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Why creatives don't find the oddball odd: Neural and psychological evidence for atypical salience processing

Madeleine E. Gross[a,1,*], James C. Elliott[a,1], Jonathan W. Schooler[a]

[a] Department of Psychological and Brain Sciences, University of California Santa Barbara, Santa Barbara, CA 93106, USA

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ABSTRACT

Creativity has previously been linked with various attentional phenomena, including unfocused or broad attention. Although this has typically been interpreted through an executive functioning framework, such phenomena may also arise from atypical incentive salience processing. Across two studies, we examine this hypothesis both neurally and psychologically. First we examine the relationship between figural creativity and event-related potentials during an audio-visual oddball task, finding that rater creativity of drawings is associated with a diminished P300 response at midline electrodes, while abstractness and elaborateness of the drawings is associated with an altered distribution of the P300 over posterior electrodes. These findings support the notion that creativity may involve an atypical attribution of salience to prominent information. We further explore the incentive salience hypothesis by examining relationships between creativity and a psychological indicator of incentive salience captured by participants' ratings of enjoyment (liking) and their motivation to pursue (wanting) diverse real world rewards, as well as their positive spontaneous thoughts about those rewards. Here we find enhanced motivation to pursue activities as well as a reduced relationship between the overall tendency to enjoy rewards and the tendency to pursue them. Collectively, these findings indicate that creativity may be associated with atypical allocation of attentional and motivational resources to novel and rewarding information, potentially allowing more types of information access to attentional resources and motivating more diverse behaviors. We discuss the possibility that salience attribution in creatives may be less dependent on task-relevance or hedonic pleasure, and suggest that atypical salience attribution may represent a trait-like feature of creativity.

1. Introduction

Creativity has long been associated with differences in attentional selection, particularly an unfocused or broad attentional scope and a proneness to attend to task-irrelevant information (Kasof, 1997; e.g. Zabelina et al., 2016; Zabelina, 2018). Such differences in attentional scope in creatives have often been interpreted as arising from a deficit in cognitive control (Vartanian, 2002; Gu et al., 2018). Yet, a more fundamental explanation may be found by viewing these findings within the context of atypical incentive salience processing. *Incentive salience* processes transform neutral sensory data into attention-worthy and motivationally-relevant information (Berridge, 2012), in effect making some information stand out against the rest. Salient information, in turn, has preferential access to higher level cognitive resources. As such, salience processes play a direct role in guiding the allocation of attention, by selectively prioritizing cognitive and perceptual information for further processing, and behavior, by motivating goal pursuit and seeding action selection processes (Harsay et al., 2012). The consideration of salience processes may therefore be central for understanding the higher level patterns of thought and behavior that underpin personality differences conducive to creativity (see Gross & Schooler, in press, for more detailed theoretical argument).

Past research has reported demonstrable variation in individuals' tendencies to attribute incentive salience to reward cues (e.g. Meyer et al., 2012; Flagel et al., 2009; Beckmann & Chow, 2015; Villaruel & Chaudhri, 2016). For example, in reinforcement learning contexts, individual differences in the tendency to attribute motivational relevance to reward associated cues have been observed; some individuals are found to reliably assign incentive salience to information related to a reward – so called sign trackers – while others only assign incentive

* Corresponding author.
E-mail addresses: madeleinegross@ucsb.edu (M.E. Gross), james.elliott@psych.ucsb.edu (J.C. Elliott), jonathan.schooler@psych.ucsb.edu (J.W. Schooler).
[1] indicates co-first authorship

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salience to the reward itself – so called goal trackers (Robinson et al., 2014; Beckmann & Chow, 2015). Various higher order personality traits have also been theoretically associated with individual differences in the attribution of salience (DeYoung, 2013), most notably curiosity (FitzGibbon et al., 2020). In particular, it has been suggested that curiosity may be characterized by a reward sensitivity to information (Kidd & Hayden, 2015; Gottlieb et al., 2020), whereby information reflects a motivationally salient reward (FitzGibbon et al., 2020). In other words, individual differences in curiosity are suggested to reflect differences in the tendency to experience information gain as rewarding, resulting in a greater attribution of incentive salience to stimuli or situational cues that indicate potential for learning (Murayama et al., 2019). These dopamine-mediated processes in turn drive the higher level patterns of thought and behavior we associate with curious individuals, such as behavioral exploration and knowledge-seeking.

Typically, information is assigned a high degree of salience if it is rewarding, relevant, or informative (e.g. surprising, novel, or aversive; Horvitz, 2000; Matsumoto, & Hikosaka, 2009; Redgrave & Gurney, 2006; Schultz, 2015); however, for some individuals these processes are altered leading to attentional abnormalities that drive downstream cognitive and behavioral differences. Indeed a growing body of research has grounded the characteristics associated with schizophrenia-spectrum disorders (i.e. from subclinical schizotypy to schizophrenia) within a salience processing framework referred to as the *aberrant salience model* (Kapur, 2003). This framework posits that several characteristics observed in schizophrenia and schizotypy stem from lower level disturbances in the assignment of incentive salience driven by dysfunctional dopaminergic activity in the midbrain (Heinz and Schlagenhauf, 2010; Heinz et al., 2019). These disturbances cause information that is irrelevant or neutral to be attributed with motivational salience, leading individuals to perceive spurious correlations and to attribute an especial significance to random information (Kapur, 2003). Over time, these processes contribute to the higher order manifestations of schizotypy and schizophrenia, including eccentric ideation, perceptual aberrations, and attentional abnormalities (Haselgrove et al., 2016).

Given the strong associations between both curiosity and creativity, and schizotypy and creativity, it is plausible that creativity reflects yet another phenotype of salience processing which, at least in part, overlaps with the patterns of salience attribution observed in schizotypy and curiosity (Gross & Schooler, in press). Similar patterns of salience processing in creatives and schizotypes could explain why much of the same attentional phenomena that has been documented in schizophrenia-spectrum disorders have been observed in the context of creativity. For example, both have previously been associated with distractibility and failures of attentional inhibition (Carson et al., 2003; Marsh et al., 2017; Minas & Park, 2007). Paradigms such as negative priming (NP) and latent inhibition (LI) test attentional inhibition by examining the degree to which irrelevant distractors interfere with on-going task performance (Beech & Claridge, 1987; Dawes et al., 2022). Reduced performance on such paradigms, reflected by an inability to ignore irrelevant information, has been demonstrated for decades in those with subclinical schizotypal characteristics (Braunstein-Bercovitz & Lubow, 1998; Moritz et al., 1998; Vink et al., 2005; Kumari & Ettinger, 2010). Importantly, these disinhibited attentional patterns have also been observed in the context of creativity (Stavridou & Furnham, 1996; Kwiatkowski et al., 1999; Carson et al., 2003; Burch et al., 2006; Chirila and Feldman, 2012). Increasing evidence suggests that attentional abnormalities in schizophrenia may result from the described deficits in incentive salience processing (Miller, 1993; Cortiñas et al., 2008; Morris et al., 2013; Miyata, 2019). Given the long observed link between schizotypy and certain forms of creativity (for *meta*-analytic review, see Acar & Runcom, 2012), it is therefore plausible that differences in salience processing may reflect the underlying mechanism driving the shared attentional differences observed between these two constructs, as well as the propensity for original or eccentric ideation.

Characteristics shared between curiosity and creativity may similarly be explained by overlaps in patterns of salience processing. Both creativity and curiosity have been associated with increased novelty-seeking (Gocłowska et al., 2019; Silvia, 2012) and intrinsic motivation (Di Domenico, & Ryan, 2017; Grigorescu, 2020; Liu et al., 2016; Tan et al., 2019). These motivated behaviors have in turn been associated with the salience coding functions of dopamine neurons. Indeed, modern theory suggests that incentive salience processes contribute to seeking behavior and motivation by imbuing information with motivational relevance (Bromberg-Martin et al., 2010; McClure et al., 2003). Curiosity – the motivation to learn– has also long been associated with dopamine activity in general (Gruber et al., 2014) and, recently, with incentive salience processes in particular (FitzGibbon et al., 2020). An increased propensity to attribute incentive salience to environmental stimuli may similarly explain the occurrence of motivated behavior, novelty-seeking, and exploratory drive observed in creatives (e.g. Prabhu et al., 2008; De Jesus et al., 2013), while further explaining the association between curiosity and creativity.

In the following studies we therefore sought to extend considerations of incentive salience processing to the domain of creativity in order to examine whether these processes may represent an underexplored factor explaining individual differences in creative performance. To do so, we borrowed two paradigms that have previously been used to study atypical salience processing in schizotypy.

In study 1 we examined a neural indicator of salience processing by employing an audio-visual oddball paradigm. The oddball paradigm has been widely used to examine atypical salience processing in schizophrenia-spectrum disorders (Ford, 1999). In this task, participants are presented with low probability (i.e. oddball) stimuli amidst higher probability standard stimuli. An established literature shows that the oddball produces stimulus-locked event-related potentials (ERPs), most notably a positive deflection at ~ 300 msec (P300) following the onset of the stimulus (for *meta*-analysis, see Jeon & Polich, 2003). However, a diminished P300 response to the oddball has been observed in individuals across the schizophrenia spectrum, from schizophrenia (Hamilton et al., 2019; Kiehl et al., 2005) to subclinical schizotypy (e.g. Mathalon, 2019; Sumich et al., 2008). Given that this task is sensitive to individual differences at the subclinical level, and further, that subclinical schizotypy has been found to be reliably associated with creativity (Acar & Runcom, 2012), we predicted that we would see a similar pattern of salience processing in creatives – namely, a diminished P300 response to the oddball.

