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# Influence of affective significance on different levels of processing using pupil dilation in an analogical reasoning task

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ABSTRACT

The present study investigates the interaction of cognition and emotion in decision making, using an analogical reasoning task. In this task, two word pairs were presented simultaneously. Each word pair could be characterized by an associative conceptual relation (object, actor, or location relation) as well as an emotional relation (negative, neutral, or positive valence). Both types of relations were equally task-relevant: Participants had to identify both types of relations, to compare them, and to decide whether or not the word pairs were *analogous*, i.e., corresponding in *both* conceptual and emotional relations. Behavioral data showed that emotional relations were identified preferentially and faster than conceptual relations. Pupil dilations reflected the descending difficulty of the conditions and were greatest in amplitude when both conceptual and emotional correspondence was shown, intermediate when only one type of relation (either the emotional or the conceptual) corresponded, and least when neither correspondence existed. Additionally, a negative valence of the word material slowed down response times and increased pupil dilation relative to positive and neutral items. In summary, pupil and response time data together support recent (neurobiological) models concerning the interaction of emotion and cognition by showing that affective significance leads to a processing advantage at a cognitively *lower level* of information processing (here, identification or retrieval of relations from long-term memory) but can also distract people from *higher level* cognitive processes (here, from the controlled comparison of retrieved relations).



## 1. Introduction

Everyday decision making includes both cognitive and affective aspects. Affective aspects of a situation are mostly vital for the immediate survival of an organism, because they can signify a potential threat or a possible reward. This processing advantage of affective aspects might be due to the fact that the brain can filter out relevant information and directs information processing automatically toward aspects of a situation that are important (e.g., for immediate survival). The so-called biased competition model of attention (Desimone and Duncan, 1995), for instance, suggests that more important aspects of a situation are selectively attended and processed faster with increased allocation of mental resources (for an extension of the biased competition model for conceptual representations, see Kan and Thompson-Schill, 2004). Moreover, this model suggests that attending to one aspect or class of stimuli reduces the cognitive resources available for others. Thus, different aspects of a situation or different classes of stimuli compete for representation, processing, and control over behavior. Sometimes, this competition results in an interference of more salient but task-irrelevant emotional stimuli on cognitive processing (for an investigation of emotional interference on cognitive control, see Hartikainen et al., 2000; McKenna, 1986; Mitchell et al., 2008).

While many studies have investigated the selective advantage of affective processing in general or an interference effect of task-irrelevant affective stimuli on executive functioning (for reviews, see Compton, 2003; Ochsner and Feldman Barrett, 2001; Pessoa and Ungerleider, 2003; Phelps, 2006), it is still unclear how cognitive and affective processes interact when both aspects are equally task-relevant and how this interaction of cognitive and affective aspects is reflected at different (lower and higher) levels of information processing.

To approach this question, we developed an analogical reasoning task based on current models of long-term memory, according to which semantic knowledge can be depicted as a network consisting of concepts and semantic relations (for a review on the organization of long-term memory in humans, see Martin and Chao, 2001).

In this task, two word pairs were presented simultaneously. To begin with, each word pair could be characterized by a *conceptual relation*, which was always an associative conceptual relation. That is,

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concepts were related to each other, because they were sharing a thematic category (e.g., CAR and GARAGE), in contrast to taxonomical conceptual relations, in which concepts are from the same (hierarchically structured) semantic category (e.g., CAR, TRAIN, BUS; cf. Lin and Murphy, 2001; Sachs et al., 2008a). Types of associative conceptual relations (Collins and Quillian, 1969; Herrmann and Chaffin, 1986; Klix, 1992) used in the word material were actor relations (for instance, the concepts BIRD and CHIRP are characterized by an actor relation, i.e., "The bird chirps."), object relations (e.g., FEED–BIRD), and location relations (e.g., BIRD–CAGE). Second, concepts and their relations were emotionally biased and could additionally be characterized by an *emotional relation* signifying either a pleasant (e.g., BIRD–SING), neutral (e.g., BIRD–FLY), or unpleasant (e.g., BIRD–ROT) evaluation (van der Meer, 1989). An analogy was defined by correspondence of *both* conceptual and emotional relations of the two word pairs presented. Participants had to identify, that is, retrieve conceptual and emotional relations in each of the two word pairs from long-term memory, compare them, and decide whether or not the word pairs were identical in both.

As the long-term memory model suggests, associative conceptual and emotional relations should be retrieved automatically (*lower level* of information processing; Sachs et al., 2008a,b; van der Meer, 1989). The cognitively *higher-level* comparison process, however, which takes place to check whether the analogy condition is fulfilled or not, requires some executive control function (Bunge et al., 2005; Krawczyk, 2002; Krawczyk et al., 2008).

We measured response times and error rates as behavioral indicators for *task performance* and recorded pupillary responses as a reliable indicator for *mental resource allocation*.

