Title: The Relationship Between Dopamine, Novelty Seeking, and Cognitive Flexibility

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Abstract: The aim of this study was to investigate whether dopamine levels (as measured by the spontaneous eye blink) correlate to novelty seeking and whether dopamine and novelty seeking moderate performance on a cognitive flexibility task. While we found an effect of task condition, neither dopamine nor novelty seeking influenced performance on the cognitive flexibility task.

Transcript

Slide 1: Bethany

Hi everyone, today we're going to discuss our research findings for our project on the relationship between dopamine, novelty seeking, and cognitive flexibility.

Slide 2: Bethany

Suppose you ask someone to sort a deck of cards by suit then afterwards ask them to sort the cards again, this time by color. Do you think they would be able to easily switch from the first task to the second? Well, some people would be better at it than others. One thing that would make people differ in their ability to switch from the first task to the second is cognitive flexibility, one of the variables we are interested in.

Slide 3: Bethany

Cognitive flexibility is the ability to adapt behavior in response to novel information or goals. In the card sorting example I used earlier, cognitively flexible individuals would easily be able to switch from sorting by suit to sorting by color, whereas less cognitively flexible individuals might have more trouble with this switch.

Slide 4: Bethany

Cognitive flexibility has been studied in the laboratory using the task switching paradigm developed by Dreisbach and Goschke, in which participants are presented with two different colored figures. They are trained to respond to a certain color then are told to respond to another color after a rule change.

There were several conditions to this paradigm. In the Learned Irrelevance condition as shown on the left, the distractor color during training -yellow- becomes the target color after the rule change and the new distractor is a novel color -black-. So after the switch, they have to now respond to the stimuli they had previously ignored.

In the perseveration condition as shown on the right, the target color during training - orange -

becomes the distractor color after the rule change. If a person perseverates, they would continue to choose the old target color instead of the new target with a novel color.

Performance on the task was assessed by comparing switch cost across conditions, switch cost being the difference in reaction time between the pre and post-switch trials. A high switch cost would indicate a large difference between the pre-switch and post-switch trials, and a low switch cost would indicate little difference between them. Participants who had lower switch cost in the perseveration condition and higher switch cost in the learned irrelevance condition were deemed high in cognitive flexibility.

Slide 5: Bethany

Dopamine is a neurotransmitter involved in learning, updating working memory, and attentional control. Learning happens through reinforcement; updating working memory goes along with updating mental goals and keeping your current goal in mind; and attentional control is the ability to either MAINTAIN or SWITCH your attentional focus to task-relevant stimuli.

As cognitive flexibility determines one's ability to switch attention from one goal to another, it should come as no surprise that being high or low in dopamine can influence one's cognitive flexibility, given dopamine's role in attentional control and working memory.

Dreisbach et al. found that people with high dopamine levels were more cognitively flexible. More specifically, they found that those with high dopaminergic activity performed better on the perseveration condition than those with lower activity, meaning they were more easily able to switch to a new rule. However, higher cognitive flexibility comes with higher distractibility, a possible reason why those with high dopamine also performed worse on the learned irrelevance condition because they struggled to endorse a target that had previously been a distractor.

Slide 6: Haley D.

There are two hypotheses for why participants high in dopamine perform the way they do in the task.

The first is that dopamine creates a novelty bias. This suggests that those participants are better at the perseveration condition because the target's novelty makes it more attention-grabbing than the distractor. On the flip side, they perform worse in the learned irrelevance condition because the distractor is novel, so the distractor is attracting their attention.

The other hypothesis is that dopamine enhances distractor suppression, and this suggests that participants high in dopamine are better at the perseveration condition because the post-switch target was not a pre-switch distractor, so attention to it is not being suppressed. In the learned irrelevance condition, it's the opposite. They make more mistakes because the new target was the old distractor they learned to ignore and they're carrying over that residual distractor suppression.

So, novelty bias says they'll do well when the target is novel. Distractor suppression says they'll do well the target has never been a distractor. And a difficulty with these hypotheses is that so far the literature hasn't been able to distinguish between the two.

Slide 7: Haley D.

Now, the novelty bias hypothesis has some support in that higher levels of dopamine have been shown to increase behaviors that reflect a preference for novel stimuli.
This preference shows up in novelty seeking, which is a personality trait that's characterized by risk-taking and approach behaviors which are motivated by a desire for intense, novel, and rewarding experiences.

The evidence that increasing dopamine levels increases novelty seeking implies that those participants high in dopamine will show a strong preference, or *bias*, for novelty.

Slide 8: Haley D.

There were three questions from Dreisbach et al.'s experiment that we wanted to answer. The first thing we wanted to know was: do novelty seeking and individual differences in dopamine correlate with one another?

We hypothesized that yes they will correlate; participants who score highly in novelty seeking should also score highly in dopamine levels.

Slide 9: Haley D.

The second question we wanted to investigate was: do novelty seeking and dopamine moderate performance on cognitive flexibility tasks?

We hypothesized that they do and we would see this as high dopamine and high novelty seeking correlating positively with high cognitive flexibility.

