The relationships among aberrant salience, reward motivation, and reward sensitivity

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Abstract

Objectives: Change in reward processing and motivation may mediate the relationship between dopaminergic dysregulation and positive symptoms of schizophrenia. We sought to investigate the measurement of aberrant salience and its relationship with behavioural measures of reward and motivation.

Methods: Participants ($n = 82$) completed measures of aberrant salience (Aberrant Salience Inventory and Salience Attribution Task), motivation (Effort Expenditure for Rewards Task), and reinforcer sensitivity (Stimulus Chase Task). Hypotheses were tested using correlation and generalised linear modelling.

Results: Results indicated no relationship between aberrant salience measures. The Aberrant Salience Inventory was positively related to effort expenditure for lower less likely rewards and predicted the use of probability alone in decision-making. The only significant relationship between reward and motivation was a positive relationship between gain sensitivity and motivated behaviour for higher more likely rewards.

Conclusions: Although some support for a relationship between measures of reward motivation and aberrant salience were found, there was no evidence that the aberrant salience measures had concurrent validity. Our results suggest caution is warranted when interpreting measures of aberrant salience.

KEYWORDS

psychometrics, reward processing, schizophrenia, schizotypy, validity

1 | INTRODUCTION

Dysregulation of the neurotransmitter dopamine has long been linked with the symptoms of schizophrenia. One prominent hypothesis on the role of dopamine in the development of symptoms is that of aberrant salience. According to Kapur (2003), dopaminergic dysregulation leads to the aberrant assignment of importance to, or salience of, external objects, and internal representations, such as thoughts. In turn, many of the consequent epiphenomena, or subjective experiences, require explanation in order to make sense of the world (Howes & Nour, 2016; Kapur, 2003). These experiences and concomitant explanations constitute the positive symptoms of psychosis. Although not fully understood, many regard the reward system and motivation as key mediators in the link between dopaminergic dysregulation and psychosis (Kapur, 2003).

Dopaminergic firing is associated with processing of reward-related stimuli (Bromberg-Martin, Matsumoto, & Hikosaka, 2011; Zhang, Doyon, Clark, Phillips, & Dani, 2009; Zweifel et al., 2009). It is critical in the evaluation of appetitive (Balconi & Crivelli, 2010; Jahn, Nee, Alexander, & Brown, 2014; McNaughton, 2004; Salamone, Correa, Mingote, & Weber, 2005; Salamone, Cousins, & Snyder, 1997; Wardle, Treadway, Mayo, Zald, & Wit, 2011) and aversive (Matsumoto & Hikosaka, 2009) stimuli and is involved in the production of motivated behaviour, as seen in reward-based learning paradigms. For example, sensitivity to reward or punishment (or reinforcer sensitivity; Corr & McNaughton, 2012) has been shown to influence motivated behaviour (Cooper, Duke, Pickering, & Smillie, 2014; Unger, Heintz, & Kray, 2012). Contextual factors have also been implicated in motivated behaviour. Motivated behaviour is influenced by the likelihood and magnitude of associated reward (Sambrook &

Goslin, 2015; Schultz, 2010), whether gain or loss is immediate or delayed (Berridge, 2013; Smith et al., 2015), and how much effort is required for a reward (Bardgett, Depenbrock, Downs, Points, & Green, 2009; Salamone & Correa, 2002).

Schizophrenia is associated with anomalous reward-related behaviour and cognitive differences in reward processing, especially when tasks require adaptation to changing stimuli or value assessments. Differences include an impaired ability to adapt learning strategies based on changing contingencies (Waltz & Gold, 2007), greater sensitivity to loss (Scholten, van Honk, Aleman, & Kahn, 2006), and a preference for smaller, more immediate rewards over larger, delayed rewards (Heerey, Robinson, McMahon, & Gold, 2007). Behavioural differences include reduced willingness to expend effort for reward (Green & Horan, 2015; Reddy et al., 2015), especially for larger, more likely rewards (Barch, Treadway, & Schoen, 2014; Fervaha et al., 2013; Gold et al., 2013), and an increased willingness to expend effort on low-incentive outcomes (Fervaha, Graff-Guerrero, et al., 2013). The difference in behaviour across high and low incentive scenarios may indicate impairments in effort-cost computation in schizophrenia (Fervaha, Graff-Guerrero, et al., 2013; Gold et al., 2013).

However, several limitations affect this literature. First, there is little if any research into if, or how, factors contributing to motivated behaviour relate to aberrant salience. Second, although some evidence has emerged consistent with the aberrant salience hypothesis of schizophrenia (Haralanova, Haralantov, Beraldi, Moller, & Hennig-Fast, 2012; Jensen et al., 2008; Micoulaud-Franchi et al., 2012), findings are inconsistent. For example, although increased aberrant salience has been found in schizophrenia (Pankow et al., 2015) and those at risk of psychosis (Cicero, Kerns, & McCarthy, 2010), other findings indicate no significant difference compared with unaffected individuals (Ceaser & Barch, 2016; Roiser et al., 2009). Third, there is a dearth of evidence that diverse measures of aberrant salience do, indeed, measure the same thing or relate to well-grounded measures of reinforcer sensitivity. Before discrepancies in schizophrenia research can be understood, it is important to ascertain the validity of aberrant salience measures in unaffected individuals. Therefore, our aim was to investigate the relationships among measures of aberrant salience, effort expenditure, and reinforcer sensitivity to better understand the construct validity of two prominent tests of aberrant salience: The Salience Attribution Test (SAT; Roiser et al., 2009) and the Aberrant Salience Inventory (ASI; Cicero et al., 2010).

