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An Experimental Examination of the Aberrant Salience Hypothesis Using a Salience Manipulation and a Behavioral Magical Thinking Task

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Abstract

A prominent hypothesis of delusions is that they reflect aberrant salience caused by increased striatal dopamine. For the first time, we conducted an experimental test of the aberrant salience hypothesis (n = 235 college students) as we manipulated salience and examined its effect on magical thinking (using a behavioral task). We also included a putative dopamine manipulation (performing a high reward or low reward task). Both the salience and the putative dopamine manipulations caused changes in magical thinking. Evidence supporting the validity of the magical thinking behavioral task included that it was associated with self-reported magical thinking and with another behavioral task (reversal learning) previously associated with striatal dopamine. In a manipulation check, the putative dopamine manipulation also caused altered performance on the reversal learning task. Overall, these results seem to be consistent with the predictions of the aberrant salience hypothesis and are potentially consistent with a role for salience and dopamine in magical thinking.

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Keywords: magical thinking, salience manipulation, reward manipulation, reversal learning, behavioral task

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Introduction

Psychotic disorders involving symptoms such as delusions have a lifetime prevalence of greater than 3% (Perala et al., 2007). Psychotic disorders are caused in part by genes (e.g., Gottesman, 1991; Timms et al, 2013) and are also related to increased and dysregulated striatal dopamine (Howes & Kapur, 2009; Laruelle, 2003). There is some evidence that interventions given to people at imminent risk for psychosis might at least delay onset of the disorder (Fusar-Poli et al., 2013). However, there is still uncertainty about how to effectively prevent psychosis in people at risk and, despite the involvement of striatal dopamine in psychosis, medications that block striatal dopamine are not recommended for the prevention of psychosis because of side effects (Fusar-Poli et al., 2013). It is hoped that a better understanding of the mechanisms involved in the development of psychosis might facilitate the development of new interventions that can help effectively treat and prevent psychotic disorder. Magical thinking (i.e., unusual forms of thought that are considered invalid by conventional standards; Eckblad & Chapman, 1983; Meehl, 1964) is common in Schizotypal Personality Disorder and also predicts future psychotic disorder (*Diagnostic and Statistical Manual of Mental Disorders*, 5th ed.; DSM-5; American Psychiatric Association, 2013; Cannon, Jones, & Murray, 2002; Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994; Werbeloff et al., 2012). Potentially research on magical thinking could help us better understand the nature of psychosis risk and mechanisms that contribute to the development of psychotic symptoms (Johns & van Os, 2001; van Os, Linscott, Myin-Germeys, Delespaul, & Krabbendam, 2009). The current research examined whether an experimental manipulation of a potentially important factor in psychosis, level of salience, could cause a decrease in level of magical thinking displayed on a behavioral task in college students.

A leading theory about the development of psychosis is that it involves a state of aberrant salience. Aberrant salience refers to the incorrect assignment of significance or importance to neutral stimuli and is thought to result from increased striatal dopamine (Kapur, 2003). Delusions are thought either to represent an attempt to explain aberrant salience experiences or to be accepted as true because of aberrant salience regarding one's own thoughts. Part of the rationale for the development of the aberrant salience hypothesis is the involvement of striatal dopamine in normal incentive salience processes (e.g., Flagel et al., 2011). In addition, the aberrant salience hypothesis seems consistent with the types of experiences that people often report having right before the development of psychotic symptoms (e.g., reporting a greater sense of significance to one's experiences; Bowers, 1973). Further, a questionnaire designed to reflect these aberrant salience experiences has been found to be strongly correlated with magical thinking in college students (Cicero, Kerns, & McCarthy, 2010; Cicero, Becker, Martin, Docherty, & Kerns, 2013). Furthermore, in an inpatient psychiatric sample, people with a history of psychotic disorder reported higher aberrant salience on this questionnaire than people without a history of psychotic disorder.

Hence, there is some support for the aberrant salience hypothesis, but the evidence is correlational in nature. In contrast, no previous study has examined whether experimental manipulations of salience cause changes in magical thinking. In the current study, we examined whether an experimental manipulation that decreases salience would result in a decrease in magical thinking displayed on a behavioral lab task. The salience manipulation involved novelty, which previous research has consistently found is associated with increased perceived salience and increased dopamine (e.g., Amso, Davidson, Johnson, Gloever, & Casey, 2005; Guitart-Masip, Bunzeck, Stephan, Dolan, & Düzel, 2010; Strange et al., 2014). Furthermore, previous research indicates that the increase in perceived salience is the result of novel stimuli drawing attention (Rumbaugh & Washburn, 2008), independent of perceived reward value (Foley, Jangraw, Peck, & Gottlieb, 2014). We were uncertain about how large of an effect our salience manipulation would have on the behavioral magical thinking lab task. Hence, to insure adequate power, we examined our salience manipulation in a relatively large college student sample.