Study 2 examined a psychological indicator of incentive salience processing in the context of everyday rewards. Both curiosity and schizotypy have been associated with dopamine-mediated reward learning in different ways. Knowledge-seeking behaviors in curious individuals are thought to be driven by both enhanced feelings of *liking* and *wanting* of information (Litman, 2005). Whereas liking simply reflects the affective experience of rewards, wanting is thought to be driven by incentive salience processes which imbue reward related information with motivational value. This in turn drives individuals to seek out potential rewards (Olney et al., 2018). In other words, incentive salience drives *wanting*, but not necessarily liking of rewards (Berridge, 2009; Berridge, 2012; Olney et al., 2018). Curiosity may therefore reflect *heightened* attribution of incentive salience to informational "rewards" (FitzGibbon et al., 2020); this in turn drives curious individuals to engage in more exploratory behaviors in order to increase the potential for information gain. On the other hand, schizotypy has been found to be associated with *aberrant* reward learning reflected by a diminished association between liking and wanting of reward related stimuli (Li et al., 2020). The aberrant salience account of schizophrenia posits that this altered functioning leads to the high order motivational abnormalities commonly observed in schizophrenia (Strauss et al., 2014).

In short, two constructs related to creativity– schizotypy and curiosity– have previously been suggested to reflect distinct patterns of association with incentive salience processing in the context of liking and wanting of rewards. Using a paradigm that has previously been used to empirically examine these relationships in schizotypes, we examined the association between liking and wanting as a function of creativity in study 2. Here it was again predicted that we would observe a similar pattern of atypical incentive salience processing for creatives as has been observed for schizotypes, namely, a diminished relationship between liking and wanting.

1.1. Summarized objective

Given the theorized influence of salience processes across various levels of processing (Chun et al., 2019), we chose paradigms that targeted multimodal aspects of incentive salience processing. Study 1 used a classic paradigm for examining aberrant salience processing in schizotypes at the neural level. Here it was predicted that creatives would display similarly diminished processing of novel stimuli– i.e., an under attribution of salience to prominent information. In study 2, we turn to psychological evidence of atypical incentive salience processing in the context of everyday rewards. Here it was again predicted that creatives would display atypical assignment of incentive salience as reflected by a reduced association between *liking* and *wanting* of rewards. Together, these studies aimed to offer initial, converging evidence of atypical incentive salience processing in creatives.

2. Study 1

A diminished neural response to oddball stimuli in schizotypes, as reflected by a reduced amplitude in the P300, is one of the most replicated findings in this area (Hamilton et al., 2019; Kiehl et al., 2005). Prevailing views consider P300 amplitude to reflect attentional shifts and salience processing (Tang et al., 2020). The context updating theory of oddball processing, for example, suggests that detection of the oddball target via sensory processes drives an attention-driven comparison to working memory based representations of previous events (Polich, 2007). As the previous events in the oddball paradigm are repeated standard stimuli, these comparison processes will flag the oddball as unexpected resulting in an update to the brain's current model. This contextual updating is reflected by a large P300 amplitude. A diminished P300 response, therefore, is interpreted to reflect diminished surprise resulting from the oddball; the surprising– and thus typically salient– stimulus is not being appraised as such.

In a solely behavioral examination of the oddball task, it was found that creativity was associated with similar response patterns as previously observed for schizophrenics (Gross et al., 2019). Here the figural portion of the Torrance Tests of Creative Thinking (TTCT; Cramond, et al., 2005) was used to measure divergent thinking, and an auditory oddball paradigm was used in which participants were required to press one of two arrow keys depending on presentation of a standard (high probability) tone or the target (low probability, i.e., oddball) tone. The results indicated that creativity was associated with an abnormal oddball response reflected by slower reaction time to the oddball stimuli; a finding that parallels existing observations in schizophrenia-spectrum research (Kiehl & Liddle, 2001). Beyond this, very little research to date has examined relationships between creativity and *neural* responses to oddball stimuli. Recent studies have examined ERP responses to unusual art, such as ambiguous paintings (Csizmadia et al., 2022) as well as novel metaphorical and nonsensical phrases (Rutter et al., 2012). However, only one study that we are aware of has examined neural responses within a traditional oddball paradigm (Zabelina & Ganis, 2018).

Zabelina & Ganis (2018) designed an experiment to examine the hypothesis that some forms of creativity rely on *enhanced* attentional control processes. Therefore an active 3-stimulus version of the oddball task was used in which participants were required to make key presses to indicate the presence of a target stimulus amidst compelling distractors. This version of the oddball task requires significant attentional control making it well-suited for examining the executive control aspect of oddball response, namely, the N200 ERP response – a negative deflection occurring roughly 200–350 ms following stimulus onset. To examine relationships between cognitive control and creativity, two forms of creativity were included; divergent thinking and real-life creative achievement. It was predicted that divergent thinking in this context would require attentional inhibition, switching, and focus, i.e., greater cognitive control. In line with this hypothesis, it was found that divergent thinking, but not real-life creative achievement, was associated with larger differences in the N200 ERP response between frequent and infrequent stimuli reflecting greater engagement of attentional control. However, no relationship was observed between divergent thinking and the P300 novelty detection response.

Based on these findings, the authors proposed that distinct attentional styles may support different forms of creativity. While some forms of creativity seem to rely on attentional *flexibility*, the ability to switch and inhibit which relies on enhanced executive control functions, others may be benefitted by *leaky* attention, whereby attention is diffuse and irrelevant information "leaks" in. Zabelina & Ganis' study was designed to examine the first attentional phenotype – attentional flexibility and control– but was not designed to investigate the potential role of salience processing in driving "leaky attention".

The present study examined the aberrant salience account of oddball processing (Cortiñas et al., 2008; Bachiller et al., 2015) as an alternative to the executive control explanation. Therefore a standard 2-stimulus oddball task was used in which an infrequent target is randomly presented amidst a stream of standard stimuli. In this version of the oddball task, the primary feature is the novelty of the infrequent stimulus, not the presence of distractors within a difficult ongoing task. Past research suggests this paradigm is better suited for examining individual differences in neural responses to salient stimuli (Polich, 1998; Katayama & Polich, 1996). While numerous versions of the oddball task exist, schizophrenia-spectrum studies have largely focused on the P300 component using a 2-stimulus task (standard and target stimuli only; see *meta*-analysis, Bramon et al., 2004). As our study was primarily motivated by the link between schizotypy and creativity, we opted to similarly employ a 2-stimulus task.

Although the classic oddball task usually uses a single sensory modality (i.e., visual or auditory), we additionally used a bimodal (i.e., audio-visual) version of the paradigm given past research indicating that increased P300 sensitivity within such paradigms (Campanella et al., 2010; Campanella et al., 2012) may make it easier to detect between group differences (e.g., Campanella et al., 2010). Furthermore, we used a figural drawing task in which participants were given a longer 10 min to complete the task. Performance on this task was previously associated with longer latencies when responding to the oddball tone (Gross et al., 2019), therefore we conjectured that this task may be suitable for capturing the type of creativity characterized by "leaky" attention.

Given the established relationship between creativity and schizotypy, as well as their shared patterns of disinhibited attention, we predicted that individuals high in creativity would exhibit a similar pattern of neural responses as observed in schizophrenia research. In particular, prior research has consistently linked schizophrenia-spectrum disorders to reduced P3b amplitude (see reviews; Ford et al., 1992; McCarley et al., 1991), with similar findings observed in unaffected first-degree relatives (Blackwood et al., 1991; Kidogami et al., 1991; Roxbourough et al., 1993), suggesting the presence of P3b as a biomarker even in nonclinical populations. Given our focus on extending these findings to personality dimensions related to schizotypy, particularly creativity, we concentrated our analysis on the P3b component (referred to here as P300), rather than other ERPs like N200 or P3a, in the oddball task. It was predicted that creativity would be associated with diminished P300 amplitude to the oddball stimulus. Such a finding would indicate that the relationship between oddball performance is not solely due to dampened executive control but rather likely reflects reduced attribution of salience to prominent stimuli.

2.1. Methods

2.1.1. Participants

The study was approved by the Institutional Review Board at University of California, Santa Barbara and met the requirements for human subjects testing. Fifty-one individuals (age range 18–27, mean: 19.77, 30 females) from the University of California, Santa Barbara, completed this experiment. Sample size was informed by (and exceeded) studies examining relationships between ERP components and creativity (i.e., Zabelina & Ganis, 2018). Additionally, the final subject number was determined by a power analysis examining a question unrelated to the current paper (to be addressed in a subsequent paper); therefore the total number of participants was determined before analysis. Participants were compensated $20/hour for their time.

2.1.2. Design

The experiment was a within-subjects experiment with 1 factor (standard stimulus vs. oddball stimulus, see Fig. 1).

