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NEGATIVE AROUSAL REDUCES SENSITIVITY FOR PROCESSING CONTEXT INFORMATION

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Increases in arousal modulate information processing, promoting and prompting a switch from a contextual cognitive system to a more rigid habit system underlying ongoing cognition. We built on previous research findings regarding effects of emotion on context processing, examining whether or not high arousal states of different valence affect context processing. We measured context processing using the AX-continuous performance task paradigm. To manipulate emotional arousal, 60 participants were exposed to short clips from existing feature films showing either a social interaction (control condition), a violent encounter (negative arousal condition), or an episode of sexual intercourse (positive arousal condition). Analyses of signal detection measures showed that, compared to the control and positive-arousal groups, participants in the negative-arousal group displayed selective impairment of context processing. Results indicated that alterations in context processing by increased arousal are valence specific.

Keywords: arousal, emotion, context processing, cognitive control, AX-continuous performance task.

General arousal is related to environmental changes, with extreme increases in response to a variety of challenging situations ranging from stress arising from a threatening event (Hermans et al., 2011) to excitement during a sexual

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encounter (Sarlo & Buodo, 2017). This arousal promotes cognitive adjustments in terms of streamlined information processing according to environmental demands (Berridge & Waterhouse, 2003). For example, stressful states impair working memory, cognitive flexibility, and cognitive inhibition, but enhance response inhibition (Shields, Sazma, & Yonelinas, 2016). Packard and Goodman (2012) found that stress biases competition of multiple systems engaged in cognition. Whereas novel events and their spatial temporal context are encoded by a hippocampus- and prefrontal-cortex-dependent memory system (Squire, Stark, & Clark, 2004), reflexive, habitual responding in terms of incremental strengthening of stimulus–response bindings is supported by a dorsal striatum-dependent system (Packard & Knowlton, 2002). These responses suggest that in learning situations, stress leads to a shift from flexible (cognitive) to rigid (habit) memory systems (Schwabe & Wolf, 2013). Although the shift to a rigid system suggests decreased engagement of systems underlying context processing during increased arousal, there is limited knowledge about how arousing encounters affect context maintenance.

Context processing helps the individual with choosing an appropriate reaction against a competing, overlearned response even when the appropriate context processing appears less dominant than an unsuitable course of action, and is associated with a prefrontal-cortex-centered network (Cohen, Barch, Carter, & Servan-Schreiber, 1999). An established paradigm to measure context processing is the expectancy variant of the AX continuous performance task (AX-CPT; Cohen & Servan-Schreiber, 1992). In the AX-CPT, participants are required to respond after presentation of a probe whenever the target pairing appears (cue "A" followed by probe "X"). The target cue-probe pairing is presented as a predominant response, appearing frequently (70% of presentations). The task consists of three further, low frequency (10% each) cue-probe pairings of letters "A" and "Y" (valid cue, invalid probe), pairings of the letters "B" and "X" (invalid cue, valid probe), and pairings of the letters "B" and "Y" (invalid cue, invalid probe). Whereas the last of these pairings represents a control trial, the first two are considered conflict trials because, in AY trials, the cue activates anticipation of a hit response, which then must be inhibited, and, by contrast, in BX trials contextual information must be maintained to overcome the tendency to execute the hit response provoked by the presentation of the valid probe. Thus, whereas in AY trials, conflict is induced by the context-cue-driven expectation of a valid probe, in BX trials, the conflicting situation arises by presentation of a valid probe after an invalid context cue. Therefore, researchers have considered errors in BX trials a measure of context processing (Cohen et al., 1999).

Evidence shows that performance-contingent and performance-noncontingent reward incentives, as well as low-arousing positive affect, alter individuals' performance in the AX-CPT (Fröber & Dreisbach, 2014; Goschke & Bolte, 2014).

