Attention Due to Arousal Can Both Hinder and Facilitate the Discovery of Relations

Penka Hristova (phristova@cogs.nbu.bg)
Department of Cognitive Science and Psychology, New Bulgarian University, 21 Montevideo Street
Sofia, 1618 Bulgaria

Nina Dimitrova (dimitrova.nina@gmail.com)
Department of Cognitive Science and Psychology, New Bulgarian University, 21 Montevideo Street
Sofia, 1618 Bulgaria

Abstract

The relational discovery was investigated with classical Bongard problems. The arrangement of the instances was varied to facilitate the discovery of the correct or wrong relation in the first comparison. Irrelevant to-the-task arousal between the two comparisons of the categories enables the discovery of the relation when the first comparison generates the correct relation. When the wrong relation is highlighted first, arousal slows the overall encoding time. The results are consistent with the hypothesis that attention enhances dominant representation, and highlight the need to reconsider the facilitative role of attention in relational discovery as it is based on multiple comparisons.

Keywords: Arousal-biased competition model; attention; relational discovery; conceptual distinction; Bongard problems

Introduction

Relations are not objects that can be spotted in physical reality, rather, they are mental representations of links between entities, requiring a highly abstract categorization and recategorization that is context-dependent (Hofstadter & Sander, 2013). Relational categorization begins with the identification of common and distinct features of objects (Ibid.) and goes through "cognitive impoverishment" (Hofstadter & Sander, 2013), higher activation of shared properties (invariants) (Doumas, Hummel, & Sandhofer, 2008), or "degenerative transformation" (Bongard, 1970).

The context of comparison seems to have a vital role in this process. Goldstone & Son (2012) claim that an object does not have invariant features, guiding the similarity and hence categorization. Rather, similarity depends on detecting corresponding elements, not pure feature matching, as stated by the so-called 'alignment-based model of similarity'. For example, when asked to compare an object with different counterparts, participants identified different numbers of its elements (i.e., three or four) depending on the salient context (Medin, Goldstone, & Gentner, 1993). This implies that the encoding of object properties and relations goes together.

One effective bottom-up support for this complex and dynamic context-sensitive categorization process may be feature similarity (Weitnauer, Carvalho, Goldstone, & Ritter, 2013, 2014). It was shown that relational discovery in physical Bongard problems is facilitated when the groups of instances depicting different physical regularities shared the same or similar elements (e.g., circles, squares etc.). The bottom-up salience of the unique novel discriminating features rose with the number of competing between-category differences in line with the "near misses" of Winston (1970) and the between-category contrast due to the interleaving effect (Brunmair & Richter, 2019 for a meta-analysis). Therefore, playing with feature matches can be a good way to study the bottom-up processes underlying relation discovery.

In addition, the Arousal-biased competition model (Mather & Sutherland, 2011) would predict an even stronger effect of the abovementioned between-category feature match, since the difference between the low- and high-priority representations is expected to be amplified by arousal via local synaptic self-regulation of the locus coeruleus–norepinephrine system (Mather, Clewett, Sakaki, & Harley, 2016). Therefore, arousal should further support the discovery of relations in the between-category similarity condition, where the bottom-up comparison will prioritize a given difference compared to the no-arousal condition. Hence faster relational discovery and a superior transfer toward new instances of the same relational category should be expected. In contrast, arousal should impair relational discovery for between-category dissimilar condition where the bottom-up comparison may delineate a false relation due to the many existing, but irrelevant differences. Hence slower relational discovery among several superficially dissimilar instances and, in turn, worse transfer to new ones can be expected.

Experiment: Bongard Problems with Different Levels of Feature Match on Arousal

The study aims to explore the role of arousal in conflict resolution due to one vs. two alternative relations between pairs of similar categories, consisting of circles, squares, and/or triangles. Each Bongard problem is presented in a sequence of two rows of instances per each of the compared categories. The instances in the first row highlight correct or wrong relation between the categories. The between-row time interval is set to 1 sec and is filled in with irrelevant to-the-task highly arousing, low arousing, or no-arousing stimulus. Therefore, relational discovery in Bongard problems can be explored under different levels of arousal to test the role of amplified attention to the dominant relation. When the first-row instances highlight the same relation as the instances in the second-row, arousal will further support the representation of the dominant relation. However, when the relations implied in the two rows contradict each other,

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arousal can interfere with the overall solution, as it can reinforce the representation of the wrong relation and thus slow down the discovery of the correct one.