2.1.3. Materials

2.1.3.1. Oddball task. Stimulus presentation and timing were controlled using a custom script built using PsychoPy v3 (Peirce, 2007; Peirce et al., 2019) on a Lenovo ThinkPad laptop running Windows 7 with a 15.5 in. display. Participants sat, unrestrained, at 70 cm from the display. All stimuli were presented on a neutral gray background. Each block of the experiment was initiated when the participant pressed the spacebar, at which time participants were presented with a fixation cross. Participants were instructed to fixate on the cross and attempt to keep their eyes at that location throughout the duration of each block. After 1500 ms, a small circle (1.4 cm diameter, subtending 1.14°) appeared for 100 ms centered on the fixation cross. Then, following a 1000 ms ISI, an image (measuring 4.5 cm square, subtending 3.7°) appeared for 100 ms. The image was either an apple (.25 probability) or a rock (.75 probability). The identity of the stimulus was determined using a truly random number generator. If an apple was presented, it co-occurred with a tone (see Fig. 1 for a schematic of a trial). The tone was the native PsychoPy sound (‘A’, or 440 hz) and was also played for 100 ms at a clearly audible, yet comfortable volume. Each 20 stimulus block lasted approximately 1 min.

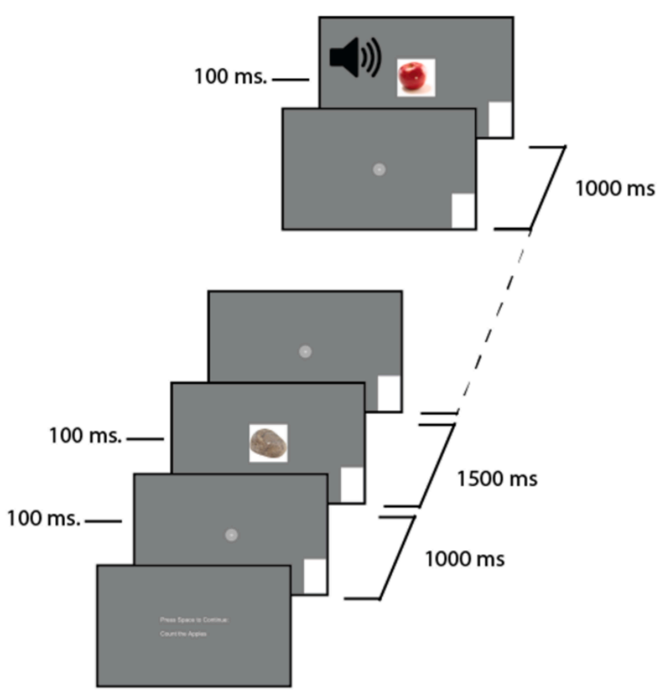

Fig. 1. Diagram of timing parameters and stimulus presentation for study 1. Note the first slide in the image reads: “Press space to continue. Count the Apples.”.

2.1.3.2. Creativity measure. Creativity was measured using the performance-based Incomplete Figures Task, which is part of the larger Torrance Tests of Creative Thinking (TTCT; Torrance, 1972) battery. In this task, participants are given a sheet of paper with four boxes, with each box containing a few ill-defined starting lines. Participants are given 10 min to complete 4 drawings making use of the initial lines provided, and are explicitly instructed to strive to be creative in this activity.

2.1.4. Procedure

After obtaining consent, participants were fitted with a 20-channel EEG cap. They were then given 10 min to complete the Incomplete Figures Test. Following this, participants were directed to a sound and light attenuated booth where they sat in a comfortable chair for the duration of the experiment.

Following instructions and completion of an instructional block delivered under observation of the experimenter, participants completed the oddball task. Participants initiated each block in the task by pressing the spacebar. Once the spacebar was pressed, a fixation cross appeared in the center of the screen and participants were instructed to fixate on the cross throughout the block. Each block consisted of 20 images and there was a.25 probability that each image would be an apple paired with a tone. Since a truly random process determined the stimulus sequence, with no restrictions, the actual number of apples varied on a block by block basis. At the end of each 20 stimulus block, participants were asked to indicate the number of apples that they counted throughout the block. They were further asked to indicate their level of fatigue on a scale from 1 to 10 and to answer a forced choice question regarding whether they were awake during the block. After a break, the duration of which was chosen by the participant, the next block was initiated with the press of the space bar.

After every 5th block, the door to the booth was opened and one of the experimenters briefly engaged with the participant while preparing the next set of 5 blocks. Each participant completed 6 sets of five blocks, for a total of 30 blocks. With breaks, the entire experiment lasted 1.5 h. At the end of the experiment, participants were taken out of the booth, the EEG cap was removed, and they were given the opportunity to clean the gel from their hair. Participants then completed a measure of creative behaviors and the paranormal ideation scale.[2]

2.1.5. EEG data collection

A Mobita EEG system (manufactured by TMSi) was used to record EEG data at a sampling rate of 1000 Hz. EEG was recorded from 20 scalp electrodes in the Electro-Caps standard 10/20 placement and two earlobe reference electrodes. There were no other electrode locations (e.g. EOG or EMG). Measuring impedance before the start of data collection was not possible, so connection quality was inspected by examining raw EEG. This included asking the participant to blink their eyes, look to the extremes, confirmation of the presence of alpha activity while eyes were closed, and examining if any of the electrodes responded differently to muscle tension or slight movement. While technical issues prevented some data collection, no participants were excused due to data quality. Attempts were also taken to electrically isolate the booth: wrapping it in

[2] Neither of these measures are reported here. The paranormal ideation scale was collected to address a question not explored in this analysis. Due to experimenter error, responses to the creative behaviors measure were lost for half of the participants.

copper cloth, using proper grounding, and using battery operated equipment. Despite these measures, 60 hz line noise was still apparent in the EEG.

2.1.6. EEG preprocessing

EEG was processed using EEGLab (Delorme & Makeig, 2004) and custom Matlab scripts. Raw EEG was re-referenced offline to the average ear lobe and was filtered with a low-cutoff of.5 and a high-cutoff of 50 using EEGlab FIR filter to minimize phase distortion. Data were epoched around the stimulus, starting 200 msec before the onset of the stimulus and ending 600 ms after stimulus presentation. The epoch was baselined to average activity before the onset of the stimulus (−200 to 0 msec). In order to reduce movement and eye blink artifacts, epochs with a deflection +/- 100 mV in any scalp electrode were excluded from analysis. On average, 30 percent of trials were rejected (minimum 3 percent, maximum 60 percent).

2.2. Results

2.2.1. Analytic overview

The results will be examined in three parts. First, the relationship between creativity and other measures associated with the Incomplete Figures Task task will be examined. Then, ERP analysis will be conducted to confirm typical P300 effects. Finally, the relationship between creativity and the P300 will be assessed. Previous studies have examined the relationship between the P300 and other personality characteristics (e.g. schizotypy; Sumich et al., 2008). The current analysis follows the same approach: averaging across electrodes based on region to decrease both noise and the number of electrodes in the analysis and followed by a regression approach using the personality characteristic (creativity in the current study) as the criterion variable and the ERP measures (mean amplitude of P300 differences wave) as predictor variables. ERP data was preprocessed and exported using EEGlab and custom Matlab scripts. All analyses were conducted in IBM SPSS statistical software, version 26.

2.2.2. Creativity measure

Each of the four drawings from the Incomplete Figures Task was scored by two trained research assistants on the following metrics: creativity, title abstractness (abstractness), artistic talent (talent), and elaborateness (effort). Scores were given on a scale from 1 (not at all) to 5 (extremely). There were positive correlations between creativity and each of the other metrics (see Table 1). In order to examine the unique relationship between creativity and the EEG measures, a separate regression was conducted with the creativity score as the DV and the remaining scores as predictor variables. The residuals from this analysis reflect the unique variability of creativity and were used in subsequent analyses.

2.2.3. Oddball vs. Standard stimuli ERP

In order to examine whether or not the typical oddball-associated P300 was observed, epochs were averaged for each stimulus type: oddball and standard. The mean amplitude of the ERP was calculated surrounding the peak of the P300, between 320 and 420 ms. Furthermore, in line with previous studies examining the relationship between the P300 and personality characteristics (Sumich et al., 2008), electrodes were grouped based on location and averaged within region (see Fig. 2). A 2 (stimulus type: oddball vs. standard) x 7 (electrode region) repeated measures ANOVA revealed that there was a significant main effect of stimulus type, $F(1,50) = 146.23$, $p < .001$, $\eta_p^2 = .74$, such that there was an increase in P300 amplitude for the oddball stimulus compared to the standard stimulus. There was also a main effect of region, $F(6,300) = 233.8$, $p < .001$., $\eta_p^2 = .89$. Finally, there was a significant interaction between stimulus type and region, $F(6,300) = 164.38$, $p < .001$., $\eta_p^2 = .77$. indicating that there was a variation in the difference between oddball and standard stimuli across regions. Follow up t-tests confirmed that there was a significant increase in mean P300 amplitude for oddball stimuli compared to standard stimuli for midline, bilateral central, and posterior regions (all p's $< .007$; corrected), but not for L.A. or R.A.. The distribution of the difference between oddball and standard stimuli during the P300 time period can also be seen in the topographical plot (see Fig. 3).

Table 1
Correlation between Incomplete Figures Task scores.

Variable	Creativity	Artistic Talent	Abstract Title	Effort
Creativity		.568**	.287*	.423**
Artistic Talent			.0441	.800**
Abstract Title				.046

Note. * indicates correlation is significant at the.05 level. ** indicates that the correlation is significant at the.01 level (2-tailed).

2.2.4. Creativity and the P300

Next, a linear regression was conducted to examine the relationship between the creativity score and the difference in mean amplitude of the P300 between oddball and standard stimuli. Specifically, the residuals for creativity were included as the DV and the difference in the mean amplitude P300 for each of the 7 regions were included as the predictor variables. Table 2 summarizes the results from this analysis.

