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The Relationship Between Subthreshold Autistic Traits, Ambiguous Figure Perception and Divergent Thinking

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Abstract This research investigates the paradox of creativity in autism. That is, whether people with subclinical autistic traits have cognitive styles conducive to creativity or whether they are disadvantaged by the implied cognitive and behavioural rigidity of the autism phenotype. The relationship between divergent thinking (a cognitive component of creativity), perception of ambiguous figures, and self-reported autistic traits was evaluated in 312 individuals in a non-clinical sample. High levels of autistic traits were significantly associated with lower fluency scores on the divergent thinking tasks. However autistic traits were associated with high numbers of unusual responses on the divergent thinking tasks. Generation of novel ideas is a prerequisite for creative problem solving and may be an adaptive advantage associated with autistic traits.

Keywords Autism · Ambiguous figures · Creativity · Autistic traits · Divergent thinking

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Introduction

Autism is characterised by a triad of impairments in the domains of social behaviour, communication, and imagination (Wing 1981). The deficit in imagination is manifested as restricted, repetitive patterns of behaviour, interests, or activities (DSM–5; American Psychiatric Association 2013). Impaired imagination being a core feature of autism, it seems paradoxical that there are high profile cases of people with autism who exhibit creative flair in their fields of special interest (Fitzgerald 2004). These savant abilities occur far more frequently among people with autism spectrum disorders (ASD) than other developmental disabilities (Treffert 2009). Therefore it has been posited that autism cannot be explained by a deficit-only model but requires that we also explain the islets of preserved or even superior ability (Happé 1999).

Current conceptions of creativity involve both components of 'novelty' and 'appropriateness' (Lubart 2001; Runco and Jaeger 2012). The capacity for producing novel ideas has been traditionally assessed through divergent thinking tasks (Guilford et al. 1978; Wallach and Kogan 1965). For example, in the Alternate Use task (Guilford et al. 1978) participants are asked to think of alternate uses for a common object such as a brick or a drawing pin. Participants must suppress the most obvious and prepotent response (its usual use) and generate other ideas. The responses have historically been scored on one or more of the following indices—fluency, originality, flexibility, and elaboration (e.g. Torrance 1966). Divergent thinking has been explored in people with a diagnosis of autism. Turner (1999) and Craig and Baron-Cohen (1999) found that participants with ASD demonstrated significantly lower fluency (quantity of responses) on such tasks than controls. Overall the balance of evidence is in favour of a divergent

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thinking fluency deficit in autism. The exceptions to this finding are explained by the characteristics of participants in the studies with null results. For example, Scott and Baron-Cohen (1996) found no difference in fluency between ASD and control groups. However, all participants had very low verbal ability (verbal mental age <5). Pring et al. (2012) found no fluency deficit in savant artists compared to an art student control group. In this case, potential group differences were masked because control group performance was at ceiling. There is also evidence of impairment from other types of creativity test, e.g. Liu et al. (2011) found that participants with Asperger syndrome had significantly lower scores on openness and flexibility on a battery of creativity tests.

Where might the positive link between autism and creativity lie if not in fluency of divergent thinking? There is some indication that ASD groups have strengths in the generation of highly original responses. Kasirer and Mashal (2014) found the ASD participants were superior to controls in the generation of novel metaphors. This is a particularly intriguing finding in light of the volume of evidence suggesting people with high functioning ASD are impaired in the comprehension of metaphors, jokes and other non-literal language (e.g. Rundblad and Annaz 2010, Gold et al. 2010). Liu et al. (2011) found that participants with Asperger syndrome were superior in the elaborateness and originality of their responses on creativity tests. Thus it may be that although there is an overall decrease in production, what is obtained may be qualitatively superior.