In the current research, we used a behavioral lab task to measure magical thinking rather than using more commonly used questionnaire or interview measures. We did this for a couple of reasons. One reason is that we did not expect the experimental manipulation to produce an effect on questionnaire measures of magical thinking that typically ask about magical thinking that occurred in the past (e.g., "I have occasionally had the silly feeling that a TV or radio broadcaster knew I was listening to him." Eckblad & Chapman, 1983; Peters, Joseph, & Garety, 1999). We also did not expect sufficient variation among college students on clinical interviews that assess delusional thinking to be able to detect a decrease in magical thinking (Cicero, Martin, Becker, Docherty, & Kerns, 2014). In contrast, based on levels of magical thinking reported in previous magical thinking behavioral research (King, Burton, Hicks, & Drigotas, 2007), we expected that a short-term change in current salience should produce an effect on a behavioral measure of magical thinking.

However, a limitation of behavioral measures of magical thinking is their limited previous evidence of validity as measures of magical thinking. In this research, we selected a promising recently developed behavioral measure of magical thinking involving dart throwing (King et al., 2007). In addition, we also examined the validity of this behavioral magical thinking measure in two novel ways. First, we examined whether it was correlated with self-reported magical thinking. Second, we examined whether it was correlated with a behavioral task that has been found to be sensitive to striatal dopamine levels that, given the relationship between striatal dopamine and psychosis (Howes & Kapur, 2009), we therefore expected to be significantly associated with magical thinking.

Although our primary goal in designing this research was to be able to examine the effect of a salience manipulation on magical thinking, we also included a putative manipulation of dopamine to examine whether it also caused a change on the behavioral magical thinking task. Importantly, although dopamine is strongly associated with psychosis (Howes & Kapur, 2009) and magical thinking predicts psychotic disorders (Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994), to our knowledge there is no evidence associating dopamine with magical thinking. This is an important issue because, although we expect magical thinking to be related to dopamine, it is possible that this is not the case. Instead, it is possible that the mechanisms that contribute to magical thinking (and predict future psychosis) are different from the mechanisms that directly produce psychotic symptoms in vulnerable individuals (e.g., it has been suggested that there might be a complex causal chain with dysregulated dopamine being only the final step in producing clinical psychosis; Laruelle, 2003; Murray, Lappin, & Di Forti, 2008). We examined the relationship between dopamine and magical thinking in two novel ways. First, we examined whether a putative dopamine manipulation would cause an increase in magical thinking on a behavioral task. Second, we examined whether self-reported magical thinking was associated with performance on a task that has been previously found to be sensitive to striatal dopamine levels (e.g., Cools, Altamirano, & D'Esposito, 2006).

Previous experimental studies examining the effect of dopamine on delusions have manipulated dopamine pharmacologically (e.g., Angrist & Gershon, 1970; Brier et al., 1997). Given our large college student sample, it was not possible to directly manipulate dopamine by pharmacological means or to directly assess changes in dopamine levels (e.g., through PET scanning). However, in addition to pharmacological manipulations, previous research has found that behavioral tasks involving rewards, including tasks where the goal is to win as many points as possible (i.e., as in video games), result in increased striatal dopamine (Abler, Herrnberger, Gron, & Spitzer, 2009; O'Doherty et al., 2004; Koepp et al., 1998; also see Smith & Lenzenweger, 2007). Hence, in the current study, we used a putative dopamine manipulation, engaging in either a highly rewarding or a non-rewarding task, that based on multiple previous studies should result in differences in striatal dopamine levels between these two conditions. We examined whether our putative experimental manipulation of dopamine also caused a change in magical thinking on a behavioral task. As a manipulation check, we also examined whether our putative dopamine manipulation resulted in altered performance on a behavioral task previously found to be sensitive to striatal dopamine levels (Cools et al., 2006). Although we did not manipulate dopamine pharmacologically and we did not assess dopamine levels directly, we still think examining the effect of this theoretically-driven putative dopamine manipulation, supported by multiple previous studies that more directly assessed striatal dopamine levels, does add some useful novel data to help our understanding of magical thinking. Furthermore, to highlight the fact that we did not directly manipulate or measure dopamine, we will always refer to our manipulation as a "putative" dopamine manipulation.

Overall, the current study was a 2 (salience level: high versus low) by 2 (putative dopamine level: high versus low) between-subjects design that for the first time examined the effects of a salience manipulation and a putative dopamine manipulation on levels of magical thinking on a behavioral task in a large college student sample. We also examined the validity of our magical thinking behavioral task by examining whether it was related to self-reported magical thinking and to a behavioral task previously found to be sensitive to striatal dopamine levels. We also examined a manipulation check of our putative dopamine manipulation by examining its effect on the behavioral task previously found to be sensitive to striatal dopamine levels. Finally, we also for the first time examined whether self-reported magical thinking was associated with performance on this striatal dopamine-related behavioral task.

Methods

Participants

Participants were college students (n = 253) recruited from a large Midwestern public university who received credit from an introduction to psychology course for their participation (56% female; mean age = 18.71, *SD* = .88, 81.0% Caucasian, 9.8% African-American, 3.4% Asian-American, 3.9% Latino/Latina, 1.5% Biracial, .4% Other). Following previous research, participants (n = 18) were excluded due to Chapman infrequency scores of 3 or greater (Chapman & Chapman, 1983), resulting in a final sample of n = 235.

Materials

Magical thinking behavioral lab task.