Consistent with the *a priori* hypothesis that creativity is related to atypical salience processing, there was a significant negative relationship between creativity and the magnitude of the P300 difference in the midline region ($\beta = -0.694$, $p = .046$), suggesting that the more creative an individual is the smaller the neural response to the oddball stimulus (see Fig. 4).

Exploratory analyses examined the relationship between the mean amplitude of the P300 difference wave and the remaining scores from the Incomplete Figures Task (Artistic Talent, Abstractness of Title, and Effort; see Table 3). After correction for multiple comparisons in these exploratory analyses, there was no relationship between the mean amplitude of the P300 difference wave and talent. However, both abstractness and effort were significantly related to a decrease in the P300 difference in the Left Posterior region (abstractness: $\beta = -1.437$, $p = .03$; effort: $\beta = -1.433$, $p = 0.033$) and an increase in the P300 difference in the Right Posterior region for abstractness ($\beta = 1.412$, $p = .011$; note that the Right Posterior region approached significance effort: $\beta = 1.242$, $p = 0.087$).

2.3. Discussion

The results of Study 1 suggest that there is an atypical assignment of salience to oddball stimuli, as indicated by a diminished P300 response, for more creative individuals. This extends a well-documented effect in schizophrenia-spectrum disorders to the domain of creativity. In doing so, this study helps establish that the relationship between schizotypy and creativity may not be driven by a superficial similarity, e.g., a shared proneness to eccentric or original ideation, but rather by similar underlying neural mechanisms.

The present study differs in important ways from the study led by Zabelina and Ganis (2018) in which neural responses to the oddball were also examined in the context of creativity. As mentioned, two types of creativity were examined in Zabelina & Ganis (2018); divergent thinking and real-life creative achievement. Divergent thinking was assessed with a composite score based on performance on three creative tests from the abbreviated Torrance Tests of creativity (Torrance, 1974): one verbal task and two figural tasks. Real life creative achievement was assessed using a self-report measure in which participants report the frequency of their creative achievements across 10 domains (e.g. music, dance). Divergent thinking, but not creative achievement, was associated with an increased N200 response (Zabelina & Ganis, 2018) indicating greater cognitive control. Typically oddball paradigms that include a third distractor variable split the P300 response into a P3a and

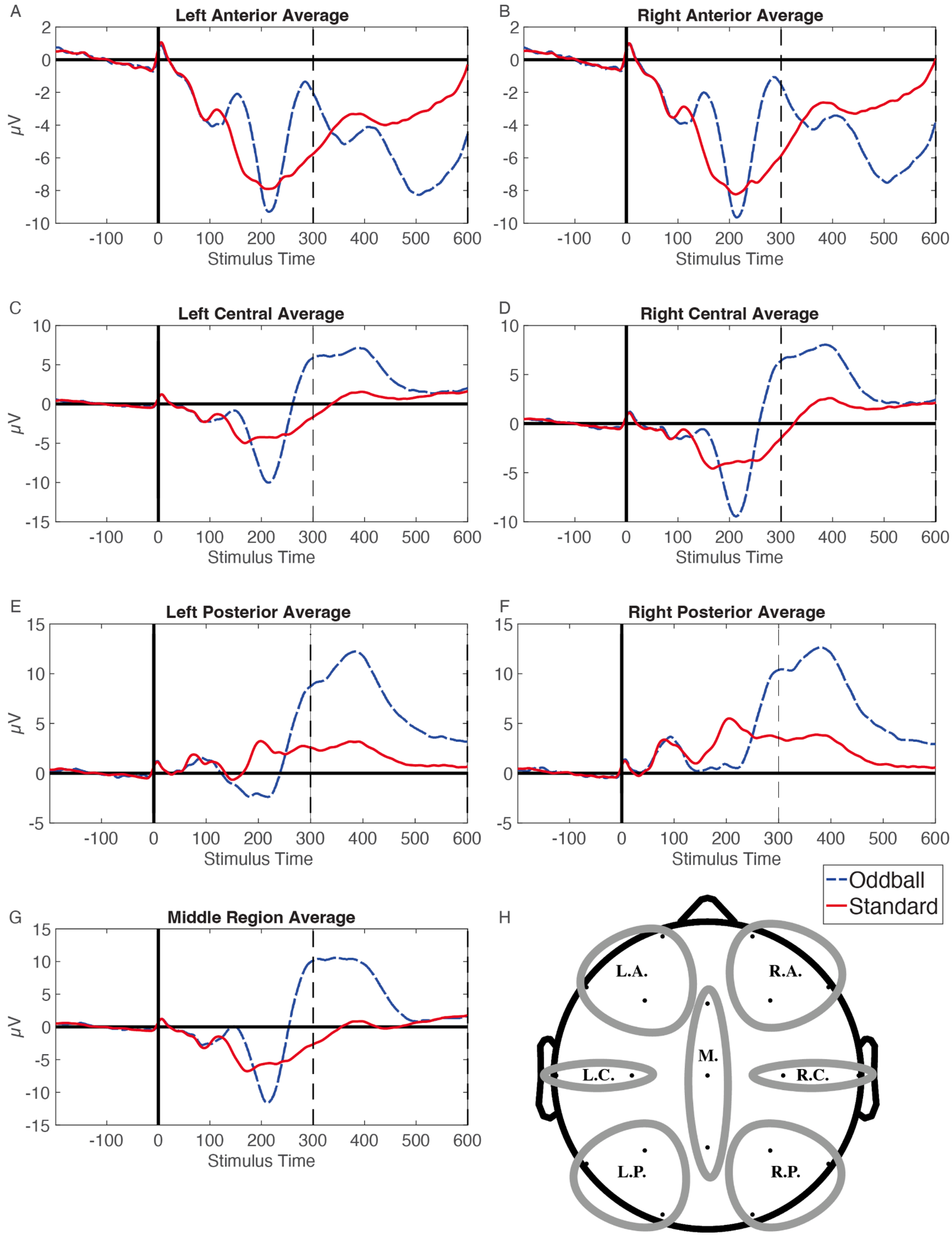

Fig. 2. A – G: ERP to audiovisual oddball (blue/dashed line) and standard (red/solid line) stimuli for each of the 7 electrode regions. H: Electrode locations and 7 regions: Left and Right anterior (L.A. and R.A.), Left and Right Central (L.C. and R.C.), Left and Right Posterior (L.P. and R.P.), and Midline (M;). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

P3b component, with the former reflecting novelty detection and the latter task-relevance. The P3b component in this case is thought to indicate the degree to which the stimulus is relevant. However, no significant relationship was observed between the P3b ERP and divergent thinking nor real life creative assessment in their study.

The capability of the present study to detect a relationship between creativity and the P300 ERP component may be attributed to the type of oddball paradigm used in this study. As previously mentioned, Zabelina & Ganis (2018) used an active, 3-stimulus oddball paradigm requiring increased executive functioning. This paradigm is well-suited for examining relationships between creativity and attentional control, but may not be as suitable for detecting relationships between creativity and salience processing of novel stimuli.

On the other hand, the 2-stimulus oddball task used in the present study has long been traditionally used to study P300 amplitudes (Polich, 1991; Polich & Herbst, 2000; for *meta*-analysis, see Bramon et al., 2004). While comparisons between the 3-stimulus and standard 3-stimulus oddball paradigms have revealed comparable P300 amplitudes

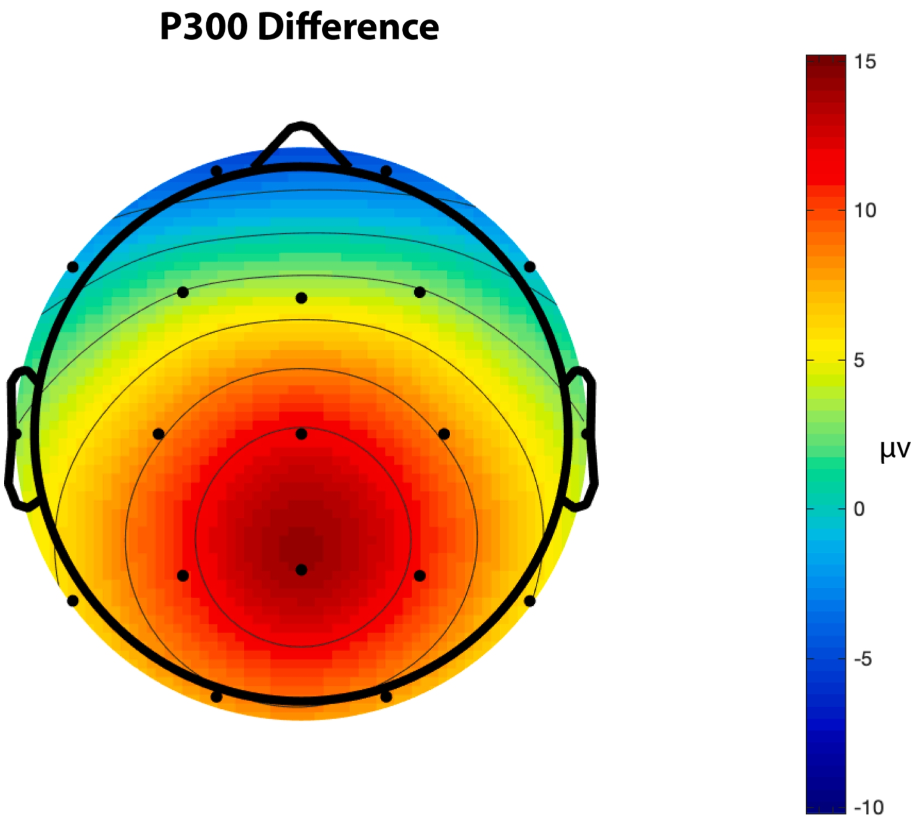

Fig. 3. Topographical plot of event-related potential difference (audiovisual oddball − standard) between 320ms and 420ms post-stimulus. The distribution and magnitude of the difference is consistent with the P300 oddball response, showing a large positive deflection in central parietal and occipital electrodes for the oddball compared to the standard stimulus.