The SAT is a computerised task that yields measures of implicit and explicit aberrant and adaptive salience. Implicit salience is inferred from response time differences across task conditions whereas explicit salience is based on awareness of predictors of reward. The ASI is a self-report measure of subjective experiences and beliefs attributed to aberrant salience. ASI scores correlate with psychotic experiences (Lelli et al., 2015). Patients with schizophrenia and those identified as at-risk of psychosis have higher ASI ratings than control participants (Cicero et al., 2010).

Performance on the SAT and ASI was compared with that on the Effort-Expenditure for Rewards Task (EEfRT; Treadway, Buckholtz, Schwartzman, Lambert, & Zald, 2009) and the Stimulus Chase Task (SCT; Hall, Chong, McNaughton, & Corr, 2011). The EEfRT is a measure of decision-making under conditions of differential effort

expenditure and differential outcome potentials. Those with schizophrenia choose hard tasks less often than unaffected individuals (Green, Horan, Barch, & Gold, 2015), especially when the value and likelihood of rewards are higher (Fervaha, Graff-Guerrero, et al., 2013; Gold et al., 2013; Reddy et al., 2015). However, when reward value and likelihood are low, patients choose hard tasks more often (Brown et al., 2013; Fervaha, Graff-Guerrero, et al., 2013).

The SCT is grounded in reinforcer sensitivity theory (Corr, 2001; Gray & McNaughton, 2000; McNaughton & Corr, 2004), which explains variations in goal-directed behaviour in terms of the sensitivity of approach, avoidance, and conflict resolution systems (McNaughton & Corr, 2014). The SCT provides indices of sensitivity of the responder to gain and loss outcomes under different conditions of approach and avoidance (Hall et al., 2011). Previous research using SCT indicates that individuals tend to exhibit loss aversion and a stronger approach than avoidance tendency (Hall et al., 2011).

We hypothesised that measures of aberrant salience would be positively correlated with each other, negatively related to effort in high-reward high-probability scenarios, and positively related to effort in low-reward low-probability scenarios. Given evidence of higher sensitivity to loss in schizophrenia (Scholten et al., 2006), it was hypothesised that aberrant salience would predict an increase in sensitivity to loss relative to sensitivity to gain. We also expected that effort expenditure would predict greater approach versus avoidance tendencies under conditions of high-reward likelihood and value but predict greater gain sensitivity under conditions of low-reward likelihood and value.

2 | METHODS

2.1 | Participants

Undergraduates ($n = 82$) in introductory courses on psychology volunteered as participants. For large effects in correlational analysis ($r = 0.50$) where $\alpha = 0.05$, a sample of 82 affords power of >0.99 . Participants were aged 17 to 57 years ($M = 20.0$, $SD = 5.7$) and most were female (68%). Most participants identified as New Zealand European (71%) with smaller numbers identifying as Māori (6%) or other ethnic identity (23%). Having completed participation, volunteers could earn a small amount of course credit based on assessment of learning about the study. Participants provided written informed consent. The study was approved by the University of Otago Human Ethics Committee (Health).

2.2 | Measures

2.2.1 | ASI

The ASI (Cicero et al., 2010) was used as an orally-administered self-report measure of aberrant salience. The ASI contains 29 questions, each requiring a yes or no response in reference to lifetime experiences. Respondents are directed to ignore experiences that occurred under the influence of drugs or alcohol. The ASI yields a single score calculated as number of yes responses. ASI shows high internal consistency ($\alpha = 0.89$; Cicero et al., 2010; Lelli et al., 2015) and test-retest reliability (0.96 over 15 days; Lelli et al., 2015).

2.2.2 | EEfRT

The EEfRT (Treadway et al., 2009) is a computerised performance task that uses decision-making as a measure of motivation. The EEfRT consists of a series of trials in which the respondent must choose between undertaking a hard and an easy task, each of which is associated with different reward values. At the start of each trial, participants are advised the probability of winning (12%, 50%, or 88%) and the amount of reward for the decision alternatives. They are then to choose to complete either the easy or hard task. The easy task reward is set at \$1 and requires participants to complete 30 button presses with the dominant index finger within 7s. The hard task reward varies between \$1.24 and \$4.30 and requires participants to complete 100 button presses with the nondominant little finger within 21s. Feedback at the end of each trial advises whether money was available for that trial and how much won.

The task runs for 20 minutes so the number of trials undertaken depends on the proportion of hard- versus easy-task decisions. For each trial, the probability of reinforcement and the reward value for the hard task vary. Over the task, the probabilities of reinforcement are equalised, with each possible combination of probability and reward value occurring at least once. The dependent variable is task choice.

Factor analysis of data collected from 94 schizophrenia patients on five motivational effort paradigms, including the EEfRT, revealed a single factor explained 53% of observed variance. The correlation between the factor score and EEfRT reward magnitude was strong ($r = 0.66$; Horan et al., 2015).

2.2.3 | SAT

The SAT (Roiser et al., 2009) is a computerised learning paradigm that uses stimulus reinforcement to assess implicit and explicit aberrant and adaptive salience. The task consists of two 64-trial blocks. In each trial, a fixation cross appears centre screen. Then, after 1,000 ms, a line drawing of an object or animal appears in duplicate, centred above and below the fixation cross. A black box then replaces the fixation cross and participants are required to press a button as soon as the black box appears but before it disappears. After each trial, auditory and visual feedback indicate whether the trial was reinforced and the amount of money earned.