Participants completed a behavioral task that has previously been labeled a measure of magical thinking, the Dart Throwing Task. We used King et al.'s (2007) version of the Dart Throwing Task (originally created by Rozin, Millman, & Nemeroff, 1986; note that our one modification from the King et al., 2007, version is that participants in current research were not paid for their performance). Participants were told that this part of the study concerned manual dexterity at common tasks and that they would throw darts at a dart board. Participants were given six practice throws. They were then told that to make the task more interesting that they would be throwing the darts at different shapes. For all participants, the first shape was a smiley face in black ink. The image was tacked (at the corners) to the dart board over the bull's eye. After throwing six darts at the smiley face, the experimenter then attached a second "shape" to the dartboard, this time a photograph of a baby that was the same size as the smiley face. It has been argued that being more inaccurate for the photograph of a baby than for the smiley face exhibits behavioral evidence of the law of similarity, a form of magical thinking, or the idea that the photograph of a baby shares some fundamental properties with a real baby (e.g., King et al., 2007; Rozin et al., 1986). For each trial, the distance in inches between the hole made by each dart and the target center (i.e., center of the image) was recorded by an experimenter who was blind to both the hypotheses of the study and the condition of the participant. We computed a *dart throwing difference score* (*M* = .29, *SD* = 1.18), which was the average distance in inches of the six darts for the baby image minus the average distance in inches of the six darts for the smiley face image. Hence, following King et al. (2007), greater magical thinking is indicated by a larger average distance from the center for the baby image than for the smiley image.

Experimental Manipulations.

We examined the effects of a salience manipulation and of a putative dopamine manipulation on the behavioral magical thinking Dart Throwing Task. Hence, before completing the Dart Throwing Task, participants completed manipulations designed to vary salience and putative dopamine levels.

Salience Manipulation.

To manipulate salience in the Dart Throwing Task in the current study, we varied the novelty of stimuli. Viewing novel images, as opposed to previously seen images, has been found to result in increases both in perceived salience and in striatal dopamine (Amso et al., 2005). In the original version of the Dart Throwing Task, the baby face can be considered a relatively novel/salient stimulus. Hence, we examined whether decreased novelty/salience of a stimulus would result in decreased magical thinking on the Dart Throwing Task.

Specifically, salience was manipulated by having participants perform an earlier Image Viewing Task that included seeing a baby face. On this Image Viewing Task, during each trial, a fixation cross was presented for 1000 ms on a computer screen, followed by a 2000 ms presentation of an image. Participants viewed six images featuring inanimate objects and six images featuring animate objects, with each image presented ten times. Participants judged whether the image was an animate or inanimate object. On the Image Viewing Task, most visual images were chosen from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 1995). The exceptions were two pictures of baby faces, with participants seeing one of these pictures during the Image Viewing Task. The particular picture of the baby seen on the Image Viewing Task determined the high and low salience conditions on the subsequent Dart Throwing Task. In the high salience condition, as in the original version of the task (King et al., 2007), participants eventually threw darts at the image of a novel baby that was *not* seen during the Image Viewing Task. In the low salience condition, participants threw darts at the image of the baby previously seen in the Image Viewing Task. Since participants in the low salience condition had previously seen the image in the Dart Throwing Task, it was presumably no longer a novel and salient image (Amso et al., 2005). Thus, to the extent that participants exhibit less accurate performance on the Dart Throwing Task for the novel than the previously seen condition, participants are potentially implicitly associating more significance with an otherwise neutral stimulus (i.e., the novel baby image), and are therefore exhibiting evidence of aberrant salience. Therefore, we expected that participants in the low salience/previously seen image condition would exhibit less magical thinking on the Dart Throwing Task. Participants were randomly assigned to either the low or high salience condition and the assignment of the particular baby picture to condition was also randomized across participants.

Putative Dopamine Manipulation.

To putatively increase dopamine, some participants performed a gambling task involving a high level of reward. As previously mentioned, there is evidence that performing behavioral tasks involving rewards, including tasks where the goal is to win as many points as possible (i.e., as in video games), result in increased striatal dopamine (Abler et al., 2009; Koepp et al., 1998; O'Doherty et al., 2004). On the gambling task, which was the same task with just two modifications (see below) used by Eisenegger and colleagues (2010), participants completed a total of 50 trials. On each trial, they were presented with an array of 10 closed boxes on a computer screen. Participants had the chance to open as many boxes as they wished. They were told that nine of the boxes contained 'wins' while one box contained a 'loss', with 'wins' meaning an increase in points (these points were specific to the game and were not tied to monetary compensation). This loss box was randomly assigned to one of the 10 boxes in each trial. This loss would make them lose all of their winnings for the current trial and end that trial. After each opened box, participants had to decide whether to continue opening boxes to increase their winnings or terminate the trial to avoid a loss.

