER, and PE as moderator variables. Allocation of a larger amount of attentional resources to angry face-cues in a spatial cueing task alone did not explain memory for these faces in a subsequent unexpected "old/new" task. This relationship became significant when individual differences in ER were taken into account, which suggests that this temperament trait might play an important role as a moderator of the memory bias. Critically, this effect was specific to angry faces, evidencing an attention-based incidental memory bias towards threat.

The current results are the first to demonstrate an association between an attentional bias and implicit-memory bias towards threat-related material (i.e., face identities with angry expressions), with the latter resulting from the deployment of a greater amount of attentional resources. Previously, attentional resources were shown to mediate memory enhancement for aversive material in contexts where memory encoding and, thus, attention deployment were demanded by the current task (e.g., Pottage & Schaefer, 2012). The present study extends these results by showing that attention will predict enhanced memory even in contexts where there is no intention to attend to or memorise threatening material. While more research is required here to provide strong evidence for a causal link, the critical novel finding of the present study lies in demonstrating that specific traits can be used to predict whether the attentional bias towards threat will also influence memory encoding.

We demonstrated that the relationship between the attentional and memory bias is moderated by individual differences in ER, but not in PE or TA. Similar results were shown by our previous study (Traczyk et al., 2010), where only threatening and neutral material was compared: Exclusively high ER participants, but not low ER, high TA, or high PE (median-split), showed a positive correlation between attentional bias as measured by RTs on invalid trials with angry face-cues and subjective measures of incidental memory for angry faces. No such effect was found for neutral faces. The novelty and importance of the current findings are demonstrated by the fact that in the research on processing biases towards threat, ER seems to play a crucial role as an indicator of one's attention-based incidental memory bias. In other words, a disposition to respond strongly to emotional material is critical for enhancing the memory encoding of threat-related but irrelevant material in situations where this material is incidentally selected, but attention might not be easily disengaged from it. Thus, the likely mechanism by which ER strengthens the relationship between the two cognitive biases is indeed increasing the amount of attentional resources that one allocates to the threatening material. Notably, the fact that the change we observed in explained variance in memory for angry faces associated with the interaction term involving ER was already much larger in magnitude than for the other two dimensions (PE, TA) suggests that the present pattern reflects a genuinely unique role of ER in linking the attentional and memory biases. However, in light of the present results we cannot definitively say that PE and TA do not play any role in moderating this relationship. The moderating effect of ER in our study was revealed to be of medium-size. Thus, it is plausible that with greater statistical power, a small effect of TA and/or PE on the memory for previously seen angry faces could be detected. A replication of the current study, involving a larger sample and different material would further substantiate the reliability of the present findings.

Our results also provide important validation for RTT (Strelau, 2006). In contrast to the critical role of ER revealed by the present findings, previous studies showed that in the processing of aversive and threatening material, ER, involved in regulating energetic aspects of information processing, might play a role similar to PE, a dimension associated with regulation of the temporal aspects of information processing (De Pascalis et al., 1999; Fajkowska et al., 2012). More broadly, our findings suggest that temperament traits, present in individuals from infancy and strongly biologically determined, might offer novel insights into the role of individual differences in the attentional and memory biases present in the typical population. Importantly, the ER and PE scales from RTT could help uncover factors critical in enhancing other cognitive biases towards threat-related information.

We demonstrated that the greater attentional bias towards threat was associated with enhanced memory for threatening material only in individuals high in ER. Interestingly, the present results also showed that, overall, memory for irrelevant face identities in the "old/new" task was better in trials where these identities were presented with angry, rather than happy or neutral expressions, but the same angry faces were not processed differently to other cues in the cueing task that preceded the memory task unless the participants' ER was taken into account. These findings seem to provide converging evidence that the incidental encoding of irrelevant threat-related stimuli measured by "old/new" task might also be supported by mechanisms operating independently of attentional selection (e.g., Vuilleumier & Driver, 2007). Importantly, in the present study emotional expressions of attentional face-cues were task-irrelevant, but their prolonged processing was not associated with performance costs. If the observed pattern of results (i.e., the overall better memory for angry faces and the critical contribution of ER) remained present also in task contexts penalising for prolonged processing of threat-related stimuli, this would strongly support the role of ER as a population-wide indicator of an involuntary tendency to deploy a greater amount of attentional resources to threat.

To summarise, the current study demonstrated that attentional bias towards threat-related material is predictive of enhanced memory for these incidentally encoded stimuli, but only in individuals high in ER. These findings offer a novel perspective for understanding processing biases in the general population by demonstrating the utility of studying individual differences in temperament.

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