Participants are advised that reward is probabilistically related to the stimulus type whereas speed of response determines the amount of money that can be earned (between 10¢ and \$1). Participants are assigned one of four possible contingencies that remain consistent throughout the task. The contingencies are whether the dimension of colour (red or blue) or shape (household object or animal) of the picture is relevant. For the task relevant dimension, one level (e.g., household object) has a high probability (87.5%) of being reinforced whereas the other (e.g., animal) has a low probability (12.5%). For the task irrelevant dimension, both levels (e.g., blue and red) have a 50% probability of being reinforced. Participants are instructed to try and identify which dimension yields the highest probability of reward. After each trial block, participants complete a visual analogue scale indicating how often (%) they believed each dimension was reinforced.

SAT output for each participant includes single measures for explicit and implicit adaptive salience and aberrant salience. Implicit salience is measured using response time (ms) whereas explicit salience is measured using a visual analogue scale rating (mm). Adaptive salience is calculated as the difference between mean response time for low (10%; e.g., household object) versus high (90%; e.g., animal) reinforcement probability trials whereas aberrant salience was calculated as the absolute difference in mean response time between the two task-irrelevant dimensions (e.g., blue and red; Roiser et al., 2009).

In unaffected individuals, the SAT shows good discriminant validity. Implicit aberrant salience was independent of learned irrelevance, reinforcement sensitivity, working memory, and probabilistic learning (Schmidt & Roiser, 2009). Although explicit measures were related to operant learning, explicit aberrant salience was not associated with schizotypy (Schmidt & Roiser, 2009).

2.2.4 | SCT

The SCT (Hall et al., 2011) is a computerised task that uses reinforcement to assess relative sensitivity to gain and loss and relative tendency to engage in approach and avoidance behaviour. In each of two phases of the task, participants start with a balance of \$180 and are advised how much they can gain or lose at the start of each trial, with the probability of gain or loss fixed at 50%. The value of gain and loss is manipulated in increments of two between eight and zero. For example, in Block 1 the gain and loss amounts are +\$8 and -\$8; Block 2 +\$8 and -\$6; Block 5 +\$8 and -\$0; Block 11 +\$6 and -\$8; and Block 12 +\$8 and -\$8. Each block consists of five trials. With 50 blocks per phase, each incremental gain and loss value combinations are presented in two blocks (10 trials) in both phases. In Phase 1, participants must click on the blue box (approach behaviour) to take a chance on gaining or losing the stated values whereas choosing not to click (avoid behaviour) will incur no change in balance. In Phase 2, avoidance behaviour (not clicking) instigates the chance of winning or losing whereas approach behaviour leads to no change in balance. Feedback is provided by a change in the colour of the blue box (to red for loss, green for gain, and grey for no change) and the balance, which is presented next to the box.

As with the SAT, the rationale underlying the SCT is that response time will vary with the value a respondent gives to a trial outcome (Hall et al., 2011). Behaviour on the SCT adheres to predictions based on the matching law (Hall et al., 2011). Therefore, the matching law is used to estimate gain:loss sensitivity and approach:avoidance tendency ratios, using modelling with the Microsoft® Excel Solver. Participants whose data does not conform to the matching law are excluded from further analysis.

2.3 | Procedure

Having provided written informed consent, participants completed a demographics questionnaire and the ASI followed by the three computerised tasks (EEfRT, SAT, and SCT). Computer tasks were administered in counterbalanced order across participants. Following completion of all the tasks, participants were debriefed, paid the money they won (\$4 = NZ\$1), and thanked for their time.

2.4 | Data analysis

For each participant, EEfRT effort was calculated as the proportion of hard task choices by dividing the number of hard task choices by the total number of trials (Treadway et al., 2009; Treadway & Zald, 2013; Wardle et al., 2011). The number of hard choices for each probability level, each reward magnitude ($\leq \$2$, $\$2$ to $\$3$, and $\geq \$3$), and each probability-magnitude combination was divided by number of corresponding trials. The estimated value was calculated by multiplying probability by reward magnitude to provide the proportion of small (<1), medium (≥ 1 and <2), and large (≥ 2) estimated values for hard task choices.

Mixed effects modelling was used to calculate group and individual beta coefficients for models of EEfRT decisions. Modelling included random intercepts and random slopes for reward magnitude, probability, and cross level reward magnitude $\times$ probability interactions. For each participant, beta coefficients for reward magnitude, probability, and their interaction were calculated then linear modelling was used to assess whether the effect of these variables on task choice during EEfRT was related to measures of ASI, SAT, and SCT. As assumptions of normality were not met, Kendall's tau was used for correlational analysis. Analysis was completed using the psych (Revelle, 2016) and lme4 (Bates, Maechler, Bolker, & Walker, 2015) packages in R (R Development Core Team, 2016) and Hmisc (Harrell Jr et al., 2016).

3 | RESULTS

Data from three participants were excluded from analyses because these participants demonstrated that they did not understand task requirements. Data from another four participants were excluded because of equipment failures. Table 1 shows the descriptive statistics from the key measures.

SCT measures of interest were overall gain:loss and approach:avoidance ratios, where a gain:loss ratio over one indicates reduced loss sensitivity and an approach:avoidance ratio over one indicates an approach tendency.

There was no evidence that ASI scores correlated with SAT indices of adaptive or aberrant salience, whether measured implicitly or explicitly, or with gain:loss or approach:avoidance ratios from the SCT (Table 2). No significant correlations were found between SCT ratios and SAT indices (Table 2). On the SAT, greater implicit aberrant salience predicted greater implicit adaptive salience. The relationships among ASI and SAT indices remained unchanged when analyses were restricted to those reporting no mental health issues ($n = 69$).