Pupil diameter is controlled by two muscles innervated by the sympathetic and parasympathetic branches of the autonomic nervous system, which get their input from the central nervous system and structures essential to both emotional and cognitive information processing (Aston-Jones and Cohen, 2005; 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). While tonic changes in pupil diameter reflect the sensitivity of the cognitive system to all kinds of stimuli ("exploration mode", cf. Aston-Jones and Cohen, 2005), phasic changes have been proven as a sensitive and reliable psychophysiological measure of the task-related processing load, with larger pupil dilation reflecting greater processing demands (Beatty, 1982; Granholm and Steinhauer, 2004; Loewenfeld, 1993). The phasic "exploitation mode" (cf. Aston-Jones and Cohen, 2005; van der Meer et al., 2010) typically occurs when an individual is engaged in a particular task and focusing on task-relevant stimuli while ignoring distracting or task-irrelevant ones. 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 individuals reach their limit of available cognitive resources (i.e., until their memory capacity of $7 \pm 2$ digits; Granholm et al., 1996). Notably, Just et al. (2003) have demonstrated that pupillary responses reflect an overall aggregate of mental resource allocation that is not limited to a specific part of the cognitive system. In studies using multiple tasks (for a review, see Beatty and Lucero-Wagoner, 2000), peak dilation has been found to increase systematically with enhanced processing demand, comprising language comprehension (e.g., Hyona et al., 1995; Just and Carpenter, 1993; Nuthmann and van der Meer, 2005; Raisig et al., 2007), attention allocation (e.g., Karatekin et al., 2004; Kim et al., 2000), higher cognitive processes (van der Meer et al., 2010), memory maintenance and semantic elaboration (e.g., Granholm et al., 1996; van der Meer et al., 2003), or valence identification (e.g., Siegle et al., 2001; Steinhauer et al., 1983). In a previous study using a very similar task as in the present study, we showed the increase of pupil diameter during emotional interference (Prehn et al., 2008). In summary, all these studies support the view that pupil size represents a general index of mental resource allocation that reflects processing of both emotional and conceptual relations.

Combining behavioral and psychophysiological measurements (in particular, using the measurement of allocated mental resources), in the present study, we aimed to investigate how cognition and emotion interact during decision making and whether one aspect dominates the other. Based on the literature reviewed above, we hypothesized that emotional relations are processed preferentially (i.e., faster and with lower error rates), relative to associative conceptual relations. Regarding the cognitively *higher-level* comparison process (in contrast to the lower-level retrieval process), we hypothesized that affective significance would lead to a processing disadvantage leading to longer response times and increased mental resource allocation during the processing of items with negative emotional valence compared to neutral items.

## 2. Methods

### 2.1. Participants

30 healthy subjects ($n = 30$, 11 males) with the mean age of 23.93 years (S.D. = 4.34) participated in this study. All participants were native German speakers, had no history of neurological or psychiatric diseases, and did not take any medication that could influence the pupillary response. Participants reported no ophthalmologic problems (other than correctable eyesight). Participants gave written consent prior to investigation, according to the Declaration of Helsinki (1964), and received either course credit or payment (20 Euro) for their participation.

### 2.2. Task and stimulus material

As described above, we developed an analogical reasoning task to investigate the processing of cognitive and affective aspects during decision making (see Prehn et al., 2008; van der Meer, 1989).

In this task, participants had to identify both the conceptual and the emotional relations in two simultaneously presented word pairs, compare them, and decide whether or not the word pairs were an *analogy*, i.e., corresponding in *both* conceptual and emotional relations. To indicate whether the item presented on a computer screen was an analogy or not, participants had to press one of two buttons (labeled "yes" or "no") of a response device as quickly and correctly as possible, using the middle and index fingers of the dominant hand. The assignment of "yes" and "no" to the response fingers was counterbalanced across participants. Half of the 216 items were identical in both conceptual and emotional relations (analogy items). In the other half (non-analogy items), either the conceptual or the emotional relations or both did not correspond (see Table 1 for a translated example for each of the four experimental conditions). Each word pair was used twice.

Thus, we had four different conditions (Con = Emo =: conceptual and emotional relations between the word pairs were identical or corresponding, $n = 108$; Con = Emo ≠: conceptual relations corresponding, but emotional not corresponding, $n = 36$; Con ≠ Emo =: conceptual relations not corresponding, but emotional corresponding, $n = 36$; Con ≠ Emo ≠: conceptual and emotional relations both not corresponding, $n = 36$). The factors "conceptual correspondence" (Con = vs. Con ≠) and "emotional correspondence" (Emo = vs. Emo ≠) were independently varied in a $2 \times 2$ factorial design.

The word material was matched across conditions for number of letters [$M = 28.57$, S.D. = 3.94, $F(3,215) = 1.83$, $p = .14$], number of syllables [$M = 4.60$, S.D. = 0.83, $F(3,215) = 0.25$, $p = .86$] and word frequencies [$M = 18.23$ per million words, S.D. = 17.82, $F(3,215) = 0.89$, $p = .45$; Baayen et al., 1993].

To further validate the word material, we conducted an additional questionnaire-based investigation ($n = 90$) and collected rating data