Table 2
Mean P300 difference in electrode regions predicting creativity.

DV	IV	B	SE		P
Creativity					
	Left Anterior	−0.103	0.069	−0.590	0.142
	Left Central	0.124	0.096	0.575	0.202
	Left Posterior	0.028	0.098	0.144	0.780
	Midline	−0.093	0.045	−0.694	0.046*
	Right Anterior	0.061	0.074	0.345	0.413
	Right Central	0.129	0.088	0.623	0.148
	Right Posterior	−0.142	0.103	−0.719	0.177

Note. * indicates $p < .05$.

(Katayama & Polich, 1996) some research suggests the 2-stimulus paradigm may be better suited for detecting differences between groups, particularly in clinical contexts (Polich, 1998; Katayama & Polich, 1996) as the two paradigms have been shown to elicit different P300 latencies (Katayama & Polich, 1996). Furthermore, the challenging 3-stimulus variation may be problematic for detecting salience based differences as increased task difficulty has been found to affect P300 amplitudes (Hagen et al., 2006) which may make it more difficult to obtain between subjects differences. Indeed, the difference in P300 amplitude between patients and controls has been found to be greatest when task difficulty is lowest (e.g. in Alzheimers patients, Polich & Corey-Bloom, 2005). A recent *meta*-analysis comparing P300 amplitudes

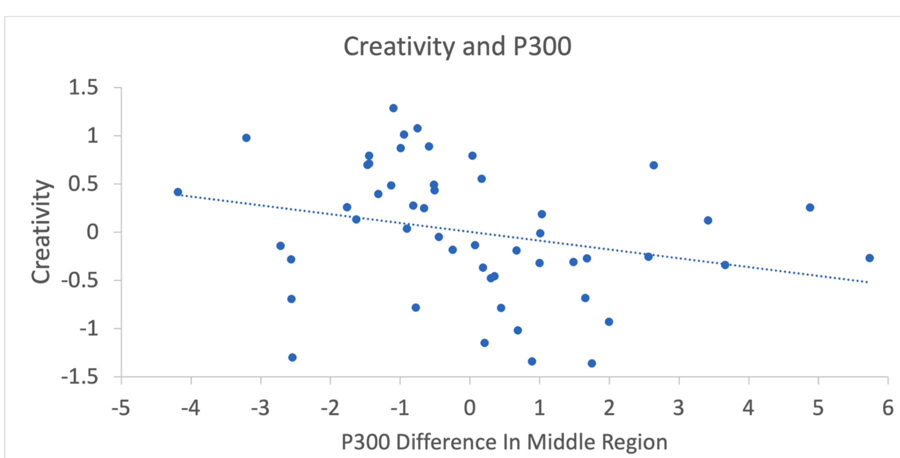

Fig. 4. The relationship between Creativity and P300 difference in Midline electrodes.

Table 3
Mean P300 difference in electrode regions predicting creativity.

DV	IV	B	SE		*P*
Artistic Talent					
	Left Anterior	0.093	0.052	0.750	0.234
	Left Central	−0.077	0.072	−0.498	0.879
	Left Posterior	0.113	0.074	0.831	0.396
	Midline	0.021	0.034	0.216	1
	Right Anterior	−0.073	0.056	−0.580	0.579
	Right Central	0.002	0.066	0.015	1
	Right Posterior	−0.050	0.077	−0.356	1
Abstractness of Title	IV	B	SE		*P*
	Left Anterior	−0.088	0.129	−0.279	1
	Left Central	0.031	0.180	0.080	1
	Left Posterior	−0.501	0.184	−1.437	0.03*
	Midline	0.090	0.085	0.370	0.885
	Right Anterior	0.133	0.139	0.411	1
	Right Central	−0.265	0.164	−0.706	0.339
	Right Posterior	0.505	0.193	1.412	0.036*
Effort	IV	B	SE		*P*
	Left Anterior	−0.087	0.057	−0.630	0.411
	Left Central	0.058	0.080	0.337	1
	Left Posterior	−0.217	0.082	−1.433	0.033*
	Middle	0.042	0.038	0.399	0.804
	Right Anterior	0.071	0.062	0.506	0.765
	Right Central	−0.104	0.073	−0.634	0.486
	Right Posterior	0.194	0.086	1.242	0.087

Note. P values are adjusted for multiple comparisons. * indicates adjusted $p < .05$.

in ADHD patients to controls further found that the two-stimulus oddball paradigm had enough power to detect differences in P3b between groups, while the three-stimulus paradigm did not (e.g. ADHD vs controls; Cui et al., 2017).

Lastly, we used an audio-visual version of the oddball paradigm which has also been found to increase sensitivity in detecting P300 differences across individuals (Campanella et al., 2010; Campanella et al., 2012). Indeed, Campanella et al. (2010) demonstrated that differences in P300 amplitudes could not be detected between two groups that differed on subclinical dimensions (anxiety and depression) using a unimodal oddball task, while bimodal task allowed these differences to be detected. Our observed effects may therefore further support the merit of a two-stimulus, bimodal paradigm for detecting individual differences in salience processing.

The current findings may further suggest that some types of creativity, or creative contexts, require attentional control while others may be benefitted by a looser, or atypical, distribution of attention. Zablina & Ganis (2018) found evidence that divergent thinking, but not real life creative achievement, is associated with enhanced cognitive control. This finding was interpreted as supporting the theoretical notion that divergent thinking and real life creativity may characterize distinct attentional phenotypes– flexible versus leaky attention, respectively (Zabelina et al., 2016). Whereas divergent thinking, which has previously been related to intelligence (Batey et al., 2009; Nusbaum & Silvia, 2011), is associated with enhanced executive functioning and attentional flexibility, real life creativity may reflect the disinhibited, "leaky" attentional patterns previously linked with schizotypy (Zabelina et al., 2015).

The authors suggested that attentional flexibility may be of particular benefit for divergent thinking in laboratory tasks given that such tasks generally require time-pressured responses; participants are required to generate as many responses as possible within a very short time frame (2–3 min). Successful performance on these tasks therefore requires increased executive function, supporting focus and inhibition towards distraction. One important difference in our study, which may further explain the different pattern of results, is that a much larger time window (over three times) was allotted to participants to complete the creative drawing task. It is possible that our measure of creativity required less attentional control, instead being benefited by an atypical attention style. Future research should further differentiate attentional characteristics associated with different types of creativity and different creative contexts.

Given the growing prominence of the aberrant salience hypothesis for explaining the characteristics of schizophrenia spectrum disorder (Van Os, 2009), more recent studies are beginning to interpret the diminished oddball effect in schizotypes within an aberrant salience framework (Cortiñas et al., 2008; Bachiller et al., 2015). We propose an extension of this framework to creativity. In particular, we suggest that the current findings, as well as previously observed attentional patterns in creatives, may reflect differences in incentive salience processing. Study 1 offered suggestive evidence for atypical salience processing in creatives. In study 2, we continue this line of research by examining psychological indicators of salience processing in the context of reward.

3. Study 2

When information is imbued with salience it drives individuals towards that information, motivating them to attend to, think about, and act upon it. These processes are particularly relevant for driving approach behavior towards potential rewards. Indeed the aberrant salience hypothesis posits that motivational abnormalities observed in schizophrenia, as well as those scoring highly in schizotypy, are the result of disrupted salience attribution of rewarding information such that individuals over-attribute salience to non-pleasurable stimuli and under-attribute salience to pleasurable ones. This is reflected by a diminished correspondence between *liking* and *wanting*, wherein individuals are less motivated to pursue what has previously been experienced as rewarding (Li et al., 2020). We sought to test whether this reduced relationship between liking and wanting holds for individuals as a function of creativity as well. To examine this, associations between creativity and incentive salience processing were examined in the context of enjoyment (liking) and pursuit (wanting) of everyday rewards.

We further investigated the mediating role of positive spontaneous thoughts. Previous research supports the notion that positive spontaneous thoughts act as a psychological indicator of incentive salience by mediating the link between liking and wanting, thereby driving approach behavior (Rice & Fredrickson, 2017). Information that has previously been associated with rewards gets encoded along with cues associated with those rewards. These cues in turn influence attention and spontaneous thought content in order to catalyze goal-directed behavior (Klinger, 2013). Indeed, one of the reasons spontaneous thoughts tend to be meaningful or goal directed (Gross et al., 2021) may be to maximize approach behavior toward potential rewards.

The theory proposing that positive spontaneous thoughts can reflect incentive salience of information is relatively new; despite this it has already been tested in the context of schizotypy (Li et al., 2020). Li et al. (2020) found that individuals high in schizotypy show reduced relationships between reported positive emotions experienced during daily activities (i.e., liking), positive spontaneous thoughts about these activities, and the desire to pursue these activities (i.e., wanting). In line with this recent work, we predicted that creativity would similarly interact with enjoyment (i.e., liking) such that the association between liking and wanting, as well as the association between liking and positive spontaneous thoughts, would be diminished for individuals high in creativity, evidencing abnormal incentive salience processing.