In the mixed effects modelling of EEfRT decisions, effort was predicted by the reward magnitude $\times$ probability interaction ($\beta = 1.89$, $z = 9.30$, $p < .001$; Figures 1 and 2) but not by reward magnitude ($\beta = 0.04$, $z = 0.30$, $p = .77$) or probability ($\beta = -1.15$, $z = -1.90$, $p = .06$).

Table 2 shows the correlation between measures of aberrant salience, effort, and SCT. There was a positive relationship between ASI ratings and effort at each level of the EEfRT variables except low probability. ASI positively correlated with effort for lower more likely rewards, higher less likely rewards, and with all reward magnitudes when the likelihood of winning was 50%. There was a negative

TABLE 1 Demographic variables for ASI, SAT, EEfRT, and SCT indices

Demographic	ASI, SAT, and EEfRT (N = 82)	SCT (N = 55)
Gender N (%)		
Female	56 (68)	36 (65)
Male	26 (32)	19 (35)
Age in years M (SD)	20 (5.71)	20 (5.29)
Ethnicity N (%)		
NZ European	58 (71)	43 (78)
Maori	5 (6)	3 (5)
Other	19 (23)	9 (16)
Currently Employed N (%)	12 (15)	10 (18)
Household income N (%)		
>200 k	8 (10)	5 (9)
101–150	23 (28)	15 (27)
76–100 k	20 (24)	15 (27)
51–75 k	14 (17)	12 (21)
26–50 k	7 (9)	4 (7)
<25 k	1 (1)	—
Mental health diagnosis N (%)	12 (15)	9 (16)
Depression	4 (5)	4 (7)
Anxiety disorder	3 (4)	2 (4)
Depression and anxiety	2 (2)	2 (4)
Eating disorder	1 (1)	—
Other	2 (2)	1 (2)

Note. ASI = Aberrant Salience Inventory; SAT = Salience Attribution Test; EEfRT = Effort Expenditure for Reward Task; SCT = Stimulus Chase Task. Percent rounded to the nearest whole number. Household income in NZ\$.

TABLE 2 Correlations (Kendall's tau) among ASI, SAT, and SCT indices

Variable	1	2	3	4	5	6
1. ASI						
2. SAT implicit aberrant salience	-.02					
3. SAT explicit aberrant salience	-.06	.06				
4. SAT implicit adaptive salience	-.06	.21**	.11			
5. SAT explicit adaptive salience	-.10	.08	-.15	-.01		
6. SCT approach:avoidance ratio	-.08	-.01	.06	.02	.04	
7. SCT: gain:loss ratio	.02	.06	-.02	.06	.04	-.27

Note. ASI = Aberrant Salience Inventory; SAT = Salience Attribution Test; SCT = Stimulus Chase Task.

** $p < .01$.

[Correction added on 8 May 2018, after first online publication: Incorrect coefficients in Table 2, row 7, variable "6.SCT approach:avoidance ratio", from column 2 (variable 1) and Table 3, column 7, measure "Approach: Avoid", from row 1 (hard choices) have been corrected in this version.]

relationship between SAT implicit aberrant salience and effort for larger more likely rewards. There were no significant correlations between effort expenditure and explicit aberrant salience. Higher implicit adaptive salience correlated with less effort for higher rewards and both low and high rewards when likelihood of winning was high.

The effects of probability on task choice during the EEfRT were predicted by ASI ratings, $R^2 = 0.05$, $F(1, 80) = 4.56$, $p = .04$. Evidence

FIGURE 1 Beta coefficient for reward magnitude on task choice during Effort-Expenditure for Rewards Task by probability of winning. Error bars represent 95% confidence intervals

FIGURE 2 Beta coefficient for probability of winning on task choice during Effort-Expenditure for Rewards Task by reward magnitude. Shaded area represents 95% confidence intervals

that ASI ratings predicted the effects of reward magnitude, $R^2 = 0.05$, $F(1, 80) = 3.77$, $p = .06$, or the probability $\times$ magnitude interaction, $R^2 = 0.04$, $F(1, 80) = 2.10$, $p = .09$, was marginal. In contrast, there was no evidence that EEfRT task parameters predicted SAT implicit aberrant salience for reward magnitude, $R^2 = 0.00$, $F(1, 80) = 0.34$, $p = .56$; for probability, $R^2 = 0.00$, $F(1, 80) = 0.29$, $p = .60$; and for their interaction, $R^2 = 0.00$, $F(1, 80) = 0.24$, $p = .63$.

There was a positive relationship between SCT gain:loss ratio and EEfRT effort for high rewards with a 50% probability of winning (Table 3). When probability of winning was 50%, the relationship between gain:loss and effort for high reward magnitudes accounted for 49.9% of the variance, with 43.6% for medium reward and

24.2% for low reward. There was no evidence that linear EEfRT variable coefficients were significant predictors of gain:loss ratio.

4 | DISCUSSION

Contrary to our expectations, there was no evidence that measures of aberrant salience were correlated. Furthermore, measures of aberrant salience did not correlate with measures of reward sensitivity. Although aberrant salience correlated with EEfRT as hypothesised, ASI positively correlated with effort for small, improbable rewards whereas SAT implicit aberrant salience negatively correlated with willingness to exert effort for large, probable rewards. Effort was related to the SCT gain:loss ratio in the direction hypothesised but only for uncertain rather than low-probability trials. Finally, there was no evidence of a relationship between effort and approach-avoidance behaviour.