High cognitive flexibility of course would be recognized as faster post-switch reaction times (meaning better performance) in the perseveration condition and slower post-switch reaction times (meaning worse performance) in the learned irrelevance condition.

Slide 10: Haley D.

The last question we wanted to answer was: Are the performance patterns of cognitively flexible individuals better explained by the idea that dopamine creates a novelty bias or that dopamine enhances distractor suppression?

Following Dreisbach et al.'s suggestion, we addressed this question by supplementing the perseveration and learned irrelevance conditions with a new control condition. In this third condition, all of the stimuli (distractors and targets) would be novel.

We had a two-part hypothesis for how performance across the three conditions might help us differentiate between novelty bias and distractor suppression.

If the high-dopamine participants' performance in the control condition was worse than perseveration but better than learned irrelevance, then we could assume that they have a novelty bias. They get middling scores in the control because both distractor and target are novel and equally attention-grabbing.

Alternatively, if those participants performed best in the control condition, then we could assume that they have enhanced distractor suppression. They get better scores in the control because neither the distractor nor the target have fulfilled previous roles, so there's no residual learning to struggle against.

Slide 11: Haley T.

In order to test these hypotheses, we ran a total of 54 participants, but dropped 4 because of unusable data and 1 because they did not meet the restrictions, so we analyzed the data of the remaining 49 participants. The Mean age of participants was 20.4 with a range of 18 to 48. As you can see, our participants were mostly female, freshmen, and caucasion. Participants were asked to not take part in this study if they had uncorrected vision problems; had a diagnosed neurological, psychiatric, or sleep disorder; had consumed caffeine or alcohol within 5 hours of the study; or used THC or nicotine more than twice a week. Participants were run between the hours of 9am to 5pm. These restrictions were put in place to avoid impacts on baseline dopamine levels.

Slide 12: Haley T.

To measure baseline dopamine levels, we looked at a person's spontaneous eye blink rate (EBR), the number of times someone blinks naturally.

This measure is supported by studies that have found that dopamine is highly correlated to eye blink rate. For example, studies have found that dopamine agonists increase EBR and that dopamine antagonists decrease it.

We used electrooculography (EOG) to measure eye blink rate. To do this, Electrodes were placed in a vertical channel three centimeters above and two centimeters below the left eye and one in the center of the forehead which served as a baseline. Using the primary gaze paradigm, participants were told to sit down and stare at a dot on the computer screen for 5 minutes, as seen in the picture above.

Slide 13: Haley T.

In the literature, a blink is typically defined as between 100 and 400 milliseconds, and greater than 100 millivolts. Due to limitations in accessing the software to analyze the blink data during remote analysis, we had to visually identify the blinks based on our knowledge of what the typical blink looks like. To analyze the data, we counted how many times the participants blinked per minute, which we averaged across a five minute recording. On the right side you can see some examples of blink data. On the top is an example of high blink rate, and on the bottom is an example of low blink rate.

Slide 14: Haley T.

In order to measure Novelty Seeking, we gave the participants the TCI-R (Revised Temperament Character Inventory). The TCI-R short form includes 140 questions on a 1-5 Likert scale. While it measures seven subscales, we focused on the novelty seeking subscale. *An example of a question the participants were given is "I often try new things just for fun or thrills."*

Slide 15: Haley T.

To measure cognitive flexibility, we replicated the attentional set shifting task Dreisbach used in the 2004 study. In this task, participants were shown two figures in different colors and asked to press a computer key to categorize it. These figures were either numbers, letters, or symbols. For example, the first slide tells participants that their target color is red and to categorize the red letters into either a vowel or consonant. In the second slide, participants pressed one key if the red letter was a vowel and another if it was a consonant.

After 20 trials, the slide tells participants that their target color has switched to green so that participants will now categorize the green letter into a consonant or vowel.

By looking at the switch cost, which is the difference in reaction time between the training trials and post-switch trials, we were able to see how easily the participants were able to switch between rules. The set-shifting task had three conditions: learned irrelevance, perseveration, and control.

Slide 16: Haley T.

In the learned irrelevance condition, the distractor color--in this case, yellow--becomes the target color after the switch, and the new distractor is a novel color. Following the switch, participants must pay attention to the color they were previously instructed to ignore and ignore the novel color instead.

Slide 17: Haley T.

In the perseveration condition, the target color during training--in this case, orange--becomes the distractor color after the switch, and the new target color is novel. Following the switch, participants must pay attention to a novel color and ignore the previous target color.

Slide 18: Haley T.

In the control condition, both colors post-switch are novel colors that are not used during the training trials. As mentioned previously, adding the control condition to Dreisbach's original paradigm allows us to better determine whether their findings were due to novelty seeking or distractor suppression.

Slide 19: Maddox

To prepare the data from the cognitive flexibility task before analysis, we removed all trials where participants responded with the wrong key from our data. We found that on average, participants responded incorrectly to 4.18% of the trials.

We also removed all trials where participants took longer than 2000 ms to respond. This accounted for 1.999% of trials.

We prepared our novelty seeking and blink data by performing a median split to determine high vs. low categories for these variables.