3.1. Methods

3.1.1. Participants

After approval by the Institutional Review Board at University of California, Santa Barbara, 200 participants were recruited from Turk prime (cloudresearch.com). As the data for this study consists of nested responses (multiple responses per participant), sample size was calculated for the level one variable (i.e. participant level) of a multi-level regression. A sample size of 193 was computed using an a priori power analysis, assuming a small effect (.2), alpha of.05 and power of.80. We collected data from 200 participants to allow a buffer for post-data collection quality control exclusions (see Procedures 3.1.3).

Given data quality concerns using Amazon Mechanical Turk, several site features were utilized as inclusion criteria. This included: blocking duplicate IP addresses, blocking suspicious geocodes, verifying worker country location and only recruiting within the US, only including CloudResearch approved participants, and utilizing Turks Universal Exclude list. Furthermore, participant Turk workers needed between 95 and 100 % approval ratings for past studies ("hits") and must have completed between 0 and 500 studies in the past. As some participants on this site can complete 99 % of the survey but not enter the code to receive payment, data was collected for 210 participants. Of these, a final N of 198 (mean age: 35.83, 132 females) was included after the removal of participants who failed to pass the attention checks (see Procedures 3.1.3).

3.1.2. Design

The study used a one-sample, nested design, in which each participant reported their wanting, liking, and positive spontaneous thoughts regarding several potentially rewarding, everyday activities.

3.1.3. Measures

3.1.3.1. Creativity task. The Alternate Uses Task (AUT), a classic measure of divergent thinking (Guilford, 1967), was used to measure creativity. In this task, participants are asked to generate creative and original uses for an everyday object, in this case a cardboard box. Participants were given 2 min to complete the task.

3.1.3.2. Incentive salience paradigm. The incentive salience paradigm was borrowed from Rice & Fredrickson (2017). In this paradigm, participants are instructed to rate assorted everyday activities, which included being physically active, eating nutritious meals, commuting, learning something new, socializing, running errands, relaxing, doing chores, purchasing consumer goods, and caring for household members. For each activity, participants rated the following: frequency of spontaneous thoughts [about the activity] within the last 24 h, how positive the thoughts were, positive emotions experienced when engaging in the activities (on a scale of 1, *not at all*, or 7, *extremely* and a "not applicable" option), how much they want to do each activity in the next 24 h (on a scale of 0, *not at all*, to 10, *extremely*). As in the original study, positive spontaneous thoughts were operationalized as an indicator of incentive salience, while positive emotions reflect *liking* of rewarding activities, and how much participants reported wanting to engage in activities reflected *wanting.* Participants were also asked the general frequency of doing each activity (on a scale of 0, *never,* to 10, *everyday*) and levels of autonomy over each activity (on a scale of 0, *no autonomy*, to 10, *total autonomy*).

3.1.3.3. Schizotypy. Given previously observed relationships between schizotypy and abnormal incentive salience processing, the Magical Ideation Scale (MIS; Eckblad & Chapman, 1983) was included to control for schizotypy. The MIS is a 30-item, True/False measure capturing individuals' endorsement of paranormal ideas, experiences, and beliefs (e.g. "Some people can make me aware of them just by thinking about me"). The measure is often used as a measure of *positive schizotypy* and has recently been reported as retaining good internal consistency (Cronbach's $\alpha = 0.77$; Kállai et al., 2021).

3.1.4. Procedures

After providing informed consent, participants completed the incentive salience paradigm described above in which they rated everyday activities on a number of dimensions, including liking, wanting, positive spontaneous thoughts, frequency, and levels of autonomy. Participants then completed the Alternate Uses Task (AUT; Guilford, 1967). Following idea generation, they were asked to select their top three creative ideas (Benedek et al., 2012). They then completed the Magical Ideation Scale (MIS). The study took approximately 15 min to complete and participants were compensated at a rate of $1 per 10 min.

Various checks were used in order to screen bots and/or inattentive responders. For "check 1" participants were required to type the word *sandwich* into a text box in order to initially proceed with the study. Failing to pass this check resulted in immediate disqualification from the study [i.e. before study participation could begin]. Within the study itself, a second attention check ("check 2") was included which asked participants to choose the response option "extremely". Lastly, at the end of the study ("check 3"), within the demographic questions, participants were asked if there was any reason their data should not be included and were given the following response options: 1) Please exclude my data because I was distracted or had trouble paying attention, 2) Please exclude my data for some other reason, 3) Please exclude my data because I didn't answer some of the questions seriously, 4) Please exclude my data because something else affected my participation negatively, 5) Include my data. Only the last option was considered a viable option for passing this check. Four individuals failed to pass check 2 and seven failed to pass check 3.

The three best ideas selected by participants in the creativity task were rated independently by two trained research assistants based on the consensual assessment technique (Amabile, 1982). Inter-rater reliability was assessed using the following two indexes: the inter-class correlation and cronbach's alpha. A criterion of > .8 was necessary in order for the ratings to be averaged across raters. This resulted in one creativity variable: the averaged AUT scores (averaged over 6 scores: 3 ideas rated by 2 research assistants). The data was then analyzed using multilevel modeling given the nested nature of the data (multiple ratings for each activity nested within subjects). Participant ID was used as the level 2 cluster. All analyses were conducted in IBM SPSS statistical software, version 26.

3.2. Results

To examine the interactions between *creativity* and *liking* (i.e., positive emotions) a hierarchical linear model and a general build-up strategy was used (Heck et al., 2014; Tabachnick and Fidell, 2013). Starting with an intercept only model we examined whether the outcome variable, *wanting* (i.e., desire to pursue the activity), differed across individuals. A second model was then run adding in the level-1 predictors (*liking* and *positive spontaneous thoughts*, and covariates *autonomy* and *general frequency of activity*). Finally, a third model was run including level 2 predictors (the individual difference measures *creativity* and *schizotypy*, with the latter included as a covariate) to examine interactions between *creativity* and *liking* in predicting *wanting.*

For the intercept-only model, *wanting* was added as a DV and a random intercept was included. Here it was observed that the fixed effect for the intercept of the outcome variable *wanting*– which reflects the grand mean of the intercepts across individuals – was 5.04 (range: 1–10). The estimates of covariance parameters revealed that the within-group variance in *wanting* was $\sigma^2_W = 11.61, p < .001$, while the between-group variance (reflecting variation in intercepts, which are simply the group means on the dependent variable) was $\sigma^2_B = 1.29, p < .001$. Based on the results of the Wald Z tests, both the within group variance component (Wald $Z = 44.69, p < .001$) and the between-group variance component (Wald Z 5.08, $p < .00$) were statistically significant indicating clustering effects in the data, i.e. individual differences effects. The intraclass correlation coefficient was calculated as ICC = .10 indicating a non-trivial amount of non-independence in the outcome variable. Collectively, then, the intercept-only model revealed a significant proportion of variation in *wanting* is explained by the grouping level, justifying further examination with the level 2 predictors. AIC (Akaike's Information Criterion) for this model was 10169.1 and BIC (Bayesian Criterion) was 10180.2.

Next, the level 1 predictors (*liking* and *positive spontaneous thoughts*) and covariates (*autonomy* and *general frequency*) were added to the model. These variables were centered-within context (group mean centered). Here a significant positive association was observed between both of the predictor variables – *liking* and *positive spontaneous thoughts*– and *wanting* such that, within a participant, activities that were rated as eliciting positive emotions (i.e. higher *liking*), and activities that were rated as eliciting *positive spontaneous thoughts*, were associated with a stronger desire to engage in the given activity (i.e. higher *wanting*); see Table 4.

The between-group variance, representing variation in intercepts, remained statistically significant, $\beta = 2.03$, $p < .001$. Furthermore, the ICC was lowered to.688 indicating two points: 1) that the inclusion of the predictors accounted for some of the variance in *wanting* between individuals, and 2) non-trivial variation in wanting between individuals, with respect to the intercepts, remains.

Next, *creativity* was added as a level 2 predictor, along with the level 2 versions of the predictors, i.e. the participant averages for *liking* (i.e., positive emotions), as well as the covariate's *autonomy* and *general frequency*, see Table 5. Random intercepts of participants and random slopes for *liking* were included in the model.

Here a main effect of *liking* (i.e., positive emotions) on *wanting* to engage in the activities, at both the within-subject and between-subject level, was observed, as well as a significant main effect of creativity on *wanting* to pursue activities, such that creative individuals tend to exhibit higher overall desire to engage in activities. The AIC, which represents model fit with an adjustment for model complexity, was used to examine changes in model fit. The AIC for this model was 7490.68, a reduction from 10169.07 for the intercept-only model and 8021.49 for the previous model containing only fixed effects; thus indicating an improvement in model fit with the addition of the random effects.

Critical to our hypothesis, however, was that the link between *liking* (i.e., positive emotions) and *wanting* (i.e., desire to pursue activity) would be moderated by *creativity* such that individuals high in *creativity* would exhibit a diminished relationship between these variables. To examine this, *creativity* along with its interaction with *liking* (within and between components) were added as predictors, see Table 6. Random intercepts of participants and random slopes of within-subject *liking* were included in the model.

Here it was observed that creativity moderated the relationship between *liking* (i.e., positive emotions) and *wanting* such that there was a diminished positive relationship between *wanting* and *liking* for higher creativity scores, $B(.076) = -.25$, $p = .001$, see Fig. 5. This suggests that creatives may under-attribute motivational salience (*wanting*) to pleasurable stimuli and/or over-attribute motivational salience to non-pleasurable stimuli.