Design

The experiment has 3 (arousal: high arousal, low arousal, no arousal) x 2 (scene arrangement: correct/wrong relation) mixed factorial design. Variable *arousal* varies within a group. Variable *scene arrangement* (i.e., the arrangement of first-row instances of each Bongard problem) is manipulated between groups. For group B the arrangement of the scenes facilitates problem-solving, for group A – the arrangement of scenes guides toward a wrong solution as the true relation is not salient in the context of these instances and is just one of the possible solutions.

Stimuli

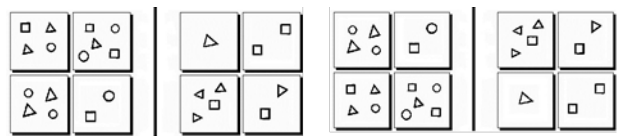
Two types of stimuli are used: nonstructured Bongard problems (Bongard, 1970) and emotional stimuli from the IAPS database (Lang, Bradley, & Cuthbert, 2008).

The emotional stimuli are colour photographs, introduced to the participant as a form of spacing without any relevance to the task. All emotional stimuli are positive, half of them of high arousal, the other half of low arousal (arousal: $t(1,6) = 11.31$, $p = .0001$, $ES = 4.62$). High and low arousal photographs are matched along close ratings on valence (valence: $t(1,6) = .26$, $p = .80$, $ES = .10$). For instance, a positive photograph of high arousal (normative rating: 6.1) that displays a hang glider soaring above a cloudy mountain (No 5626) is matched to a positive, low arousal one (normative rating: 3.55) depicting horses grazing in a foggy meadow (No 5764). In the control condition, the emotional photograph is replaced by a white square outlined with a black border of the same size and position as in the low and high arousal conditions.

Unstructured Bongard problems are used as emotionally neutral stimuli to explore relational discovery. The experimental phase consists of 18 relatively easy Bongard problems, based on Foundalis's data on average time and accuracy in solving original Bongard problems (Foundalis, 2006). All of them were white and black and contained circles, squares, and triangles, arranged differently. Considering the complexity of Bongard problems, only basic relations are presented: higher than, more than, etc. The included problems (numbers 21, 24, 25, 26, 27, 28, 36, 37, 38, 47, 48, 56, 57, 60, 79, 84, 149 and 189) and the correct formulations of the target relational concepts (i.e., problem solutions) were taken from https://www.foundalis.com/res/bps/bpidx.htm.

In the original Bongard task 5 scenes on the left and 5 scenes on the right are represented and the sixth member of categories is saved for recognition. Here, the entire third row of problems is retained for recognition with 2 examples on the left and 2 examples of categories on the right. The difference is only in the instances, presented first in the two arrangement conditions, which facilitate the discovery of the correct (Form B) or wrong (Form A) relation (Figure 1). The first row of form B becomes a second row in form A and vice versa. The test phase is identical for group A and group B.

Form A's arrangement of the first row is achieved by placing in a category the most superficially similar instances, while the most superficially dissimilar examples of a category are set together in Form B (Figure 1). The degree of similarity is based on the subjective judgments of the authors and not on the objective variation of objects across instances as in Weitnauer et al. (2013, 2014).



Form A: first-row wrong relation: more-than

Form B: first-row true relation: presence-absence of a circle

Figure 1: Illustration of two types of arrangements of Bongard problem 24 as numbered in https://www.foundalis.com/res/bps/bpidx.htm.

Procedure

There are 6 training and 18 experimental trials (6 Bongard problems per arousal condition). Each trial began with a Bongard task requiring the discovery of the unique relation between all instances of Category A and Category B, which ended when participants pressed a button to indicate that they had finished and found it. They then see two options to decide which one is an example of that relation and finally are asked to describe in their own words the relation they have found. Participants are randomly assigned to Form A/Form B (every second goes to Group B), and the experimental trials are randomized on arousal. The study was conducted in person and on e-Prime. The experiment lasts 40 minutes on average.

