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Neuroticism influences pupillary responses during an emotional interference task

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ABSTRACT

We used behavioral and pupillary measures during an analogical reasoning task to investigate the processing of conceptual and emotional relations as well as their interaction. In particular, we examined how mental resource consumption is modulated by individual differences in neuroticism in healthy participants during conditions with *emotional interference*.

Two word pairs were presented simultaneously, each with a conceptual and an emotional relation. In one experimental block, participants had to decide whether *conceptual* relations between the two word pairs were corresponding (*conceptual task*). In the other block, participants had to decide whether *emotional* relations were corresponding (*emotional task*).

When participants had to focus on the correspondence of emotional relations, they were faster, more accurate, and showed greater pupillary responses than during the conceptual task. Moreover, participants with comparably higher neuroticism scores showed increased pupillary responses during conditions with emotional interference (i.e., during the conceptual task when they had to ignore incongruent information on the correspondence provided by the task-irrelevant emotional relations).

These results demonstrate that affective aspects of stimuli (here: emotional relations) are preferentially selected for information processing. Moreover, increased mental resource consumption due to emotional interference in participants with comparably higher neuroticism scores might reflect a possible mechanism making these individuals more vulnerable to mood or anxiety disorders.

1. Introduction

Everyday decision making includes both cognitive as well as affective aspects. Affective aspects of a situation are very important for immediate survival of the organism because they might signify a potential threat or a possible reward. Therefore, affective aspects, such as the valence of a stimulus, are selectively attended and processed automatically and more quickly than cognitive aspects, such as conceptual features (for reviews see Compton, 2003; Ochsner and Feldman Barrett, 2001; Pessoa and Ungerleider, 2003; Phelps, 2006). Although it might be a selective advantage for the organism to direct information processing toward those aspects of a situation that are emotional and important, effective mental functioning also requires that cognitive deliberation processes are protected from emotional interference induced by task-irrelevant but emotionally salient stimuli.

To gain a more comprehensive understanding of the underlying mechanisms concerning effective mental functioning, in the present study we investigated affective and cognitive processing as well as their interaction in healthy participants which individually differ in their susceptibility to emotional interference.

Traditionally, emotional interference has been investigated using the emotional Stroop task. In this task participants have to identify the ink color of words while they have to ignore the word meaning in neutral words contrasted with emotionally negative and positive words (Mathews and Macleod, 1985; McKenna, 1986). Responses are typically slower for color naming of emotional words relative to color naming of neutral words, at least, in participants with clinically manifest mood or anxiety disorders (e.g., Mathews and Macleod, 1985; Williams et al., 1996). Slowing of response times for color naming of emotional words relative to neutral words in the emotional Stroop task serves as a measure of emotional interference. However, the meaning of the emotional words, which interferes with identifying the ink color, is neither semantically related to the task-relevant

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information (namely, the ink color), nor do the emotional stimuli lead to responses that directly compete with the selection of the correct response (Algom et al., 2004; Etkin et al., 2006). Therefore, in this task there is no *direct interaction between affective and cognitive processing* and only the extent to which the emotional content of the word stimuli withdraws attention from the main task (namely, identifying the ink color) is measured.

To directly compare cognitive and affective processing and to investigate how affective processing interferes with cognitive processing, we developed an analogical reasoning task (cf. van der Meer, 1989). In this task two word pairs were presented simultaneously (e.g., TUMOR — BRAIN and RAT — CELLAR, cf. Methods and Table 1). Between the words of each pair there was a *conceptual relation*. The word pair TUMOR — BRAIN, for instance, is characterized by a location relation ("The tumor is in the brain."). Other types of conceptual relations were actor relations (e.g., BIRD — CHIRP) and object relations (e.g., FEED — BIRD; Collins and Quillian, 1969; Herrmann and Chaffin, 1986; Klix, 1992). Word pairs could additionally be characterized by an *emotional relation* which signified a positive (e.g., BIRD — SING), neutral (e.g., BIRD — FLY) or negative (e.g., BIRD — ROT) valence.

The word material was used in two experimental blocks with different task instructions. In one experimental block (A), participants had to focus on the conceptual relations and were required to decide whether the two word pairs corresponded in their conceptual relations (*conceptual task*). That is, during the conceptual task an analogy was defined by the correspondence of the conceptual relations between the two word pairs (Con=; e.g., the item CANCER — BREAST and SHELL — BEACH is an analogy because both word pairs are characterized by location relations, whereas SPIDER — BED and BODY — DECAY is not an analogy because conceptual relations are different). In the other experimental block (B), participants had to focus on the emotional relations (*emotional task*). Here, an analogy was defined by the correspondence of the emotional relations (Emo=; e.g., the item CHILD — LAUGH and TREASURE — CHEST is an analogy because of the positive relations between CHILD — LAUGH and TREASURE — CHEST which are corresponding, whereas POISON — KILL and STAR — SHINE is a non-analogy item because emotional relations do not correspond).