The failure to find a relationship between the aberrant salience measures raises the question of validity of one or both measures. Previous research utilising the SAT has yielded inconsistent patterns of results in the sensitivity of explicit versus implicit aberrant salience to differentiate healthy participants from those on the schizophrenia spectrum (Pankow et al., 2015; Roiser et al., 2009; Roiser, Howes, Chaddock, Joyce, & McGuire, 2013). Furthermore, evidence suggests that this cannot simply be attributed to differences in cognitive ability (Katthagen et al., 2016). One issue with the SAT is the assumption that aberrant salience results in all irrelevant stimuli becoming salient. Given the aberrant salience hypothesis suggests an errant pairing of dopaminergic firing and irrelevant stimuli. The inconsistent findings using SAT may indicate individual differences in the salience attributed to specific irrelevant stimuli. Similarly, the ASI may lack discriminant validity. The ASI measures a trait associated with schizophrenia, labelled aberrant salience. However, there is no evidence that the ASI measures a trait that is unique to schizophrenia. Furthermore, the ASI questions are open to interpretation and a high ASI score may, for example, reflect the openness personality trait.

The difference in the relationships of the EEfRT with the ASI and SAT further support that the two measures of aberrant salience are measuring either different constructs or different aspects of aberrant salience. Implicit aberrant and adaptive SAT measures were positively related and both associated with less effort for large, probable rewards. These findings suggest that implicit SAT measures are measuring a similar construct (e.g., speed of response). The construct validity of SAT is further challenged by the lack of evidence supporting a relationship between EEfRT and explicit aberrant salience or predictive associations between the weighting of EEfRT variables during task choice and SAT measures.

In contrast, higher ASI scores were associated with aberrant decision-making during the EEfRT that appears to be based on mental effort. For example, higher ASI was associated with hard task choice for high-value low-probability trials as well as high-probability low-value trials. The weight assigned to variables during EEfRT supports an association between ASI score and reduced mental effort. Overall, participants appeared to use combined reward magnitude and probability to determine task choice. However, participants with higher ASI scores were more likely to use probability alone in deciding task choice

TABLE 3 Correlation coefficients (Kendall's tau) for EEfRT with ASI, SAT, and SCT indices

Measure	ASI	Aberrant salience		Adaptive salience		Approach: Avoid	Gain: Loss
		Implicit	Explicit	Implicit	Explicit		
Hard choices	.28***	-.08	.05	-.11	-.19*	-.14	.17
L Pr	.11	-.13	.14	-.04	-.23**	-.03	.10
M Pr	.28***	.00	.04	-.03	-.09	-.16	.21*
H Pr	.19*	-.13	.05	-.12	-.13	-.00	.09
L \$	.18*	-.04	.05	-.06	-.17*	-.11	-.04
M \$	.19*	-.02	.11	-.04	-.13	-.16	.12
H \$	.27***	-.08	.06	-.17*	-.13	-.20*	.15
L Pr, L \$	.07	-.13	.01	-.01	-.13	-.03	.13
L Pr, M \$	.08	-.10	.11	-.03	-.15	-.05	.01
L Pr, H \$	.17*	-.11	.08	-.06	-.22**	-.05	.12
M Pr, L \$	.18*	.06	.10	.13	-.12	-.14	.06
M Pr, M \$	.16*	.03	.04	.07	-.07	-.20*	.19
M Pr, H \$	.29***	-.04	.01	-.12	-.09	-.12	.25**
H Pr, L \$	.17*	-.07	.01	-.16*	-.10	-.04	-.09
H Pr, M \$	.21*	-.09	.06	-.05	-.12	.02	.15
H Pr, H \$	.13	-.17*	.09	-.18*	-.07	.03	.19
L EV	.15	-.07	.11	.04	-.24**	-.07	.09
M EV	.28***	-.02	.04	-.06	-.14	-.12	.14
H EV	.13	-.10	.01	-.08	-.03	.03	.14

Note. L = low; M = medium; H = high; Pr = probability; \$ = reward magnitude; EV = expected value; ASI = Aberrant Salience Inventory Score. EEfRT tasks are based on proportion of hard task choices for three Pr levels (L = .12, M = .5, H = .88); for three levels of RM (<\$2.00, \$2.00 to \$3.00, ≥\$3.00). EV = Pr × \$.

* $p < .05$, ** $p < .01$, *** $p < .001$.

during the EEfRT. Task selection based on one of three probabilities arguably requires less mental effort than the evaluation of a combined probability and reward magnitude or even determining the subjective value of a continuous reward magnitude. The greater weight given to probability also explains the lack of evidence supporting the predicted negative relationship between ASI and hard task choices during high-reward high-probability trials. These findings are interesting considering evidence from previous research suggesting an impaired cost–effort computation in schizophrenia (Fervaha, Foussias, Agid, & Remington, 2013) and, overall, indicating that the ASI may be a more informative measure of aberrant salience than the SAT.

It is unclear whether the lack of evidence supporting a relationship between aberrant salience and loss sensitivity is due to the sample population or measures. However, evidence supported an association between reward sensitivity and reward motivation. Given that the SCT outcome probability is constant (50%) and the EEfRT does not include loss (deduction of reward) outcomes, the correlations between the gain:loss ratio and hard task choice during 50% probability EEfRT trials suggest an increased gain sensitivity rather than loss sensitivity. The results, therefore, indicate that higher gain sensitivity is related to increased willingness to expend effort for higher value rewards.

Although a healthy sample was required to ascertain baseline relationships between the measures, this is one of the key limitations of the study. The current evidence suggests no relationship between the measures of aberrant salience. One explanation for the null relationship is that the different constructs of aberrant salience, employed by the SAT and ASI, are associated with differences in sensitivity. Therefore,

although the current study had adequate power, a case-control design may show a relationship between these measures that was masked by a restricted range of scores from the student sample. Interpretation of the results within the framework of an association between aberrant salience and schizophrenia should, therefore, be cautiously applied.