Since rewards increase striatal dopamine (Abler et al., 2009; Schultz, 1997), to attempt to increase dopamine our one modification to the task by Eisenegger and colleagues (2010) was to fix reward levels to ensure that each participant performing the gambling task received a high number of rewards. Thus, unbeknownst to the participant, the number of reward trials was fixed, so that participants won 50% of the first ten trials, 60% of the second set of ten trials, 70% of the third set of ten trials, 80% of the fourth ten trials, and 90% of the last ten trials. The other modification was that, for reward trials, a smiley face, a "+100" sign, and a positively-valenced high-pitched sound were presented as feedback (instead of receiving a small monetary reward, as in Eigenegger et al., 2010). For punishment trials, a sad face and a negatively-valenced low-pitched sound were presented as feedback, indicating that participants had lost all points for the current trial (instead of losing the monetary earnings they had collected on the current trial, as in Eisenegger et al., 2010). During the task, participants also saw their total amount of points and they were told that the goal was to accumulate as many points as possible. Therefore, participants in the high reward condition completed a total of 50 gambling task trials involving frequent rewards.

In contrast to the putatively high dopamine gambling task, participants in the putatively low dopamine condition performed a non-gambling syntactic judgment task modeled after the task used by Ni and colleagues (2000). In this task, participants were asked to judge whether a series of 60 sentences were grammatically correct. It was determined through piloting that the time it took to grammatically judge 60 sentences was comparable to the time it took to complete the gambling task. Sentences were presented one at a time on a computer screen and participants judged whether or not the sentence was grammatically correct. We did not provide participants' with feedback regarding their performance, in order to ensure that this was not a rewarding task, and therefore was appropriate as a low reward/putatively low dopamine task. Thus, while this task still required that participants made choices (as in the gambling task), these choices did not lead to reward.[1,2]

Self-Reported Magical Thinking.

To validly and broadly assess self-reported magical thinking, participants completed three self-report measures of magical thinking.

Magical Ideation Scale.

The first self-reported magical thinking measure was the Magical Ideation Scale (M = 8.91, SD = 4.94; Eckblad & Chapman, 1983), a 30-item true–false questionnaire designed to measure "beliefs in forms of causation that by conventional standards are invalid" (Eckblad & Chapman, 1983, p. 215; e.g., "I have worried that people on other planets may be influencing what happens on Earth." α in current study = .80). Previous research has found that high scorers on the Magical Ideation Scale are at increased risk for future psychosis (Chapman et al., 1994). Participants also completed the Chapman Infrequency Scale (Chapman & Chapman, 1983), a 13-item true-false questionnaire designed to measure invalid or careless responding (e.g., "I have never talked to someone wearing eyeglasses"). Following previous research, participants who answered "true" to three or more items (n = 18) were excluded from the analyses (Chmielewski, Fernandes, Yee, & Miller, 1995).

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[1] To examine whether the salience and dopamine manipulations simply affected how much people liked the faces of the baby images, following the Dart Throwing Task, participants were asked to report how much they liked each image (i.e., the smiley face and baby), as well as how much they liked throwing darts at each image, on a 10-point Likert scale (with 0 being not at all and 9 being extremely like). There were no significant differences (all p's > .20; all d's < .16) between the high and low salience, or the high and low putative dopamine, experimental conditions on either liking variable.

[2] In addition to the Dart Throwing Task, we also included a second task that has been claimed to measure magical thinking, the Preference Ratings Task (Berenbaum, Boden, & Baker, 2009; Rozin et al., 1986). However, this task does not involve a behavioral measure but only relies on self-report of preferences (e.g., it is comparable to simply asking people on the Dart Throwing Task how much they want to throw the dart at a picture of a baby without actually measuring their behavioral performance). Hence, there are strong reasons to doubt whether this task is a behavioral measure of magical thinking. For the Preference Ratings Task, there was no effect of the salience or putative dopamine manipulations (effect sizes d = .00 and d = -.14, respectively), and the task was not significantly correlated with the Dart Throwing Task (r = .09). For the sake of brevity, we will not discuss this task further.

Peters et al. Delusions Inventory.

Self-report trait magical thinking was also assessed using the Peters et al. (1999) Delusions Inventory (PDI), a 40-item yes-or-no questionnaire designed to measure delusional ideation in a nonclinical population (e.g., "Do you ever think people can communicate telepathically?" scale α in this study = .79; *M* = 6.31, *SD* = 3.26). Each endorsed belief is subsequently rated on a 5-point Likert scale for the distress, preoccupation, and conviction associated with the delusional belief. This questionnaire has been used to measure delusional ideation in community samples (Peters et al., 1999) and is strongly correlated with another measure of magical thinking (i.e., the Foulds Delusions-Symptoms-State Inventory; Peters, Joseph, Day, & Garety, 2004).

Aberrant Salience Inventory.

A third measure of magical thinking was the Aberrant Salience Inventory (ASI; *M* = 14.18, *SD* = 6.20; Cicero et al., 2010), a 29 yes-or-no item questionnaire designed to assess pre-psychotic thoughts and experiences thought to be indicative of aberrant salience (e.g., "Do certain trivial things ever suddenly seem especially important or significant to you?" α = .83). Previous research has found that the ASI is strongly correlated with other measures of magical thinking (e.g., Magical Ideation Scale) and is associated with a history of psychotic disorder in psychiatric inpatients (Cicero et al., 2010; Cicero et al., 2013).

As expected, the three magical thinking self-report measures were all significantly correlated with each other (*r*'s from .43 to .57). Therefore, we created a latent variable from the variance shared between these three measures. In order to create this latent variable, exploratory maximum likelihood factor analysis was conducted (Fabrigar et al., 1999). On the basis of this EFA, one factor was identified on the basis of examining the eigenvalues as well as the scree plot (i.e., the first factor eignenvalue = 1.67, the second factor eigenvalue = .79, and the third factor eigenvalue = .54). Factor scores for each participant obtained from this one factor were used in all further analyses.