A task that has previously been linked to both divergent thinking performance and autism is ambiguous figure reversal. Ambiguous figures are pictures that have two stable percepts (see Fig. 1 the duck-rabbit ambiguous figure). Most people who can see both versions experience reversals, where the percept alternates as the participant views the figure. Previous research has found that young people with high levels of autistic traits see fewer reversals of an ambiguous figure (Best et al. 2007). Developmental work with children with autism also suggests infrequent reversal is characteristic of autism (e.g., Ropar et al. 2003; Sobel et al. 2005; but see also Wimmer and Doherty 2010). Wiseman et al. (2011) hypothesised that perception of ambiguous figures is related to creative insight. They confirmed this link, finding a close relationship between the frequency of reversals and divergent thinking fluency in typically developing adolescents and adults. This finding has since been replicated by Doherty and Mair (2012). The ability to reverse ambiguous figures relies on the executive function of inhibition in normal development (Wimmer and Doherty 2011) and on working memory (Intaite et al. 2014). Performance on divergent thinking tasks is also related to inhibition plus working memory 'updating' (Benedek et al. 2013). Thus it seems plausible that reversals of ambiguous figures and divergent thinking may share a common reliance on cognitive abilities of inhibition and working memory function. This study will further examine the perception of ambiguous figures in relation to autistic traits and explore how this relates to performance on divergent thinking measures.

Fig. 1 The duck-rabbit ambiguous figure

A number of recent studies have examined autistic traits in the 'typically developing' population rather than clinically defined samples. It is thought that the impairments present in autism may be distributed continuously through the population (Constantino 2011). That is, differences between people with an autism spectrum diagnosis and people with sub-threshold behavioural traits are quantitative rather than qualitative in nature. The present study examines divergent thinking across the full range of autistic traits in the population. Previous studies taking this approach provide mixed evidence of a link between autistic traits and creativity. Happé and Vital (2009) in a population-based twin study found autistic-traits, and specifically 'restricted and repetitive behaviours and interests', were more pronounced in children reported to have talents outstripping older children. An important study looking at both schizotypy and autistic traits in relation to divergent thinking (Claridge and McDonald 2009) did not find any relationship between divergent thinking (responses assessed for creativity not fluency) and autistic traits. However, the authors note that their study was limited by a small sample size (77 students). The present study tests the link between divergent thinking and autistic traits in a larger sample (>300) and the recruitment strategy was adapted to obtain a wider range of subclinical autistic traits than are typically present in a student sample.

To recruit a large sample of adults with a range of autistic traits (and also potentially reduce the interpersonal demands/cues provided by human testing) we conducted this study over the internet, including websites aimed at people with ASD and their relatives. We measured autistic traits with the self-completion Subthreshold Autism Trait Questionnaire (SATQ; Kanne et al. 2011). The SATQ is a 24 item self-report questionnaire that assesses a broad range of subthreshold autism traits. The SATQ is brief and easy to administer and is relevant to the general population (Kanne et al. 2011; Nishiyama et al. 2014). It has good internal consistency and reliability (Cronbach's alpha coefficient = .73, test–retest reliability = .79; Kanne et al. 2011). The measure was developed to enable the study of individuals who have various degrees of ASD phenotypic expression in order to gain insight into autism as a disorder. Furthermore, the SATQ has been subject to factor analysis to identify five subdomains: social interaction and enjoyment, oddness, reading facial expressions, expressive language, and rigidity (Kanne et al. 2011). In this study we assessed whether fluency and originality of responding on a divergent thinking task is related to level of autistic traits in a population based sample. This study assessed the relationship between autistic traits as assessed by the SATQ, divergent thinking and ambiguous figure perception. Divergent thinking was assessed using the alternate uses tasks (as used by Wiseman et al. 2011) and Wallach–Kogan figures (as used by Turner 1999; Claridge and McDonald 2009; Doherty and Mair 2012). The hypotheses were as follows:

1. The first hypothesis was that measures of divergent thinking fluency would have a significant negative linear relationship to level of autistic traits in a non-clinical population. That is, the alternate uses and Wallch Kogan fluency measures will both be significantly negatively correlated with Subthreshold Autism Trait Questionnaire score.
2. The second hypothesis was that measures of divergent thinking 'unusualness' would have a positive linear relationship to level of autistic traits in a non-clinical population. That is, the alternate uses unusualness measure will be significantly positively correlated with Subthreshold Autism Trait Questionnaire score.
3. Thirdly frequency of perceived ambiguous figure reversals would have a significant negative linear relationship to level of autistic traits in a non-clinical population. That is, the total number of ambiguous figure reversals perceived will be significantly negatively correlated with Subthreshold Autism Trait Questionnaire score.
4. Finally, frequency of perceived ambiguous figure reversal would have a positive linear relationship with divergent thinking measures. That is, the total number of ambiguous figure reversals perceived will be significantly positively correlated with Wallach–Kogan and alternate uses fluency measures.

In addition, we conducted exploratory analysis of the relationship between the SATQ subdomains, the ambiguous figures, and divergent thinking measures.

Methods

Ethical Review

This research study was approved by the University of Stirling Psychology ethics committee.

Data Collection

The data was collected in two phases via an anonymous online survey. The first phase was conducted between 1 and 30 August 2012 and a link to this survey was advertised on the University website and social media sites. The second phase of the online survey was conducted between November 2012 and May 2013; the link to this survey was posted on Autism charity websites, social media pages related to autism and Asperger syndrome, as well the University web pages. The study was conducted in two phases in order to ensure a good range of autistic traits within the sample as a whole. The first phase of the study obtained a very narrow range of SATQ scores which is why the second phase was focused on recruiting participants with higher levels of autistic traits. The purpose is not to compare the two populations so the two phases were combined by appending the datasets without weighting for demographic variables.

Survey

The survey was anonymous. Participants were asked questions regarding:

Demographic Information

Participants were asked for their age, gender, level of education, and subject studied at highest level of education (Maths/computer science/engineering, Natural sciences, Arts, Languages, Social sciences, Sports, Business studies, Other).

Autism Diagnosis and Traits

Participants were asked whether they had an ASD diagnosis (no, Asperger syndrome, autism, other). They were also asked to complete the Subthreshold Autism Trait Questionnaire (SATQ; Kanne et al. 2011).

Ambiguous Figures

Participants were shown three ambiguous figures in series. These were selected to represent the three different types of ambiguous figures (Long and Toppino 2004), those involving reversals of content (duck-rabbit, Fig. 1), perspective (Necker cube, Fig. 2), or figure and ground (face-vases, Fig. 3). For each of the ambiguous figures the participant was asked if they had seen the figure before (yes/no). They were then shown the two disambiguated versions of the figure. Next participants were asked which version they had seen first and whether they could see the other version. Following this they were asked to look at the figure for 30 s and click the mouse every time they saw the figure reverse. The order of presentation of the figures was counterbalanced between participants. The number of reversals of each of the three figures was summed to give a composite score for use in the linear regression analysis.

Tests of Divergent Thinking

Participants were given a variation on the alternate uses test (Guilford et al. 1978). They were asked to provide as many alternative uses as they could think for either a brick or a paper clip in 1 min. Participants' responses were rated for quantity, discounting the usual use and duplicates. Their responses were also rated for elaborateness and for unusualness. Elaborate responses were those that provided a high level of detail. Unusual responses were those that were given by less than 5 % of respondents. Quantity (fluency), unusualness and elaborateness were scored by two researchers (CB, SA) on 148 cases. Quantity and unusualness were rated as scale variables-number of legitimate responses and number of unusual responses. The intraclass correlation coefficients (two-way mixed, consistency) were 0.99 and 0.87 respectively. Elaborateness was a dichotomous variable, scored 1 if any of the answers provided additional levels of detail and specificity. For example for paperclip: 'could be unwound and used to removed splinters if sterilised first' would score 1 and 'needle' would score 0. On 148 cases Cohen's Kappa for Elaborateness was 0.56 indicating a moderate level of agreement (Landis and Koch 1977). Elaborateness score was not used in further analyses due to the moderate level of agreement between raters.