Future research should include additional measures of reward and motivation, such as probabilistic learning and learned irrelevance, and neurological measures, such as EEG. These additional measures would help to clarify the relationship between SAT indices and reward processing. Furthermore, explanations for inconsistent findings from the SAT focus primarily on medication and stage of symptom development (e.g., at risk, prodromal, or active). The inclusion of schizotypy measures would assist in understanding whether specific schizotypy factors or subscales predict the relationship between the ASI and the SAT. In future research, the relationship between measures should be assessed in individuals with active symptoms (schizophrenia). Finally, it is important to note that the current findings may have wider implications. Although the aberrant salience hypothesis has been applied to schizophrenia, reward processing is affected in other disorders and diseases, such as Parkinson's disease and addictions. Thus, research is needed to ascertain whether the aberrant salience hypothesis is unique to schizophrenia.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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REFERENCES

- Balconi, M., & Crivelli, D. (2010). FRN and P300 ERP effect modulation in response to feedback sensitivity: The contribution of punishment-reward system (BIS/BAS) and Behaviour Identification of action. *Neuroscience Research*, 66(2), 162–172. <http://doi.org/doi:10.1016/j.neures.2009.10.011>
- Barch, D. M., Treadway, M. T., & Schoen, N. (2014). Effort, anhedonia, and function in schizophrenia: Reduced effort allocation predicts amotivation and functional impairment. *Journal of Abnormal Psychology*, 123(2), 387–397. <https://doi.org/10.1037/a0036299.supp>
- Bardgett, M. E., Depenbrock, M., Downs, N., Points, M., & Green, L. (2009). Dopamine modulates effort-based decision making in rats. *Behavioral Neuroscience*, 123(2), 242–251. <https://doi.org/10.1037/a0014625>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). lme4 package in R. *Journal of Statistical Software*, 67(1), 1–48. <http://doi.org/10.18637/jss.v067.i01>
- Berridge, K. C. (2013). Computation of reward motivation. *The European Journal of Neuroscience*, 35(7), 1124–1143. <https://doi.org/10.1111/j.1460-9568.2012.07990.x>
- Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2011). Dopamine in motivational control: Rewarding, aversive, and alerting. *Neuron*, 68(5), 815–834. <https://doi.org/10.1016/j.neuron.2010.11.022>
- Brown, J. K., Waltz, J. A., Strauss, G. P., McMahon, R. P., Frank, M. J., & Gold, J. M. (2013). Hypothetical decision making in schizophrenia: The role of expected value computation and “irrational” biases. *Psychiatry Research*, 209(2), 142–149. <https://doi.org/10.1016/j.psychres.2013.02.034>
- Ceaser, A. E., & Barch, D. M. (2016). Striatal activity is associated with deficits of cognitive control and aberrant salience for patients with schizophrenia. *Frontiers in Human Neuroscience*, 9(February), 1–17. <https://doi.org/10.3389/fnhum.2015.00687>
- Cicero, D. C., Kerns, J. G., & McCarthy, D. M. (2010). The Aberrant Salience Inventory: A new measure of psychosis proneness. *Psychological Assessment*, 22(3), 688–701. <https://doi.org/10.1037/a0019913>
- Cooper, A. J., Duke, E., Pickering, A. D., & Smillie, L. D. (2014). Individual differences in reward prediction error: Contrasting relations between feedback-related negativity and trait measures of reward sensitivity, impulsivity and extraversion. *Frontiers in Human Neuroscience*, 8, 248. <https://doi.org/10.3389/fnhum.2014.00248>
- Corr, P. J. (2001). Testing problems in J. A. Gray's personality theory: A commentary on Matthews and Gilliland (1999). *Personality and Individual Differences*, 30(2), 333–352. [http://doi.org/doi:10.1016/S0191-8869\(00\)00028-3](http://doi.org/doi:10.1016/S0191-8869(00)00028-3)
- Corr, P. J., & McNaughton, N. (2012). Neuroscience and approach/avoidance personality traits: A two stage (valuation-motivation) approach. *Neuroscience and Biobehavioral Reviews*, 36(10), 2339–2354. <https://doi.org/10.1016/j.neubiorev.2012.09.013>