Reversal Learning Task.

To provide a manipulation check for the putative dopamine manipulation and to test the validity of the behavioral measure of magical thinking, participants completed a task thought to be related to striatal dopamine levels, the Reversal Learning Task (Cools et al., 2009). In general, on reversal learning tasks, participants first learn that one stimulus is rewarded and that a different second stimulus is punished. Subsequently, the associations with reward and punishment are switched and participants have to learn that the first stimulus is now punished and that the second stimulus is now rewarded, with this pattern repeating through a number of reversals. There are two trial types that are most important for this task: (1) unexpected reward trials, where a stimulus that was previously associated with punishment is now associated with reward; and (2) unexpected punishment trials, where a stimulus previously associated with reward is now associated with punishment. It has been argued by Cools and colleagues (2009) that heightened dopamine activity should facilitate a more rapid learning of stimulus-reward associations. In particular, given its role in reward learning, it is thought that increased dopamine is associated with better reversal learning on unexpected reward trials than on unexpected punishment trials. Consistent with this, recent imaging studies have found that increased striatal dopamine is associated with improved performance on unexpected reward relative to unexpected punishment trials on this Reversal Learning Task (Cools et al., 2009; van der Schaaf et al., 2012) and that a manipulation that increased dopamine improved unexpected reward based learning relative to unexpected punishment based learning on this task (Cools et al., 2009). Hence, we expected that better performance on unexpected reward relative to unexpected punishment to be at least somewhat related to striatal dopamine levels.

In the current study, we used the same Reversal Learning Task used by Cools and colleagues (Cools et al., 2009). Following previous research using this task (Cools et al., 2006; Cools, Robinson, & Sahakian, 2008), accuracy proportions scores were arcsine transformed. An overall *Reversal Learning Score* was computed which was the standardized sum of difference scores for accuracy (*M* = -.004 & *SD* = .15) and reaction time (RT; *M* = 35.48 & *SD* = 161.03), with higher scores indicating more accurate and faster learning after rewards than after punishment.[3]

Current Mood.

To examine whether performance on the magical thinking behavioral Dart Throwing Task was related to current mood, current mood was assessed using the Positive and Negative Affect Schedule (PANAS: Watson, Clark, & Tellegen, 1988), consisting of two 10-item mood scales, separately assessing positive ($M = 2.14$, $SD = .99$) and negative ($M = .67$, $SD = .71$) affect. Participants indicated how they currently felt on a scale from 1 to 5 ($\alpha = .76$ for PA and $\alpha = .81$ for NA).

Procedure

Following random assignment, participants completed the study in the following order: demographic questionnaire (asking about the participant's age, gender, and ethnicity), Image Viewing Task (i.e., salience manipulation), either Gambling Task or Syntactic Judgment Task (i.e., the putative dopamine manipulation), Dart Throwing Task, Reversal Learning Task, PANAS, Magical Ideation Scale, Aberrant Salience Inventory, and Peters et al. Delusions Inventory (questionnaires were completed last so that the questionnaire item content would not influence or in some way "prime" the experimental manipulations and task performance). All measures and tasks were administered through E-prime software (Psychology Software Tools, 2006).

Data Analysis Plan

In terms of data analysis, an ANOVA was conducted to analyze the effect of the salience and putative dopamine manipulation on magical thinking. Then, correlations were conducted to examine the association between the behavioral and self-report measures of magical thinking, as well as the relationship between self-reported magical thinking and the Reversal Learning Task. An ANOVA was used to examine whether the putative dopamine manipulation had an effect on Reversal Learning Task performance. An ANOVA was conducted to examine whether the groups exhibited significant differences on current mood. Lastly, correlations were conducted to examine whether the tasks were significantly associated with current mood.

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[3] We also included the Finger Tapping Task (Reitan, 1969) as a possible dopamine-related behavioral task. However, evidence that finger tapping is related to dopamine is based on one correlational study with n = 20 that measured dopamine receptors but not dopamine levels (Yang et al., 2003). Hence, in contrast to the Reversal Learning Task, there is scant evidence that the Finger Tapping Task is associated with striatal dopamine, including no evidence that a dopamine manipulation influences finger tapping. We found that this task was not significantly correlated with the Reversal Learning Task, $r = .09$, $p = .22$, and it was also not significantly associated with any other variable in this research. For the sake of brevity, we do not discuss this task further.