Lastly, to examine the potential moderation of *liking* on *positive spontaneous thoughts* – the theorized concomitant of incentive salience – by creativity, a HLM was conducted with within-subject and between-subject *liking*, as well as the level 1 and level 2 versions of *autonomy* and *general frequency* (Table 7). Additionally, *creativity* along with its interaction with *liking* (between components) were added as predictors, and *positive spontaneous thoughts* was included as the outcome. Random intercepts of participants and random slopes of within-subject *liking* were included in the model. Here again we observe that the relationship between *liking* and *positive spontaneous thoughts* is diminished as a function of creativity, $B(.055) = -.11$, $p = .050$.

3.3. Discussion

Applying a psychological paradigm that has previously been used in schizotypy research, we explored differences in individuals' attribution of incentive salience to rewarding everyday activities as a function of creativity. We find evidence that creativity shows a distinct pattern of associations with the proposed components of the reward cycle – liking, wanting, and positive spontaneous thoughts – in several key respects.

First, creativity showed a main between-subjects effect on *wanting*, or the desire to engage in activities. Recall that modern neurobiological theory posits that dopamine mediates the assignment of motivational *wanting* by conferring stimuli with a property referred to as *incentive salience* (e.g., Berridge, 2012; Horvitz, 2000). Incentive salience attribution refers to the processes by which neutral stimuli become imbued with motivational relevance or value, thereby driving approach behavior and associated feelings of cognitive desire. Due to heightened dopaminergic activity (Chermahini & Hommel, 2010; de Manzano, Cervenka, Karabanov, Farde, & Ullen, 2010; Mayseless, Uzefovsky, Shalev, Ebstein, & Shamay-Tsoory, 2013; Reuter, Roth, Holve, & Hennig, 2006), creative individuals may exhibit a heightened propensity to confer incentive salience to information which in turn drives an increased motivational stance. In the current study, this is reflected by an overall increased drive to engage in potentially rewarding everyday activities.

In general, wanting co-occurs with liking– we tend to pursue what has previously been experienced as enjoyable; however dissociations between these components can occur (Berridge, 2017). Indeed, substantial research has shown that dopamine affects wanting, or the urge to pursue reward, independently of liking, or the hedonic impact of the reward (e.g. Ikemoto & Panksepp, 1999; Smith, Berridge & Aldridge, 2011; see Berridge, 2006 for review). If dopamine-driven abnormalities in incentive salience processes exist in creatives, we should not expect wanting to be tied to increased enjoyment or liking. In line with this, creatives exhibited diminished relationships between overall wanting and liking at the between-subjects level. This finding parallels existing schizophrenia-spectrum research revealing motivational abnormalities in reward-driven behavior. In particular, past research suggests an aberrant assignment of incentive salience such that individuals under-attribute salience to rewarding, pleasurable, or prominent cues, and over-attribute salience to non-rewarding, emotionally-neutral, or irrelevant cues.

At an individual difference level, creatives appear to exhibit an overall heightened motivation to pursue activities and rewards, and this drive is less reliant on the enjoyment – or hedonic pleasure – of those rewards. Much of human behavior is reward-driven, and therefore pleasure tends to act as a primary motivator for engagement in activities. For creative individuals, it is possible that the increased motivational drive, and diminished relationship between this drive and overall enjoyment in activities, may lead them to engage in more diverse

Table 4
Multilevel regression predicting *wanting* from the level 1 predictors.

Estimates of Fixed Effects	β(SE)	t	df	p	95 % CI	AIC	BIC
Outcome: wanting							
Intercept	4.96 (.11)	43.51	202.17	<.001	[4.74, 5.19]	8021.5	8032.4
Liking (within)	0.43 (0.0356)	12.10	1611.90	<.001	[.36,.50]		
Spontaneous positive thoughts (within)	0.59(0.031)	19.10	1610.45	<.001	[.53,.65]		
Autonomy (within)	.043(0.024)	1.76	1598.43	.078	[-.0048,.090]		
General Frequency (within)	0.097 (0.025)	3.88	1619.31	<.001	[.049,.15]		

Table 5
Multilevel regression predicting *wanting* from the level 1 and level 2 predictors.

Estimates of Fixed Effects	β(SE)	t	df	p	95 % CI	AIC	BIC
Outcome: wanting							
Intercept	1.88 (0.46)	4.080	1004.11	<.001	[.97, 2.78]	7490.7	7506.9
Liking (CWC)	0.96 (0.038	24.96	85.28	<.001	[.88. 1.03]		
General Frequency (CWC)	0.11 (0.030)	3.61	1637.62	<.001	[.050,.17]		
Autonomy (CWC)	0.041 (0.030)	1.37	1656.89	0.171	[-.018,.099]		
Liking (mean)	0.60 (0.043)	13.97	1040.63	<.001	[.52,.68]		
General Frequency (mean)	−0.033 (0.047)	−0.71	1016.96	0.479	[-.13,.059]		
Autonomy (mean)	0.088 (0.034)	2.61	973.50	0.009	[.022,.15]		
Creativity (mean)	−0.24 (0.11)	−2.12	1031.80	0.034	[-.46, −.018]		

Table 6
Multilevel regression predicting *wanting* from the level 1 and level 2 predictors, and interactions.

Estimates of Fixed Effects	β(SE)	t	df	p	95 % CI	AIC	BIC
Outcome: wanting							
Intercept	−1.59 (1.17)	−1.36	1043.47	0.18	[-3.88,.071]	7490.8	7507.04
Liking (CWC)	0.96 (0.038)	25.080	88.26	<.001	[.88, 1.03]		
General Frequency (CWC)	0.11 (0.030)	3.72	1639.69	<.001	[.053,.17]		
Autonomy (CWC)	0.041 (0.030)	1.37	1657.33	0.17	[-.018,.099]		
Liking (mean)	1.17 (.18)	6.44	1062.11	<.001	[.81, 1.53]		
General Frequency (mean)	−0.036 (.047)	−0.77	1039.65	0.44	[-.13,.056]		
Autonomy (mean)	0.097 (.034)	2.88	995.31	0.004	[.031,.16]		
Creativity (mean)	1.22 (0.47)	2.62	1044.29	0.009	[.31, 2.14]		
Creativity*Liking (between)	−0.25 (.076)	−3.23	1060.25	0.001	−0.39, −.096]		
Creativity*Liking (within)	.0097(.051)	.19	1648.0	.85	−.091,.11]		

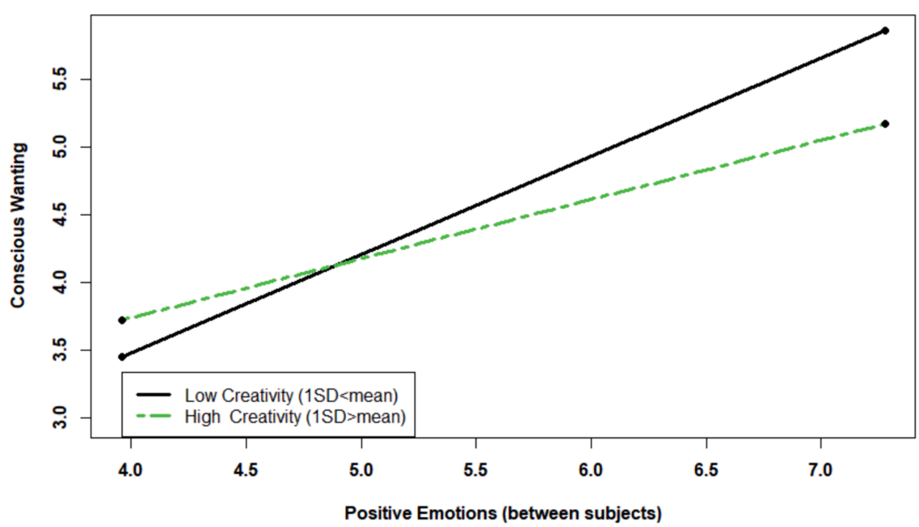

Fig. 5. Graph depicting the strength of the relationship between *liking* (i.e., positive emotions) and *wanting* as a function of *creativity* level.

Table 7
Multilevel regression predicting *positive spontaneous thoughts* from the level 1 and level 2 predictors, and interactions.

Estimates of Fixed Effects	β(SE)	t	df	p	95 % CI	AIC	BIC
Outcome: positive spontaneous thoughts							
Intercept	−1.21 (0.85)	−1.42	1666.0	.16	[-2.88,.47]	6869.3	6885.5
Liking (CWC)	.84(.095)	8.82	1666.0	<.001	[.65, 1.03]		
General Frequency (CWC)	.031(.022)	1.38	1666.0	.17	[-.013,.074]		
Autonomy (CWC)	.0083(.022)	.38	1666	.71	[-.034,.052]		
Liking (mean)	1.00(.13)	7.56	1666	<.001	[.74, 1.26]		
General Frequency (mean)	0.84 (.034)	2.46	1666	.014	[.017,.15]		
Autonomy (mean)	.061(.024)	2.50	1666	.012	[.013,.11]		
Creativity (mean)	.63(.34)	1.85	1666	.065	[-.039, 1.30]		
Creativity*Liking (between)	−.11(.055)	−1.96	1666	.049	[-.22, −.00]		
Creativity*Liking (within)	.0053(.038)	.14	1666	.89	[-.070,.080]		

behaviors. However, future research is necessary to determine possible implications of these findings for creatives.