- Fervaha, G., Foussias, G., Agid, O., & Remington, G. (2013). Neural substrates underlying effort computation in schizophrenia. *Neuroscience & Biobehavioral Reviews*, 37(10, Part 2), 2649–2665. <http://doi.org/doi:10.1016/j.neubiorev.2013.09.001>
- Fervaha, G., Graff-Guerrero, A., Zakzanis, K. K., Foussias, G., Agid, O., & Remington, G. (2013). Incentive motivation deficits in schizophrenia reflect effort computation impairments during cost-benefit decision-making. *Journal of Psychiatric Research*, 47(11), 1590–1596. <http://doi.org/doi:10.1016/j.jpsychires.2013.08.003>
- Gold, J. M., Strauss, G. P., Waltz, J. A., Robinson, B. M., Brown, J. K., & Frank, M. J. (2013). Negative symptoms of schizophrenia are associated with abnormal effort-cost computations. *Biological Psychiatry*, 74(2), 130–3223. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3703817/pdf/nihms-434975.pdf>
- Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (Second ed.). Oxford: Oxford University Press.
- Green, M. F., & Horan, W. P. (2015). Effort-based decision making in schizophrenia: Evaluation of paradigms to measure motivational deficits. *Schizophrenia Bulletin*, 41(5), 1021–1023. <https://doi.org/10.1093/schbul/sbv084>
- Green, M. F., Horan, W. P., Barch, D. M., & Gold, J. M. (2015). Effort-based decision making: A novel approach for assessing motivation in Schizophrenia. *Schizophrenia Bulletin*, 41(5), 1035–1044. <https://doi.org/10.1093/schbul/sbv071>
- Hall, P. J., Chong, C. W., McNaughton, N., & Corr, P. J. (2011). An economic perspective on the reinforcement sensitivity theory of personality. *Personality and Individual Differences*, 51(3), 242–247. <https://doi.org/10.1016/j.paid.2010.06.023>
- Haralanova, E., Haralakov, S., Beraldi, A., Moller, H. J., & Hennig-Fast, K. (2012). Subjective emotional over-arousal to neutral social scenes in paranoid schizophrenia. *European Archives of Psychiatry and Clinical Neuroscience*, 262(1), 59–68. <https://doi.org/10.1007/s00406-011-0227-1>
- Harrell Jr, F. E., & and with contributions from many other users. (2016). Hmisc: Harrell miscellaneous. R package version 3.3.1.
- Heerey, E. A., Robinson, B. M., McMahon, R. P., & Gold, J. M. (2007). Delay discounting in schizophrenia. *Cognitive Neuropsychiatry*, 12(3), 213–221. <https://doi.org/10.1080/13546800601005900>
- Horan, W. P., Reddy, L. F., Barch, D. M., Buchanan, R. W., Dunayevich, E., Gold, J. M., ... Green, M. F. (2015). Effort-based decision-making paradigms for clinical trials in schizophrenia: Part 2-external validity and correlates. *Schizophrenia Bulletin*, 41(5), 1055–1065. <https://doi.org/10.1093/schbul/sbv090>
- Howes, O. D., & Nour, M. M. (2016). Dopamine and the aberrant salience hypothesis of schizophrenia (editorial). *World Psychiatry*, 15(1), 94.
- Jahn, A., Nee, D. E., Alexander, W. H., & Brown, J. W. (2014). Distinct regions of anterior cingulate cortex signal prediction and outcome evaluation. *NeuroImage*, 95, 80–89. <https://doi.org/10.1016/j.neuroimage.2014.03.050>
- Jensen, J., Willeit, M., Zipursky, R. B., Savina, I., Smith, A. J., Menon, M., ... Kapur, S. (2008). The formation of abnormal associations in schizophrenia: Neural and behavioral evidence. *Neuropsychopharmacology*, 33(3), 473–479. <http://doi.org/10.1038/sj.npp.1301437>
- Kapur, S. (2003). Psychosis as a state of aberrant salience: A framework linking biology, phenomenology, and pharmacology in schizophrenia. *American Journal of Psychiatry*, 160(1), 13–23.
- Katthagen, T., Dammering, F., Kathmann, N., Kaminski, J., Walter, H., Heinz, A., & Schlagenhauf, F. (2016). Validating the construct of aberrant salience in schizophrenia—Behavioral evidence for an automatic process. *Schizophrenia Research: Cognition*, 6, 22–27. <https://doi.org/10.1016/j.scog.2016.10.001>
- Lelli, L., Godini, L., Sauro, C. L., Pietrini, F., Spadafora, M., Talamba, G. A., & Ballerini, A. (2015). Validation of the Italian version of the Aberrant Salience Inventory (ASI): A new measure of psychosis proneness. *Journal of Psychopathology*, 21(3), 281–286.
- Matsumoto, M., & Hikosaka, O. (2009). Two types of dopamine neuron distinctly convey positive and negative motivational signals. *Nature*, 459(7248), 837–841. <https://doi.org/10.1038/nature08028>