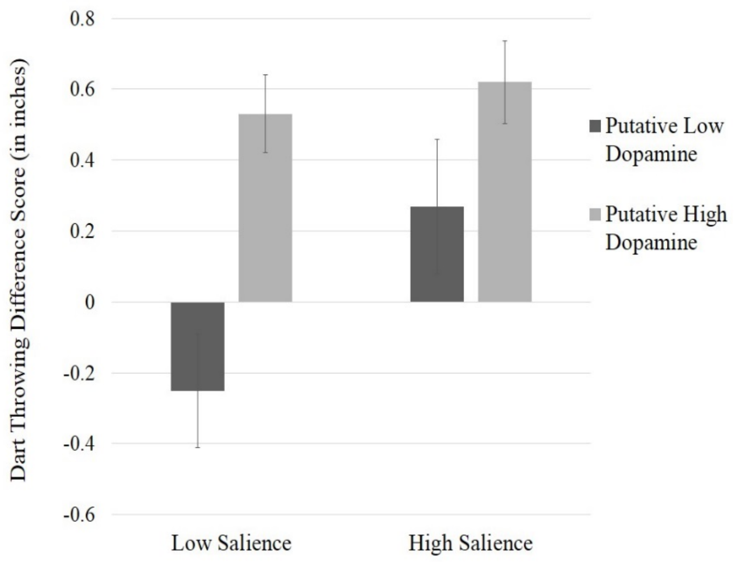

Figure 1: Effect of salience and putative dopamine manipulations on Dart Throwing Task difference scores. Error bars reflect standard errors of the mean.

Results

Effects of salience and putative dopamine manipulations.

We first examined whether performance on the behavioral magical thinking Dart Throwing Task was influenced by experimental manipulations intended to vary salience and putative dopamine levels. As previously mentioned, larger dart throwing difference scores were indicative of greater behavioral evidence of magical thinking. As can be seen in Figure 1, on the Dart Throwing Task, participants who received the low salience (i.e., previously seen image) manipulation exhibited significantly less behavioral evidence of magical thinking than participants who received the high salience (i.e., high novelty) manipulation, F (1, 231) = 4.43, $p < .05$, $d = .27$ (low salience: $M = .14$, $SD = 1.00$; high salience: $M = .44$, $SD = 1.35$). Hence, it appeared that the low salience manipulation decreased magical thinking, as participants were more accurate when throwing at the low salience, previously seen image than at the high salience, novel image.

In addition, as can be seen in Figure 1, for the Dart Throwing Task, participants who received the putative high dopamine (i.e., high reward) manipulation exhibited significantly greater behavioral evidence of magical thinking than participants who received the putative low dopamine manipulation, F (1, 231) = 15.38, $p < .001$, $d = .50$ (putative high dopamine: $M = .58$, $SD = 1.22$; putative low dopamine: $M = .01$, $SD = 1.08$). Hence, in comparison to the putative low dopamine group, the putative high dopamine group was significantly less accurate in throwing the dart at the baby than at the smiley face. Note that the interaction between the salience and the putative dopamine manipulations was not significant, F (1, 231) = 2.20, $p = .14$, $d = .19$.

Test of Validity of Magical Thinking Behavioral Measure.

Next, in order to examine the validity of the magical thinking behavioral measure, we examined the association between behavioral and self-reported magical thinking. As expected, the behavioral magical thinking Dart Throwing Task was significantly correlated with self-reported magical thinking ($r = .21$, $p < .01$). Next, we examined the association between the behavioral magical thinking Dart Throwing Task and performance on the Reversal Learning Task, a task previously found to be sensitive to striatal dopamine levels. The Dart Throwing Task was significantly positively associated with performance on the Reversal Learning Task ($r = .19$, $p < .01$), indicating that better learning from reward than from punishment was positively associated with greater evidence of magical thinking on the Dart Throwing Task. Also, there were no significant differences between the groups on any of the questionnaires (all *p*s

> .12, *d*s < .23). Hence, the behavioral magical thinking measure was associated both with increased self-reported magical thinking and with performance on a task associated with striatal dopamine.

Next we examined whether self-reported magical thinking was also associated with performance on the Reversal Learning Task. Importantly, to our knowledge, no previous study has examined whether a measure of self-reported magical thinking is associated with performance on a task sensitive to striatal dopamine. We found that self-reported magical thinking was significantly correlated with the Reversal Learning Task, $r = .15$, $p < .05$.

Putative Dopamine Manipulation Check.

Thus far, we have reported that the putative dopamine experimental manipulation increased behavioral evidence of magical thinking. Next, we examined a manipulation check of the putative dopamine manipulation, whether the putative dopamine manipulation also influenced performance on the Reversal Learning Task that is sensitive to striatal dopamine levels. As expected, participants who received the putative high dopamine manipulation exhibited the expected pattern of performance on the Reversal Learning Task (i.e., better learning on unexpected reward trials relative to unexpected punishment trials) to a greater extent than participants who received the putative low dopamine manipulation, F (1, 231) = 12.00, $p < .001$, $d = .44$ (for overall reversal learning scores, putative high dopamine: M = .18, SD = .81; putative low dopamine: M = -.18, SD = .81), as the putative high dopamine group was both more accurate (putative high dopamine: M = .03, SD = .12; putative low dopamine: M = -.04, SD = .16; $p < .001$, $d = .51$) and tended to be faster (putative high dopamine: M = 52.00, SD = 178.98; putative low dopamine: M = 19.20, SD = 139.90; $p = .09$, $d = .20$) in learning from reward than from punishment in comparison to the low dopamine group. Hence, it appeared that the putative dopamine manipulation not only affected performance on the behavioral magical thinking Dart Throwing Task but also affected performance on the Reversal Learning Task.

Current Mood.