Training Phase

The training phase consists of 6 Bongard problems with automated feedback (correct/wrong) for recognition. After each problem participants are asked to formulate the difference between instances on the left and instances on the right in their own words. The experimenter writes down their responses literally and confirms the discovered difference or explains why the stated difference is wrong.

Bongard's original instruction (Bongard, 1970, p.52), adapted to the smaller number of instances, was used to introduce participants to the task: „Bongard problems have 4 examples on the left and 4 examples of the right, divided by a vertical line. Examples on the left represent one category and those on the right – another category." The participant's task was to find the difference between instances on the left and instances on the right. They are told that each problem has only one solution.

Experimental Phase

The experimental phase consists of 18 Bongard problems. Every problem is step-like presented (Figure 2).

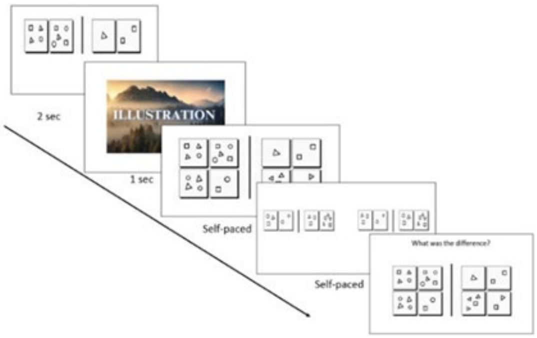


Figure 2: Example of a trial: condition with the wrong relation on the first row, the colour photograph is illustrative.

It starts with e short presentation of the first row, followed by a colour photograph/blank screen for 1 sec., automatically replaced by the full presentation of the same Bongard problem (first 2 rows, consisting of 4 examples of category A and 4 examples of category B). Participants are asked to press the SPACE button as soon as they find the difference between category A and category B. Then a test phase follows where the participants have to recognize the same difference between a new combination of the same stimuli (Figure 3).

Test Phase

Participants choose between two options that consist of the same elements (Figure 3): true (i.e., the third row of the Bongard problem) or false (i.e., a mixer of elements between A and B categories per a given Bongard problem). The two options are randomly positioned on the left or right of the screen. The task is to identify the option with the same AB difference as in the preceding Bongard problem.

Figure 3: An example of the test phase for the problem depicted in Figure 1. The option on the left is the correct answer for the example of the Bongard problem. The other option is a distractor (i.e., the right option). The arrow below the distractor indicates the rearrangement of the two elements, making the correct option wrong.

Once the participants make their decision by choosing the example on the left or the example on the right, the full Bongard problem appears once again on the screen (the two rows from the experimental phase with 4 category instances on the left and 4 category instances on the right). Participants are asked to formulate the difference in their own words. The experimenter writes down their answer literally without any comments or confirmation. For example, a correct formulation of Bongard problem 24 may sound like: 'on the left circles in all instances/non on the right', ‘triangles, squares and circles on the left/ triangle and squares on the right’, ‘three kinds of figures on the left/ two on the right’ etc. In case during recognition participants see that their formulations are wrong and cannot inform the choice between left and right combination, they are asked for the initial formulation before the test phase.

Participants

110 students at New Bulgarian University took part in the experiment, 62 females and 52 males, between 18 and 39 years of age. Every second who agreed to participate was assigned to form B. One participant did not finish the experiment, data from 109 participants was used for analyses.

Results

For the purposes of the study, the most conservative accuracy measure was undertaken: formulation accuracy (i.e., verbal formulation of the correct relation) and recognition accuracy (i.e., the correct recognitions followed by a correct verbal formulation of the relation). The response time measures, i.e., encoding time and recognition time were calculated in 2 ways. First, for trials with correct formulation and second, for trials with both correct formulation and correct recognition. These two calculations lead to partly overlapping samples. The correct recognitions were sometimes (26%) associated with a wrong or other (6%) formulation. The opposite was also true, i.e., 16 % of correct formulations ended in wrong recognitions. Wrong recognitions were always associated with a wrong verbal formulation.