Notably, in half of the items in each task, the information on the correspondence provided by the task-relevant type of relation (conceptual information in block A *or* emotional information in block B) was congruent with the task-irrelevant type of relation. For example, when conceptual relations in the conceptual task corresponded, emotional relations were also corresponding (e.g., TUMOR — BRAIN and RAT — CELLAR). In the other half, information on the correspondence provided by the task-irrelevant type of relation was incongruent with information provided by the task-relevant type of relation. For example, in CANCER — BREAST and SHELL — BEACH conceptual relations are corresponding, whereas emotional relations are not. Here, a response conflict caused by the task-irrelevant stimulus dimension was induced (cf. Methods and Table 1).

Table 1
Examples for word material in the analogical reasoning task

	Emo=	Emo≠
a) Conceptual task		
Con=	TUMOR—BRAIN/ RAT—CELLAR *n* = 24	CANCER—BREAST/ SHELL—BEACH *n* = 24
Con≠	SPIDER—BED/ BODY—DECAY *n* = 24	MURDERER—PARK/ BIRD—CHIRP *n* = 24
b) Emotional task		
Con=	DOLPHIN—JUMP/ SUN—RISE *n* = 24	POISON—KILL/ STAR—SHINE *n* = 24
Con≠	CHILD—LAUGH/ TREASURE—CHEST *n* = 24	BELL—JINGLE/ VIRUS—BLOOD *n* = 24

Emo=, emotional relations corresponding; Emo≠, emotional relations non-corresponding; Con=, conceptual relations corresponding; Con≠, conceptual relations non-corresponding. The gray colored fields show analogy items, that is, conditions in which participants had to answer "yes". In contrast, white fields show non-analogy items. Bold framed fields indicate conditions with interfering information (information on the correspondence provided by conceptual and emotional relations not congruent).

We measured response times and error rates as two indicators for *task processing performance*. As a reliable indicator for *mental resource consumption* during both tasks we recorded pupillary responses.

Pupil diameter is controlled by two muscles innervated by the sympathetic and parasympathetic branches of the autonomic nervous system, which get their input from brain structures that are essential to both affective and cognitive information processing (Granholm and Steinhauer, 2004; for a detailed description of the neural basis of pupillary responses see Hoeks and Ellenbroek, 1993 or Steinhauer and Hakerem, 1992). Here, in particular, the norepinephrine system and the locus coeruleus seem to play a crucial role. The locus coeruleus, which receives input from the cingulate cortex, from prefrontal areas, and the amygdala, has been associated with the regulation of cognitive performance and conflict processing (Usher et al., 1999; Aston-Jones and Cohen, 2005) on the one hand and with emotional arousal during the induction of stress and fear (e.g., see Liddell et al., 2005) on the other hand.

Phasic changes in pupil diameter have been proven as a sensitive and reliable psychophysiological measure of the task-related (cognitive and affective) processing load, with larger pupil dilation reflecting greater processing demands (Granholm and Steinhauer, 2004; Loewenfeld, 1993). Using a digit span recall task, Kahneman and Beatty (1966), for example, demonstrated that pupil diameter proportionally increases as a function of the number of digits that have to be maintained in short term memory. Pupil diameter increases until the participants reach their limit of available cognitive resources (i.e., until their memory capacity of 7 ± 2 digits; Granholm et al., 1996). Notably, Just and Carpenter (1993) characterized pupillary responses as an indicator of how *intensely* the processing system is operating and defined intensity as the "*rate of mental resource consumption*" (p. 311) that supports information processing. Peak dilation has been found to increase systematically with enhanced processing demand in studies using a variety of tasks (for reviews see Beatty and Lucero-Wagoner, 2000), comprising language comprehension (Hyona et al., 1995; Just and Carpenter, 1993; Nuthmann and van der Meer, 2005), attention allocation (e.g., Karatekin et al., 2004; Kim et al., 2000), memory maintenance and semantic elaboration (e.g., Granholm et al., 1996; van der Meer et al., 2003), as well as emotion processing, namely, valence identification (e.g., Siegle et al., 2001; Steinhauer et al., 1983).

Individual differences in the susceptibility to emotional interference can be operationalized by measuring individual differences in neuroticism. The personality trait neuroticism is defined as the tendency to experience nervousness, tension, anxiety, emotional instability, hostility, and sadness (John and Srivastava, 1999). Using a dichotic dual-task paradigm, Osorio et al. (2003) showed that more neurotic participants responded slower in the presence of stressful distractors in the unattended ear compared to less neurotic participants. This indicates that neurotic individuals are less able to ignore stressful words and to shift attention away from emotional information. Neuroticism seems to have a neural basis and is considered to be a predisposition for mood and anxiety disorders, such as depression and phobias (for a meta-analysis see Malouff et al., 2005). Recent neuroimaging studies showed functional (Canli et al., 2001; Canli, 2004; Deckersbach et al., 2006) and structural neuroanatomical correlates (Wright et al., 2006) of neuroticism in brain regions that are associated with emotion processing and cognitive control. In an fMRI study with highly neurotic individuals, Canli et al. (2001) found enhanced activity in responses to emotional stimuli in brain regions associated with emotion processing. More specifically, Haas et al. (2007) demonstrated that neuroticism correlates positively with