Finally, we examined whether the groups in the different experimental manipulation conditions significantly differed on current mood. The groups did not significantly differ on either negative or positive mood, with effect sizes *d*'s < .13. In addition, we examined whether current mood was related to, and whether it could statistically account for associations with, the behavioral measure of magical thinking. Negative mood was not significantly related to any of the measures. Increased positive mood was significantly associated with increased behavioral evidence of magical thinking on the Dart Throwing Task ($r = .15$, $p < .05$). However, after removing variance shared with positive mood, the effects of both the salience and putative dopamine manipulations on the Dart Throwing Task and all previously reported significant correlations with the Dart Throwing Task were still significant.

Discussion

The current study found a number of novel and potentially important results. For the first time, we found that a salience manipulation caused decreased evidence of magical thinking on a behavioral magical thinking measure. In addition, for the first time we found evidence that a behavioral manipulation that putatively affects striatal dopamine levels also increases behavioral evidence of magical thinking. As a manipulation check, we also found that this putative dopamine manipulation also altered performance on a task that has been found to be sensitive to striatal dopamine levels. Moreover, for the first time, we found novel evidence for the validity of the Dart Throwing Task as a measure of magical thinking, as it was associated with both self-reported magical thinking and with performance on a task that has been found to be sensitive to striatal dopamine levels. Additionally, to our knowledge, this is the first time that self-reported magical thinking has been found to be associated with performance on a task that has been found to be sensitive to striatal dopamine levels. Hence, overall, the current results provide additional support for the involvement of both salience and dopamine in magical thinking.

An important issue in our research is to what extent we can infer that our salience and putative dopamine manipulations did in fact manipulate salience and dopamine. Potentially other plausible interpretations exist to explain the effects of either the salience or putative dopamine manipulations on the behavioral magical thinking measure. One potential interpretation is that for the salience manipulation the low salience condition involved seeing the critical baby face stimulus more often than in the high salience condition, which potentially might result in people liking the baby face more in the low salience condition (i.e., the mere exposure effect; Murphy & Zajonc, 1993). However, if true, it seems this should make people less and not more accurate in the low salience condition, which is the opposite of what we found. Further, we asked people how much they liked the pictures and liked throwing darts at the pictures, and there were no differences between the conditions. We also found no differences in current mood between the conditions, making it less likely that current mood can account for our results. Another general issue that has been raised is whether demand characteristics might vary by condition and could account for the effects of one or both of the manipulations. Although in general this is possible, it is not clear why or how demand characteristics would vary by condition (e.g., why would people in the putative high dopamine/high reward condition be more likely to think they should not throw at the baby face and therefore be less accurate?). Another issue in this research is that we did not directly manipulate dopamine or measure striatal dopamine levels. However, at the very least, our putative dopamine manipulation is consistent with multiple previous studies that did more directly measure striatal dopamine functioning, with previous research clearly supporting the view that our putative dopamine manipulation should increase striatal dopamine levels (e.g., Koepp et al., 1998; O'Doherty et al., 2004). In addition, a possible limitation of the current study is that our low putative dopamine manipulation involved performing a task that could potentially be viewed as tedious, and therefore could have possibly affected performance on the behavioral magical thinking task. However, it should be pointed out that this group was more accurate than the high putative dopamine manipulation. Hence, it does not seem like performing the more tedious task made people in the low putative dopamine group less accurate. In addition, although the current study employed an internally valid between-groups experimental design (e.g., Campbell & Stanley, 1963), one limitation of the current study is that we did not measure magical thinking prior to the manipulation. Overall, it is still potentially possible that there is another explanation for the effects of the salience and putative dopamine manipulations on the behavioral magical thinking task. Nevertheless, without another compelling plausible explanation, we think the most reasonable tentative interpretation of the manipulations is that these manipulations involved salience and putatively dopamine.

Another issue in our research is whether the behavioral magical thinking task did in fact measure magical thinking. In previous research, this task has clearly been identified as a magical thinking task on logical grounds (i.e., given that it follows the magical "law of similarity" that similar things share fundamental properties, which in the case of the Dart Throwing Task is not logically accurate; King et al., 2007; Rozin et al., 1986). However, there has been no direct empirical evidence in previous research supporting that this task involves magical thinking. In the current research, we found that performance on this task was associated with self-reported magical thinking and with performance on a task that has been found in previous research to be sensitive to striatal dopamine levels. Hence, for the first time, the current study has provided empirical evidence supporting the validity of this task as a behavioral measure related to magical thinking. Overall, we still think it is possible that performance on this behavioral task could be affected by factors other than magical thinking. For example, it is possible that, given that anxiety symptoms are related to magical thinking (Simonds, Demetre, & Read, 2009; West & Willner, 2011), that anxiety symptoms could be associated with behavioral magical thinking task performance, but the current study did not measure anxiety symptoms. Future research should examine the relationship between anxiety symptoms and behavioral magical thinking task performance. Also, we acknowledge that although the Reversal Learning Task has clearly been found to be sensitive to striatal dopamine levels, performance on this task also involves other unknown factors and Dart Throwing Task performance might be more strongly associated with those other factors rather than striatal dopamine. It should be noted that although many of the significant correlations in the current study were in the expected direction, the effect sizes for these correlations were also small. Nevertheless, based on the current research, our current best tentative interpretation of the Dart Throwing Task is that it at least to some extent measures magical thinking.