Participants were then shown four drawings adapted from the Wallach and Kogan tests of creativity (Wallach and Kogan 1965), shown in Fig. 4. These tests have been shown to have good levels of reliability and validity (Cropley and Maslany 1969). Participants were asked to provide as many interpretations as they could of each figure in 1 min. Responses were rated for fluency, i.e. the number of ideas produced.

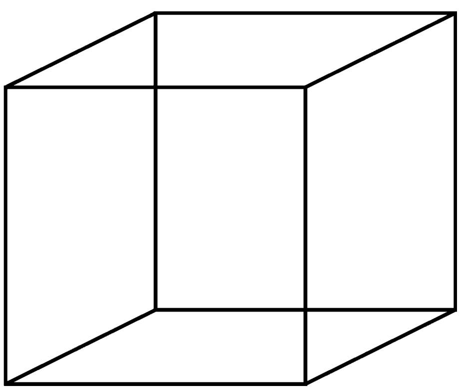

Fig. 2 The Necker cube ambiguous figure

Analysis

Analysis by Spearman's rank order correlation and multivariable linear regression were conducted in Stata version 13 and SPSS version 21. Non-parametric correlations (r_s) were employed because of the skewed nature of many of the variables. The statistical significance of the correlations was corrected for False Discovery Rate (FDR) as recommended by Benjamini and Hochberg (1995) using the

Fig. 3 The face-vase ambiguous figure

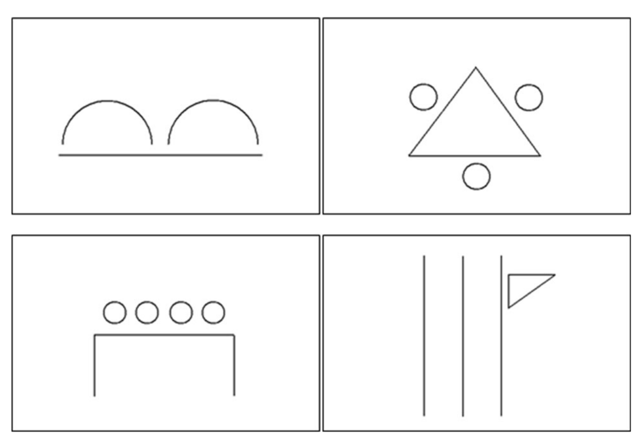

Fig. 4 Wallach and Kogan's creativity test stimuli

online FDR calculator at www.sdmproject.com (Radua et al. 2015).

Multivariable linear regressions were conducted with SATQ score (level of autistic traits) as the dependent variable. Nested models were tested by likelihood ratio ($p < 0.05$ retained) for inclusion in the final model. Variables that violated the assumption of multivariate normality (assessed by plots) were transformed to categorical indicators. In the final model 'Unusualness' was dichotomised to four or more, or fewer than four unusual responses on the alternate uses divergent thinking tasks.

Variance Inflation factors and tolerance were assessed for all variables in the final model and these were acceptable (variance inflation factors <1.3).

Results

A total of 393 participants started the online survey, 168 the first phase and 225 the second. Participants were included in the analysis if they entered demographic information and completed the SATQ. Duplicates were identified using the demographic information plus IP address and duplicates were removed. The time each respondent spent on each item of the test and the number of clicks on each page were recorded automatically thus people who did not complete the full survey could be distinguished from people who completed the survey but gave no response. Responses to the divergent thinking tests were assessed for compliance with task instructions. None of the respondents were excluded based on this assessment. From the first phase, 164 participants were included and from the second 148. This is a 98 % inclusion rate for the first phase and 66 % for the second (Table 1).

The mean age and proportion of male and female respondents were similar for the two phases. Respondents to the first phase had a higher average level of education and were less likely to report a diagnosis of an autistic spectrum disorder.

Table 2 shows the scores on the measures of creativity and the number of reversals of the ambiguous figures.