In addition, researchers have demonstrated that positive emotion modulates cognition depending on the degree of arousal, with states high in arousal promoting attentional perseverance and low arousal states leading to enhanced flexibility (Liu & Wang, 2014). Our aim was to add to this existing picture of affective modulation of AX-CPT performance by investigating alterations to individuals' AX-CPT performance by negative and positive states high in arousal. We assumed that context maintenance in the AX-CPT, as measured by errors in BX trials, would rely on a flexible cognitive strategy, whereas an arousal-induced shift toward a stimulus–response habit strategy (Schwabe & Wolf, 2013) would promote increased perseverance and would lead to an erroneous hit response in BX trials. Because BX trials contain a valid probe, increased arousal should activate the dominant stimulus–response association and thereby hamper the ability of the individual to overcome a tendency toward the probe-related hit response. Thus, we predicted that being in a high arousal state would disrupt the individual's context processing. To test our hypothesis, we applied a behavioral experiment using the AX-CPT. Arousal states were experimentally manipulated as the between-subject factor using three short clips from existing films (cinematographic fragments): a social conversation (control condition), a violent encounter (high negative arousal), and sexual intercourse (high positive arousal). The selected fragments used to induce the targeted arousal states (i.e., stress in terms of high negative arousal and sexual excitement as a state of high positive arousal) are materials that have been applied successfully by previous researchers (Hermans et al., 2011; Rupp & Wallen, 2008; Sarlo & Buodo, 2017).

Method

Participants

All participants (46 women, 14 men; M_{age} = 21.30 years, SD_{age} = 2.45; age range: 18–27 years) were healthy volunteers with normal or corrected-to-normal vision who were recruited from the University of Innsbruck. Informed consent was obtained according to the guidelines of the Ethics Committee of the Department of Psychology, University of Innsbruck.

Procedure

In a 3 (arousal state) × 4 (trial type) factorial design, each participant was randomly assigned to one of three conditions (control, violence, erotica; between-subject variable) and performed the AX-CPT consisting of four trial types (AX, AY, BX, BY; within-subject variable).

The experimental task was developed using E-Prime software Version 2.0 (Schneider, Eschman, & Zuccolotto, 2012) and was presented on a Samsung 943BM computer monitor (32-bit true color, resolution 1280 pixels × 1024 pixels, refresh rate = 60 Hz).

Experimental Manipulation of the Arousal State

Three short cinematographic fragments of 60 seconds duration each were used with the aim of inducing altered states of arousal: (a) a neutral, low arousal state; (b) a negative, high arousal state; and (c) a positive, high arousal state. All selected fragments described above had similar volume and pitch (auditory characteristics) and luminance and contrast (visual characteristics).

The AX-CPT

The AX-CPT comprises a series of trials presenting single letters in cue-probe pairings: a valid A followed by a valid X (AX), a valid A followed by an invalid Y (AY), an invalid B followed by a valid X (BX), and an invalid B followed by an invalid Y (BY). Participants are instructed to respond as fast as possible to the probe letter, classifying AX sequences as *target* and the other sequences (AY, BX, and BY) as *nontarget*. The alternative letter sequences are presented in a randomized order.

First, participants see a fixation cross on the computer screen for 1,000 ms, followed by the cue for 300 ms. After the presentation of another fixation cross for 1,500 ms, the probe is presented either until the participant makes a response or for a maximum of 1,000 ms. At the end of each trial, the screen is blank for 1,000 ms and this is paired with an acoustic feedback tone, which signals either a correct response, a false response, or a no/too slow response.

Data Analysis

We calculated sensitivity and response bias according to signal detection theory (Macmillan & Creelman, 1991), both representing our dependent variables for statistical analysis. Change detection performance was quantified using d-prime (*d'*) as a measure of sensitivity. Based on the *z*-transformed probability of correct match responses (hits, *H*) and incorrect match responses (false alarms, *F*) for each condition separately, we calculated sensitivity by subtracting the *z*-transformed false-alarm rate from the *z*-transformed hit rate. We computed sensitivity *d'* context as a signal-detection index using AX hits and BX false alarms for context maintenance (X-probe *d'*), as well as AX hits and AY false alarms for proactive preparedness (A-cue *d'*).