Having discussed important potential limitations to the inferences that we can draw in the current research, we now discuss what our results might mean for aberrant salience, dopamine, and behavioral measures of magical thinking. Overall, we think the current study does generally support the aberrant salience hypothesis of psychosis (Kapur, 2003). This hypothesis views psychotic delusions as the by-product of aberrant salience, as neutral stimuli are inappropriately given importance and significance. For the first time, we experimentally manipulated salience levels and found that the low salience condition exhibited lower levels of magical thinking on the behavioral measure. Given that magical thinking predicts future delusions (e.g., Chapman et al., 1994), our results then are generally consistent with the view that aberrant salience might also be important for delusions. Hence, the current research provides novel experimental evidence supporting the aberrant salience hypothesis. Interestingly, our salience manipulation involved decreasing salience as the original task involves seeing a highly salient and novel stimulus. Hence, the manipulation we developed decreased novelty/salience by showing participants an image a number of times in the low salience condition. Therefore, the current study suggests that decreasing salience to some extent can potentially decrease magical thinking, which could be relevant for treatment development. However, a limitation of the current study is that our salience manipulation was very specific to our particular behavioral measure of magical thinking and cannot be directly generalized to other contexts. In ongoing research we are investigating the possibility that more general manipulations that decrease salience could have a broader effect on magical thinking. Given the need for additional and improved methods for preventing and treating psychosis (e.g., dopamine antagonists not recommended for preventing psychotic disorder; Fusar-Poli et al., 2013), it is hoped that research on manipulations that decrease salience could help us identify novel means to decrease magical thinking. Treatments have been developed for mood disorders in which attentional biases towards negative or threatening words are reduced through reducing the salience of these words (Foland-Ross & Gotlib, 2012). Potentially a similar type of treatment could be developed for magical thinking and aberrant salience via computerized training that attempts to implicitly reduce the salience of stimuli. Along these lines, recently developed treatments for delusional ideation include Metacognitive Training, which teaches patients about cognitive distortions and teaches alternative strategies for coping with these distortions (e.g., Moritz et al., 2013; van Oosterhout et al., 2014). Likewise, the Maudsley Review Training Program provides patients with psychoeducation about reasoning biases and teaches strategies for reducing these biases (Garety et al., 2014). In terms of aberrant salience, potentially a similar treatment could be developed in which aberrant salience is reduced by providing explicit training to reappraise aberrant salience experiences.

In addition, the current research also found some novel evidence supporting the role of dopamine in magical thinking. Dopamine is strongly associated with psychotic symptoms such as delusions (e.g., Howes & Kapur, 2009). However, to our knowledge there has been no evidence that magical thinking, which predicts psychosis (Chapman et al., 1994), is also associated with dopamine. Given that dopamine has been viewed as potentially only the final part of a causal chain that leads to psychosis (Laruelle, 2003; Murray et al., 2008), it is possible that magical thinking may not necessarily reflect dopamine dysregulation. However, in the current research, for the first time we found some evidence linking magical thinking with dopamine, as a putative dopamine manipulation increased magical thinking on a behavioral task and self-reported magical thinking was associated with performance on a task previously found to be sensitive to striatal dopamine (i.e., the Reversal Learning Task; also note that the association between the magical thinking behavioral task with the Reversal Learning Task also supports an association between magical thinking with dopamine). The fact that the salience and putative dopamine manipulations did not interact potentially could mean that the manipulations had an effect on magical thinking through different mechanisms. Conversely, it could mean that these manipulations each influence the same mechanism but that their effects are additive (e.g., as an analogy, two medications that both increase dopamine in an additive manner). Future research could examine the effects of pharmacological dopamine manipulations on magical thinking and also attempt to more directly assess the association between magical thinking and striatal dopamine functioning.

Again, the current research also found some novel evidence supporting the validity of the Dart Throwing Task as a measure of magical thinking. This could be useful for research on magical thinking in multiple ways. First, given limitations of self-report (e.g., Schwarz, 1999), especially for magical thinking and delusions which are thought to be related to impairments in insight (e.g., Carpenter, Strauss, & Bartko, 1973; Cuesta, Peralta, Campos, & Garcia-Jalon, 2011), valid behavioral measures could provide useful converging measures of magical thinking. It is also possible that behavioral measures of magical thinking are implicit measures of magical thinking, and thereby bypass more conscious processes, such as social desirability. In addition, in research that attempts to experimentally manipulate mechanisms that could decrease magical thinking, which could foster novel treatment development (e.g., MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; MacLeod & Mathews, 2012), it would be useful to have measures that could be sensitive to short-term changes in magical thinking, in order to examine whether the treatment is associated with changes on behavioral measures of magical thinking. We think the current Dart Throwing Task, as well as other potential behavioral measures of magical thinking (e.g., the Jumping to Conclusions Task; Garety et al., 2005), could be useful in examining the short-term effects of manipulations that could decrease magical thinking. Future research examining the validity of behavioral measures of magical thinking could investigate their performance in clinical populations and could examine whether they are affected by pharmacological dopamine manipulations.

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