- McNaughton, N. (2004). The conceptual nervous system of J.A. Gray: Anxiety and neuroticism. *Neuroscience and Biobehavioral Reviews*, 28(3), 227–228. <https://doi.org/10.1016/j.neubiorev.2004.04.001>
- McNaughton, N., & Corr, P. J. (2004). A two-dimensional neuropsychology of defense: Fear/anxiety and defensive distance. *Neuroscience and Biobehavioral Reviews*, 28(3), 285–305. <https://doi.org/10.1016/j.neubiorev.2004.03.005>
- McNaughton, N., & Corr, P. J. (2014). Approach, avoidance, and their conflict: The problem of anchoring. *Frontiers in Systems Neuroscience*, 8, 124. <https://doi.org/10.3389/fnsys.2014.00124>
- Micoulaud-Franchi, J. A., Aramaki, M., Merer, A., Cermolacce, M., Ystad, S., Kronland-Martinet, R., ... Vion-Dury, J. (2012). Toward an exploration of feeling of strangeness in schizophrenia: Perspectives on acousmatic and everyday listening. *Journal of Abnormal Psychology*, 121(3), 628–640. <https://doi.org/10.1037/a0026411>
- Pankow, A., Katthagen, T., Diner, S., Deserno, L., Boehme, R., Kathmann, N., ... Schlagenhauf, F. (2015). Aberrant salience is related to dysfunctional self-referential processing in psychosis. *Schizophrenia Bulletin*, sbv098. <https://doi.org/10.1093/schbul/sbv098>
- R Development Core Team. (2016). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <https://www.r-project.org/>
- Reddy, L. F., Horan, W. P., Barch, D. M., Buchanan, R. W., Dunayevich, E., Gold, J. M., ... Green, M. F. (2015). Effort-based decision-making paradigms for clinical trials in schizophrenia: Part 1—Psychometric characteristics of 5 paradigms. *Schizophrenia Bulletin*, 41(5), sbv089. <https://doi.org/10.1093/schbul/sbv089>
- Revelle, W. (2016). Psych package in R. Evanston, Illinois: Psych: Procedures for personality and psychological research, Northwestern University. Retrieved from <https://cran.r-project.org/package=psych>
- Roiser, J. P., Howes, O. D., Chaddock, C. A., Joyce, E. M., & McGuire, P. (2013). Neural and behavioral correlates of aberrant salience in individuals at risk for psychosis. *Schizophrenia Bulletin*, 39(6), 1328–1336. <https://doi.org/10.1093/schbul/sbs147>
- Roiser, J. P., Stephan, K. E., den Ouden, H. E., Barnes, T. R., Friston, K. J., & Joyce, E. M. (2009). Do patients with schizophrenia exhibit aberrant salience? *Psychological Medicine*, 39(2), 199–209. <https://doi.org/10.1017/S0033291708003863>
- Salamone, J. D., & Correa, M. (2002). Motivational views of reinforcement: Implications for understanding the behavioral functions of nucleus accumbens dopamine. *Behavioural Brain Research*, 137(1–2), 3–25. [https://doi.org/10.1016/S0166-4328\(02\)00282-6](https://doi.org/10.1016/S0166-4328(02)00282-6)
- Salamone, J. D., Correa, M., Mingote, S. M., & Weber, S. M. (2005). Beyond the reward hypothesis: Alternative functions of nucleus accumbens dopamine. *Current Opinion in Pharmacology*, 5(1), 34–41. <http://doi.org/doi:10.1016/j.coph.2004.09.004>
- Salamone, J. D., Cousins, M. S., & Snyder, B. J. (1997). Behavioral functions of nucleus accumbens dopamine: Empirical and conceptual problems with the anhedonia hypothesis. *Neuroscience & Biobehavioral Reviews*, 21(3), 341–359. [http://doi.org/doi:10.1016/S0149-7634\(96\)00017-6](http://doi.org/doi:10.1016/S0149-7634(96)00017-6)
- Sambrook, T. D., & Goslin, J. (2015). A neural reward prediction error revealed by a meta-analysis of ERPs using great grand averages. *Psychological Bulletin*, 141(1), 213–235. <https://doi.org/10.1037/bul000006>
- Schmidt, K., & Roiser, J. P. (2009). Assessing the construct validity of aberrant salience. *Frontiers in Behavioral Neuroscience*, 3, 58. <https://doi.org/10.3389/neuro.08.058.2009>
- Scholten, M. R., van Honk, J., Aleman, A., & Kahn, R. S. (2006). Behavioral inhibition system (BIS), behavioral activation system (BAS) and schizophrenia: Relationship with psychopathology and physiology. *Journal of Psychiatric Research*, 40(7), 638–645. <https://doi.org/10.1016/j.jpsychires.2006.03.005>
- Schultz, W. (2010). Dopamine signals for reward value and risk: Basic and recent data. *Behavioral and Brain Functions : BBF*, 6, 24. <https://doi.org/10.1186/1744-9081-6-24>
- Smith, C. T., Wallace, D. L., Dang, L. C., Aarts, E., Jagust, W. J., D'Esposito, M., & Boettiger, C. A. (2015). Modulation of impulsivity and reward sensitivity in intertemporal choice by striatal and midbrain dopamine synthesis in healthy adults. *Journal of Neurophysiology*, 115(3), 1146–1156. 20132(Md), jn.00261.2015. doi:<https://doi.org/10.1152/jn.00261.2015>
- Treadway, M. T., Buckholtz, J. W., Schwartzman, A. N., Lambert, W. E., & Zald, D. H. (2009). Worth the “EEFRT”? The effort expenditure for rewards task as an objective measure of motivation and anhedonia. *PLoS One*, 4(8), e6598. <https://doi.org/10.1371/journal.pone.0006598>
- Treadway, M. T., & Zald, D. H. (2013). Parsing anhedonia translational models of reward-processing deficits in psychopathology. *Current Directions in Psychological Science*, 22(3), 244–251. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3989147/pdf/nihms570853.pdf>
- Unger, K., Heintz, S., & Kray, J. (2012). Punishment sensitivity modulates the processing of negative feedback but not error-induced learning. *Frontiers in Human Neuroscience*, 6, 186. <https://doi.org/10.3389/fnhum.2012.00186>
- Waltz, J. A., & Gold, J. M. (2007). Probabilistic reversal learning impairments in schizophrenia: Further evidence of orbitofrontal dysfunction. *Schizophrenia Research*, 93(1–3), 296–303. <https://doi.org/10.1016/j.schres.2007.03.010>
- Wardle, M. C., Treadway, M. T., Mayo, L. M., Zald, D. H., & de Wit, H. (2011). Amping up effort: Effects of d-amphetamine on human effort-based decision-making. *The Journal of Neuroscience*, 31(46), 16474–16597. Retrieved from <http://www.jneurosci.org/content/31/46/16597.full.pdf>
- Zhang, L., Doyon, W. M., Clark, J. J., Phillips, P. E. M., & Dani, J. A. (2009). Controls of tonic and phasic dopamine transmission in the dorsal and ventral striatum. *Molecular Pharmacology*, 76(2), 396–404. <https://doi.org/10.1124/mol.109.056317>
- Zweifel, L. S., Parker, J. G., Lobb, C. J., Rainwater, A., Wall, V. Z., Fadok, J. P., ... Palmiter, R. D. (2009). Disruption of NMDAR-dependent burst firing by dopamine neurons provides selective assessment of phasic dopamine-dependent behavior. *Proceedings of the National Academy of Sciences of the United States of America*, 106(18), 7281–7288. <https://doi.org/10.1073/pnas.0813415106>

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