Experimental Phase

Encoding time is the time from the presentation of the second row of instances until participants indicate by pressing the bottom that they discovered the unique difference between the left and right categories of a given Bongard problem. The data has a long positive tale. It is z-transformed, RTs above 2SD are not included.

A repeated measures ANOVA on encoding time for trials with a correct formulation (i.e., including trials with true as well as false recognition in the test phase) with arousal as a within-subject variable and alignments as a between-subject variable reveals an arousal-alignment interaction ($F(2,198) = 4.45$, $p=.013$, $n^2 =.043$). Arousal seems to have a reversal effect on arrangement. Low and high arousal speed up the encoding of form B, i.e., when the correct relation is salient, and slow it down when the wrong relation is salient (i.e., form A) (Figure 4).

The same arousal-arrangement interaction ($F(2,190) = 4.42$, $p=.013$, $n^2 =.044$) was obtained when the time for relation discovery was pooled only for trials with correct formulation as well as correct recognition.

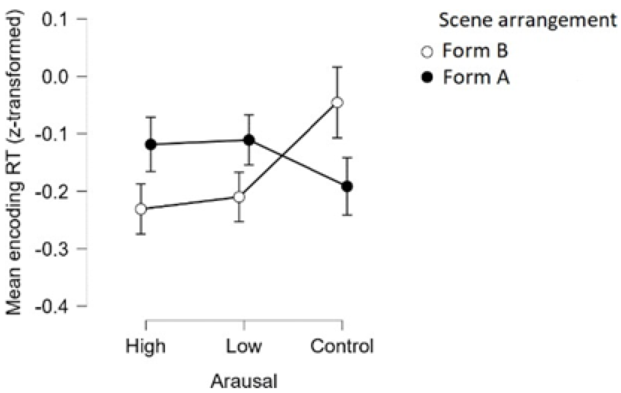


Figure 4: Interaction between arousal and scene arrangement on mean encoding RT.

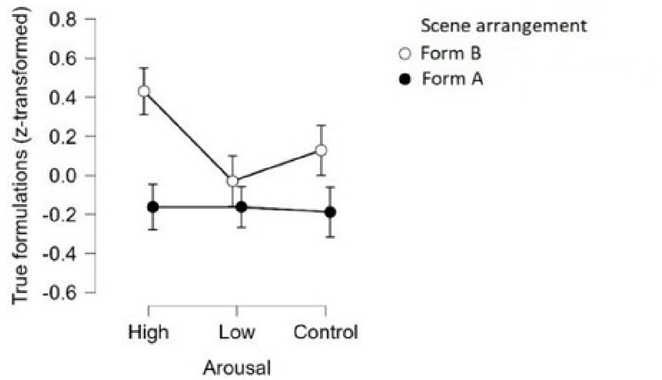


Figure 5: Effect of arousal and scene arrangement on the true formulation.

Recognition RT

Recognition time is processed the same way as encoding time: the data is z-transformed and statistical analyses are applied on trials varying up to 2 SD. The repeated measure ANOVA reveals a main effect of scene arrangement on recognition accuracy (correct recognitions followed by correct formulation) (F (1,93) = 5.66, p=.019, n^2 =.057). Form B arrangement speeds recognition of the relation in novel stimuli. The effect of arousal (F (2,186) = 1.04, p=.357, n^2 =.011) and the interaction between the factors (F (2,186) = 0.43, p=.648, n^2 =.005) were not significant.

However, when the recognition time was calculated for trials with correct formulation no significant effects were obtained.

Accuracy

The number of correct answers in the recognition phase is recorded as well as verbal formulations of the discovered difference. The latter are coded as recognition of the correct relation (e.g., 'there is a circle on the left', Bongard problem 24), recognition of the false relation (e.g., 'more figures on the left', Bongard problem 24), and wrong formulation (e.g., 'figures on the left dispersed/ clustered on the right'). The participant's formulations were independently coded by two researchers, and the discrepancies in coding were resolved by a judge.