In order to determine each participant's response strategy, we calculated response bias using *c* (C-bias; Macmillan & Creelman, 1991), which represents the distance between the criterion and the point at which each response is chosen with equal frequency (in standard deviation units). As for *d'*, we calculated *c* separately for false-alarm rates in BX trials (X-probe *c*) and false alarm rates in AY trials (A-cue *c*). Response bias *c* was calculated by averaging the *z*-transformed false-alarm rate and the *z*-transformed hit rate by multiplying the result by negative one (-1). As a result, negative values of *c* indicate a bias toward responding "No" rather than "Yes." Corrections for extreme values in hit rates or false alarms were applied following the log-linear approach (Snodgrass & Corwin, 1988).

Both signal detection measures *d'* and *c* were calculated for each participant independently. To examine the effects of the different arousal states on signal-detection measures, independent-measure analyses of variance (ANOVAs) were applied on estimates of sensitivity *d'* and response bias *c* (see Table 1) with arousal state (control, violence, erotica) as the between-subject variable. An alpha level of .05 was used for all statistical tests. All reported *p* values are two-tailed.

Results

Data from all participants were used for statistical analysis. Effect sizes are reported using partial eta squared η_{Part}^2 (0.01 = small; 0.06 = medium; 0.14 = large) for ANOVAs.

Effects of Arousal States on Sensitivity

The ANOVA for independent measures with the between-subject variable arousal state on A-cue *d'* showed no main effect, $F(2,57) = 0.86$, $MSE = .34$, $p = .429$. By contrast, results showed a strong main effect of the between-subject variable arousal state on X-probe *d'*, $F(2, 57) = 4.90$, $MSE = .16$, $p = .011$, $\eta_{Part}^2 = .15$ (see Figure 1). Planned contrasts revealed impaired performance in the negative arousal group as compared to the control group with a difference of .36 [$SE = .12$], Bonferroni-adjusted $p = .022$, as well as the positive arousal group with a difference of .32 [$SE = .12$], Bonferroni-adjusted $p = .049$. There was no difference in X-probe *d'* between the control and positive arousal groups, $\Delta = .04$, $SE = .12$, Bonferroni-adjusted $p = .944$.

These results indicate strong impairment of context processing following experimental elicitation of high negative arousal. We found it interesting that alterations in estimates of sensitivity d' appeared exclusively in BX trials in the negative-arousal condition. In contrast, performance of context processing in the positive-arousal group remained unaffected compared to the control group. In addition, we found no evidence in any group for alterations in preparatory effort, as measured by A-cue *d'*.

Effects of Arousal States on Response Bias

When we assessed the effects of arousal state on response bias *c*, the results did not reveal a significant alteration in A-cue *c*, $F(2, 57) = .32$, $MSE = .05$, $p = .725$, or an alteration in X-probe *c*, $F(2, 57) = .74$, $MSE = .04$, $p = .484$. We concluded that, regardless of valence, variations in arousal state did not affect the strategies our participants used in their responses to the AX-CPT.

Table 1. *Effects of Alterations in Arousal on Error Rates, Sensitivity d', and Response Bias c.*

	Arousal state					
	Control		Violence		Erotica	
	M	*(SE)*	*M*	*(SE)*	*M*	*(SE)*
Hit rates AX	.991	(.002)	.986	(.003)	.991	(.003)
False-alarm rates AY	.071	(.015)	.071	(.014)	.052	(.012)
False-alarm rates BX	.002	(.002)	.027	(.008)	.008	(.004)
A-cue *d'* (AX|AY)	3.795	(.128)	3.693	(.144)	3.934	(.119)
X-probe *d'* (AX|BX)	4.358	(.070)	4.000	(.106)	4.315	(.084)
A-cue *c* (AX|AY)	-.432	(.051)	-.376	(.048)	-.394	(.050)
X-probe *c* (AX|BX)	-.150	(.035)	-.222	(.052)	-.204	(.041)

Note. Standard errors in parentheses.