Slide 20: Maddox

In order to address our first question --do novelty seeking and individual differences in dopamine correlate with one another? -- we ran a bivariate correlation of these two variables.
We hypothesized that these two variables would be positively related to one another. Our analysis did not yield a significant correlation between dopamine and novelty seeking; however, the result was in the same direction that we initially predicted and it was fairly close to significant. Low power due to a small sample size likely affected our results, as well as the necessary use of remote data analysis for the blink data.

Slide 21: Maddox

To address our second question --do novelty seeking and dopamine moderate performance on cognitive flexibility tasks?-- we ran two two-way mixed ANOVAs.

First, a two-way mixed ANOVA was performed to determine whether the switch costs for learned irrelevance, perseveration, and control task-switching conditions differed as a function of dopamine levels. If you look at the graph on this slide, you can see the general patterns of our results. The y-axis represents switch cost. The higher the switch cost, the longer the participant took to respond to the stimuli after the switch compared to before the switch. The x-axis represents the 3 conditions in the cognitive flexibility task. The blue bar represents low EBR (our measure for low dopamine levels) and the orange bar represents high EBR (our measure for high dopamine levels).

Ultimately, we found that there was a significant main effect for condition. If you look at the results for the three conditions on the graph here, you can see that the switch cost for the learned irrelevance condition was much higher than in the perseveration or control.
However, the main effect of dopamine level was not significant (meaning that participants with low dopamine and participants with high dopamine did not differ in switch cost overall).

Lastly, and of main interest to our hypothesis, we found that the interaction was not significant. We predicted that participants with high dopamine would differ in pattern of responses compared to participants with low dopamine. But the non significant interaction effect indicates that dopamine level does not make a difference in how an individual performs on the cognitive flexibility task. We thought that high dopamine levels would result in individuals having small switch costs in the perseveration condition and larger switch costs in the learned irrelevance condition (because this response pattern is indicative of cognitive flexibility). If you look at the graph, you can see that the pattern of the bars were not even headed in the proper direction for our hypothesis.

Slide 22: Brighton

To address the other half of our second question --do novelty seeking and dopamine moderate performance on cognitive flexibility tasks?-- we ran another two-way mixed ANOVAs.

This two-way mixed ANOVA was performed to determine whether the switch costs for learned irrelevance, perseveration, and control task-switching conditions differed as a function of novelty seeking scores.

Again, if you look at the graph on this slide, you can see the general patterns of our results which are similar to the results for the previous ANOVA. The axes are the same on this graph as the previous graph. Here, the blue bar represents low novelty seeking and the orange bar represents high novelty seeking.

Just as before, we found that there was a significant main effect for condition. This is apparent in the graph where you can see that the switch cost for the learned irrelevance condition was much higher than in the perseveration or control.

The main effect of novelty seeking was not significant, so participants who scored low on novelty seeking and participants who scored high on novelty seeking did not differ in switch cost overall). And, again, we found that the interaction effect was not significant which indicates that novelty seeking does not make a difference in how an individual performs on the cognitive flexibility task.

In terms of our third question which was “Are the performance patterns of cognitively flexible individuals better explained by the idea that dopamine creates a novelty bias or that dopamine enhances distractor suppression?,” we were unable to draw any conclusions since we did not find that dopamine played a part in whether an individual’s pattern of performance reflected cognitive flexibility.

<u>Slide 23: Brighton</u>

Since our data collection was cut short, it is possible that the number of participants from which we were able to collect data was simply not enough for us to get reliable data and to see an accurate pattern of results. This is most relevant for the dopamine/novelty seeking correlation that was in the direction that we predicted but was not quite significant.

It is also possible that the change from our intended blink analysis due to COVID-19 affected our results. Originally, we had planned to analyze the blinks using software programmed to determine whether a peak met the requirements to qualify as a blink; however, we did not have access to this software once we transitioned to remote learning. Because of this limitation, we had to visually determine and count how often a participant blinked per minute, which we averaged across the five minute recording. This less precise method may have resulted in data that was not accurate.

Our data was very noisy which was clear in the error bars on the graphs in the previous slides.

The standard deviations, relative to the actual mean values, were very large. Based on these observations, it is possible that only using the average of the 5 trials before and the average of the 5 trials after the switch to determine the switch cost, was not enough to get reliable switch cost data (although this *was* how Dreisbach determined switch cost). However, we ran an analysis using switch costs determined by averaging 10 trials before and 10 trials after the switch, and that analysis did not provide results with patterns that we predicted either, so that does not seem to be the issue here.

Because the addition of the control condition lengthened the running time for each participant, we shortened the length of each condition compared to what Dreisbach did (we changed it from 40 training trials to 20 and from 20 test trials to 10). This change may have resulted in a weakening of the rule switch effect since participants did not have as long in the training condition.

Lastly, it is possible that the addition of the control condition caused the pattern of results to alter; however, it seems unlikely that this would be the case. An addition of another condition (especially since the arrangement that the conditions were presented to participants was counterbalanced) should not alter the pattern of results in this way.

All of the points are things that could be improved upon in future studies.

Slide 24:

Thank you for listening. We hope everyone is staying safe and healthy.