Formulation Accuracy

Data on true formulations is z-transformed, and a repeated measures ANOVA analysis is applied with arousal as a within-subject variable and arrangements as a between-subject variable. There are no significant within-subject effects (F (2, 212) = 1.91, p=.149, n^2 =.018). The arrangement of the instances has a significant effect on true formulations (F (1,106) = 7.36, p=.008, n^2 =.065). Form B arrangement, which highlights one correct relation between the categories produces more correct formulations on all levels of arousal factor (Figure 5). The interaction between the factors was not significant: F (2,212) = 1.83, p=.162, n^2 =.017.

Arousal affects formulation accuracy for Form B only (F (2,104) = 3.46, p=.035, n^2=.062). High arousal produces more correct formulations unlike the control condition as well as the low arousal condition.

Recognition Accuracy

Accurate recognitions were correct recognitions during the test phase, followed by a correct verbal formulation of the unique difference. This conservative accuracy measure was z-transformed and processed with a repeated measure ANOVA. No main effects of scene arrangement (F (1,106) = 2.59, p=.110, n^2 =.024), arousal (F (2,112) = 1.53, p=.217, n^2 =.014), and no significant interaction between the two was found (F (2,112) = 2.37, p=.096, n^2 =.022).

Conclusions

The experiment highlights the role of arrangement in relational discovery. Bottom-up salience of the candidate relations was an important facilitator of relational discovery similar to the between-category similarity reported in previous research (Goldstone & Medin, 1994; Weitnauer et al., 2013, 2014). Although the categories were always similar and comprised the same elements, the initial comparison turned out to be of key importance for the current study. Participants were always presented with the same category instances but in a different order and the first-made comparison dramatically determined the likelihood of relational discovery, especially under high arousal. So, on the one hand, bottom-up comparison processes are important and can aid or hinder relational discovery when all other conditions are equal. On the other hand, attention, operationalized here as irrelevant arousal present during relational discovery may have distinct roles depending on the dominant representation highlighted from the bottom-up comparisons.

In contrast to research on between-category similarity with Bongard problems (Weitnauer et al., 2013, 2014), the operationalization of scene arrangement in the present experiment does not change the instances being compared, but rather their order. The first row allows for one or more hypotheses of a possible unique relation, but instances for the two arrangement conditions are completely identical. Hence between-category similarity (Weitnauer et al., 2013, 2014) is not an applicable explanation here. The same holds for timing (i.e., short processing time), which can obscure relations and encourage surface similarity (Goldstone & Medin, 1995). The present experiment uses a fixed time for the presentation of the first row (i.e., 2 sec) and a self-paced procedure for the processing of the second row. Hence, no time pressure upon relational discovery was imposed and timing cannot explain the obtained differences between the arrangement conditions. Individual differences (Doumas, Morrison, & Richland, 2018) due to the between-subject manipulation of the arrangement also appear to be insufficient. As it turned out, encoding time depended on the interaction between scene arrangement and arousal.

In part, this is consistent with the DORA account for the role of attention in asynchronous (consecutive in time) binding of the relational concepts to particular instances (role-filler bindings) during the process of relational discovery (Doumas et al, 2008). Attention maintains and therefore disambiguates possible correspondences between individual roles and fillers. Similarly, arousal helps resolve the competition for the limited attentional resources according to the ABC theory (Mather & Sutherland, 2011). It enhances the dominant and respectively inhibits the irrelevant representation(s). A similar effect in relational encoding has been reported for anxiety (Hristova & Kokinov, 2011). It enhances recognition of the same relation between different stimuli on two consecutive trials in terms of both speed and accuracy.

However, the data presented show that irrelevant arousal supports the detection of relations only when a single relation between entities is possible. The bottom-up perception is then further reinforced and supported. When an incorrect relation among many possible ones is detected and the subsequent comparison necessitates its inhibition, arousal rather slows down the relational discovery.

Therefore, if relational discovery is grounded on many comparisons that are mutually constrained, as stated at the very beginning of the paper (Bongard, 1970; Doumas et al., 2008; Hofstadter & Sander, 2013), conflicting representations are more than likely and attention may be an issue. The paper hints at this possibility by showing that attention due to task-irrelevant arousal can strengthen misrepresentation of a given relation and hence, be an obstacle for the subsequent comparisons underpinning the relational discovery.

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