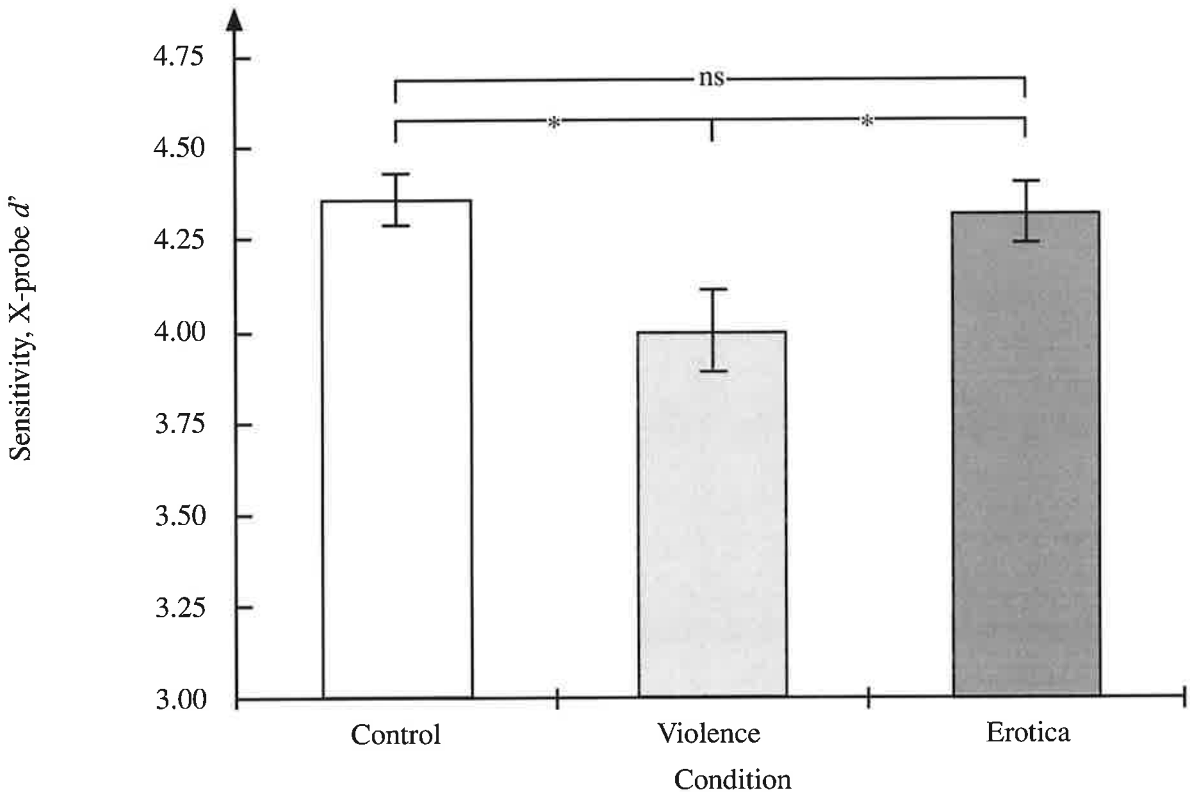

Figure 1. Sensitivity X-probe *d'* for different arousal groups. Standard errors are represented in the figure by the error bars attached to each data point.

Discussion

We focused on context processing, a hallmark of higher cognition supporting the selection of appropriate responses depending on situational context, and its modulation by increased arousal. Context processing and preparatory effort are modulated by both reward incentives and low arousal positive affect (Fröber & Dreisbach, 2014; Goschke & Bolte, 2014). We tested how states of both negative and positive high arousal affect context processing. Results show that being in a high arousal state impaired context processing in a valence-specific manner as measured by accuracy decrements in BX trials in the AX-CPT. Compared to the control and positive-arousal groups, participants in the negative-arousal group made more errors in BX trials, showing reduced sensitivity for context information.