On the other hand, the link between individuals' desire to pursue activities and to enjoy activities was preserved at the within-subjects level; creatives and non-creatives exhibited no difference in the strength of the relationship between *activity-specific* liking and wanting. While creative individuals seem to have a generally stronger motivation to try out different activities that could be rewarding, once they start an activity, experiencing more enjoyment from it will increase their desire to continue or repeat that particular activity or experience.

Our findings further revealed that creativity predicts greater positive spontaneous thoughts, a proposed indicator of incentive salience (Rice & Fredrickson, 2017). Past research using the current paradigm found that positive spontaneous thoughts mediate the relationship between liking and wanting (Rice & Fredrickson, 2017). This finding was interpreted as support for the hypothesis that positive spontaneous thoughts may act as an indicator of incentive salience, reflecting an individual's interests and motivating them to seek out stimuli and experiences related to those interests. The processing of salient and rewarding stimuli is integral to engaging our attention, stimulating anticipation for future events, and driving goal-directed behaviors. Together these processes reflect deeper processing of important stimuli relative to neutral or non-rewarding stimuli. Indeed, research on spontaneous thought indicates that the content of thought reflects current concerns and interests (Klinger & Cox, 2004), while a primary function of spontaneous thoughts has long been associated with goal pursuit (Stawarczyk et al., 2011). Information previously experienced as rewarding, and thus assigned a high degree of salience, is more likely to be processed deeply and linger in individuals' thoughts (Bellana et al., 2022) playing a role in driving further thought and goal directed behavior. Similarly to the effect observed for wanting, the main effect of creativity on positive spontaneous thoughts may then be interpreted as reflecting creative individuals' heightened predisposition for incentive salience attribution, which in turn drives them to think about and pursue a greater number of reward related activities.

These patterns of results differ from the previously observed relationships for schizotypy. As observed in the current study, although there is a generally increased motivational desire towards everyday rewarding activities, the ability to selectively reinforce activities that elicit greater pleasure is preserved in creatives; on the other hand, schizotypes were previously found to show a diminished desire to pursue activities experienced as rewarding, as indicated by the reduced relationship between wanting and liking at the within-subjects level (Li et al., 2020). Li et al. (2020) also did not find a relationship between schizotypy and overall wanting or positive spontaneous thoughts (Li et al., 2020), indicating that individuals high in this trait do not exhibit increased motivational drive to pursue potentially rewarding activities. Creatives may therefore exhibit a distinct pattern of salience processing that does not include the non-adaptive patterns characterizing reward processing in schizotypes.

Creativity may instead be associated with a sensitivity to potential reward opportunities revealed through broad, or exploratory, approach behavior. This pattern parallels past research in the domain of curiosity suggesting that increased functioning of incentive salience processes, resulting from an increased sensitivity to the reward value of information, confers an enhanced motivational desire for information-seeking in turn driving increased exploration and novelty seeking (e.g. Lau et al., 2018). This pattern is also consistent with a substantial basis of research on dopamine function suggesting a central role for dopamine in driving motivated, engaged, and exploratory behaviors (e.g. Panksepp, 1998; Kaasinen et al., 2004) as well as research revealing a role for dopamine in encoding the context and behaviors associated with potentially rewarding outputs (Redgrave & Gurney, 2006).

4. General discussion

To the best of our knowledge, these studies represent the first empirical attempts to directly extend considerations of incentive salience to creativity. Two very different paradigms were used in order to establish converging evidence for atypical incentive salience attribution, providing both neurological and psychological evidence, while examining salience processing both in the context of novelty and reward. Across both studies we find evidence that creativity is related to a distinct pattern of incentive salience processing. In study 1, we observe a diminished neural response in a passive oddball task. This indicates that the context-specific attribution of salience to novel information is diminished for individuals high in creativity, a result that parallels findings in schizotypy research. In study 2, we extend this line of research by examining another modality of incentive salience processing; enjoyment and pursuit of everyday rewards. Here we again find further preliminary evidence for atypical incentive salience processing in creatives, however the pattern differs to the previously observed relationships in schizotypy.

In study 1, the neural consequences of atypical salience processing were considered. We find that creatives show a diminished P300 ERP response to the oddball, suggesting characteristic differences in novelty processing. Extending the theoretical framework outlining aberrant salience in schizotypes (Kapur, 2003; Van Os, 2009), this finding can be interpreted as atypical salience processing, specifically an under-attribution of salience to the prominent, oddball stimuli. In the oddball paradigm, stimuli that are less common typically elicit a larger P300; however the reduced response to the oddball suggests that creative individuals do not update their priors in a context-specific manner to the same degree that non-creative individuals do (Donchin & Coles, 1998; Polich, 2007). This results in an under-attribution of salience to the novel stimuli.

The tendency to under-attribute salience could be beneficial for creative performance, particularly when salient, context-specific information overpowers attention leading to fixation. Consider prevalent creativity tasks that measure creative thinking through the occurrence of insights (e.g. Lin et al., 2012; Fleck & Weisberg, 2013) or the generation of uncommon ideas (Cortes et al., 2019). In these paradigms individuals are instructed to generate novel ideas, or ideas that are not obvious within the context of the problem. Less creative individuals often exhibit functional fixedness in which they are unable to direct attention away from the prepotent features of the problem space in order to come up with original ideas (Storm & Angello, 2010). By under-attributing salience to prominent, context-specific features of the problem space, creatives may be better able to think "outside the box" – to notice other, less (normatively) salient features of the problem – leading to creative solutions.

Creativity has also been associated with an over-attribution of salience to information that is typically ignored or overlooked. For example, past research has found that creatives do not dampen the salience of information to which they have previously been exposed (Carson, 2010; Carson et al., 2003), i.e., reduced latent inhibition. Latent inhibition occurs when information that has previously been learned as irrelevant draws less attention over time. However, creatives do not show this effect to the same degree; information that typically becomes less salient over time will remain salient for creatives. Collectively, these findings suggest that creatives may display atypical salience processing in both directions, an under-attribution of normatively salient information and an over-attribution of information that is typically ignored.

Given the novelty of approaching the characteristic attentional and motivational phenomena in creatives through the lens of salience processing, more research is necessary to understand the particular characteristics of atypical salience processing in creatives. The findings from study 1 suggest that at least in some respects salience processing in creatives resembles patterns previously described in schizophrenia-spectrum literature as *aberrant salience* (Kapur, 2003). However, in study 2, we find that creativity is characterized by a distinct pattern of associations to liking, wanting, and thinking about everyday rewards as compared to schizotypes, suggesting that the pattern of salience processing associated with creativity may have different characteristics or play out in different contexts.

Study 1 and study 2 differed in that they entailed different types of salient information: the first entailed processing of *novel* information, while the second entailed processing of *rewarding* information. The results from these two studies raise the possibility that atypical salience processing in creatives is particularly related to the processing of novel, rather than rewarding, information. Neuroscientific evidence suggests that the circuitry responsible for processing rewarding and novel information is linked; a functional interpretation of this link is that novelty acts to motivate exploration of potential rewards (Bunzeck et al., 2011). It is possible that disrupted novelty processing in creatives may enhance motivation to pursue potential rewards by flagging unusual, or at times neutral, information as novel. This would help explain why we see both aberrant salience processing in study 1 and enhanced motivation to pursue potential rewards in study 2. Furthermore, aberrant novelty detection may play a particularly important role in creative idea generation, given that creativity is typically defined as the ability to generate novel ideas.

Future research should further investigate the relationship between schizotypy-related personality types and oddball processing. While this study focused on the P300 component (P3b) using a 2-stimulus oddball paradigm, it's crucial to acknowledge that different variations of the oddball task can yield diverse outcomes. Additionally, evidence suggests that schizophrenia-spectrum conditions may predict abnormalities in other aspects of the oddball signature. Future studies should explore alternative oddball task variants (e.g., 3-stimulus oddball) to assess additional ERP components (e.g., N200, P3a). These efforts will enhance our understanding of potential overlaps between non-clinical traits, such as creativity, and the underlying mechanisms of schizotypal symptoms. Despite the benefits proposed by multimodal paradigms in prior research (Campanella et al., 2010; Campanella et al., 2012), it's important for future studies to replicate these findings using more conventional oddball variants, particularly those based on auditory stimuli only.

A long and growing foundation of theoretical work has attempted to specify the diverse ways in which dopamine may impact personality characteristics (Gray, 1973; Panksepp, 1998; Smillie & Wacker, 2014; DeYoung, 2013). Although existing models need to be further tested and specified, it is clear that the central role that dopamine plays in attentional and motivational processes likely has a profound role in shaping thought and behavior– overarching regularities that form the basis of an individual's personality. The current paper extends existing personality frameworks by considering the role that dopamine plays in the attribution of motivational salience. This particular role has been considered at length in schizophrenia spectrum research, and, more recently, in the domain of curiosity. Here we consider how incentive salience processes may play out in creatives. We find a distinct phenotype of salience processing that in part resembles schizotypy– as reflected by aberrant processing of salient information in study 1– and may in part resemble curious traits – as reflected by a heightened attribution of incentive salience to potential rewards. We hope these initial findings inspire further research to examine trait-like variation in incentive salience processing and, in particular, how such differences impact creative ability.

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CRediT authorship contribution statement

Madeleine E. Gross: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. **James C. Elliott:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing – review & editing. **Jonathan W. Schooler:** Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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