Two mechanisms could account for these alterations during high arousal. On one hand, responding correctly in BX trials requires the respondent to hold the invalid cue in his or her working memory, thereby inhibiting the erroneously hit response to the valid probe. Increased negative arousal could have disrupted maintenance of context (i.e., the invalid cue) and, thereby, could have promoted failure to resist executing a hit response to the valid probe. On the other hand, because the sequences of BX trials contained the valid probe, increased arousal could have strengthened the dominant stimulus–response association and, thereby, could have hampered the respondent's ability to overcome a tendency toward the probe-related hit response, thus resulting in a state of enhanced perseverance (Liu & Wang, 2014). As an increase in arousal interferes with holding the cue in working memory, it would be logical to expect accuracy improvements in AY trials. Disrupted cue maintenance should weaken the tendency to make a hit response as induced by the valid cue, but no such alterations in terms of an improved performance because of a reduced reliance on the context cue in AY trials were observed. Hence, although both mechanisms do not exclude each other and could act in concert (Packard & Goodman, 2012), it seems less likely that impaired context maintenance rather than strengthened stimulus–response activation was the underlying trigger for alterations in accuracy.

Previous findings have provided evidence for cognitive adaptations resulting from monetary incentives (e.g., Chiew & Braver, 2016). Rewarding accurate responses in the AX-CPT leads to improved task performance, but an increased error rate in AY-trials (Chiew & Braver, 2013). As reward and increased emotional arousal result in a state of enhanced motivational preparedness (Lang, 2010), we expected that both would promote similar effects on context processing. Thus, findings on reward-driven adaptations seem contradictory to our results. However, reward-driven alterations in cognition are supported by distinctive neural activity and neuromodulatory dynamics, other than adaptation promoted by general arousal (Aarts et al., 2010; Beck, Locke, Savine, Jimura, & Braver, 2010; Berridge & Waterhouse, 2003; Chiew & Braver, 2011; Goschke & Bolte, 2014; Jimura, Locke, & Braver, 2010). In addition to our results, there is evidence from recent experiments indicating that the cognitive adaptations promoted by the different levels of arousal intensity of emotions differ from those elicited by monetary incentives (Chiew & Braver, 2014; Fröber & Dreisbach, 2012, 2014), suggesting that both motivational influences might affect different cognitive functions (Pessoa, 2009). In the light of our findings, it seems reasonable to conclude that increased negative arousal promotes behavioral perseverance through enhanced reliance on habitual actions, whereas, in the case of monetary incentives, cue-induced expectations in response selection are strengthened in terms of preparatory control (Chiew & Braver, 2016).

Our findings support the idea that stress produces a shift toward the use of a less demanding striatum-dependent habit strategy by impairing a more complex cognitive strategy supporting task performance (Schwabe & Wolf, 2013). In our study, reduced reliance on context information and increased habitual responding based on active stimulus–response associations might have impaired maintenance of the invalid cue and strengthened reflexive responding to the valid probe. Thus, at the relevant behavioral point in time, inhibitory influence of the invalid cue on response selection was reduced, which facilitated the erroneous activation of the predominant hit response by appearance of the target stimulus.

One clear limitation in our study was the mixed-gender sample. The arousal states of males and females are differentially susceptible to the same erotic stimuli (Rupp & Wallen, 2008). Consequently, the absence of effects of positive emotion high in arousal might be attributable to the mixed-gender sample, with men showing higher arousal after observing a sexual encounter than did women.

We concluded that sensitivity for context during high arousal states varies as a function of valence. Our findings increase understanding of cognitive adjustments during high arousal states, showing valence-specific alterations of our participants' context processing by increased arousal. Thus, we concluded that negatively experienced states high in arousal, such as stress, selectively impair context processing, likely promoting increased reflexivity of habitual stimulus–response bindings.

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