Outliers on the ambiguous figures tests were identified from boxplots and removed from the analysis (n = 12).

Results of the Non-parametric Correlation Analyses

The results of the pairwise nonparametric correlations are shown in Table 3. Level of autistic traits were significantly negatively correlated with Wallach–Kogan figure fluency $r_s(283) = -0.20$ $p < 0.01$ but not correlated with alternate uses fluency $r_s(303) = -0.06$ $p = 0.28$.

Thus the first hypothesis is partially upheld. The level of autistic traits was not correlated with the number of unusual responses, i.e., there was not a simple linear relationship between SATQ score and 'unusualness'. Therefore Hypothesis 2 is not upheld. There was a significant negative relationship between number of reversals of the ambiguous figures and level of autistic traits confirming Hypothesis 3. There was a positive relationship between both measures of divergent thinking fluency and the number of reversals of the ambiguous figures confirming Hypothesis 4.

Results of the Multivariable Linear Regression Analyses

The variables of interest were initially individually regressed on SATQ score (see column 1 Table 4). The scores from the Wallach–Kogan figures and Alternate Use tests were, as would be expected, highly correlated and hence risked collinearity in the model. For this reason fluency and unusualness were drawn from different divergent thinking tasks. The fluency score from the Wallach–Kogan figures and the unusualness score from the alternate uses test to minimise covariance. Wallach–Kogan fluency was selected as it was found to have a significant correlation with autistic traits. Note that alternate uses fluency would not have been significant in the model. The Wallach–Kogan fluency score [coefficient −0.31 (95 % CI −0.55 to −0.06)] was a significant negative predictor of autistic traits. That is, the higher the fluency score the lower the participant's level of autistic traits tended to be. The

Table 1 Participant characteristics

	Survey phase 1 (n = 164)	Survey phase 2 (n = 148)	Total combined (n = 312)
Sex % female	67 %	69 %	67.9 %
Age mean (SD)	37.29 (13.43)	33.78 (13.99)	35.63 (13.79)
Level of education % degree level	81.7 %	44.7 %	68.9 %
Reported ASD diagnosis % diagnosis	1.2 %	49.3 %	24.1 %
Science main subject studied	26.1 %	25.7 %	26.0 %

Table 2 Descriptive statistics for the measures: SATQ (autistic traits), reversals of the ambiguous figures and divergent thinking measures (alternate uses and Wallach–Kogan)

	N	Mean	SD	Range	Skew	Kurtosis
Reversals/30 s duck-rabbit	297	10.10	9.18	0–50	1.53	3.05
Reversals/30 s Necker cube	297	6.48	6.27	0–34	1.71	3.61
Reversals/30 s face-vases	297	10.37	8.85	0–40	0.97	0.50
Ambiguous figures total	285	25.44	18.86	0–98	1.00	1.17
Alternate uses–fluency	303	3.58	3.43	0–24	2.55	9.92
Alternate uses—unusualness	286	0.56	1.20	0–8	3.57	15.58
Alternate uses–elaborateness	298	0.19	0.39	0–1	1.58	0.49
Wallach–Kogan–fluency	283	12.51	7.54	0–51	1.09	3.31
SATQ	312	29.34	15.66	0–67	0.36	−0.92

Table 3 Non-parametric correlations (r_s) between level of autistic traits (SATQ), number of reversals of the ambiguous figures, and divergent thinking measures (r_s, p corrected for FDR, n)

	SATQ	Ambiguous figures	Wallach–Kogan fluency	Alternate uses unusualness	Alternate uses fluency
SATQ (autistic traits)	1	**−0.14**	**−0.20**	−0.01	−0.06
	0	**0.02**	**<0.01**	0.84	0.28
	312	**285**	**283**	300	303
Ambiguous figures	**−0.14**	1	**0.38**	**0.22**	**0.32**
	0.02	0	**<0.01**	**<0.01**	**<0.01**
	285	285	**268**	**280**	**283**
Wallach–Kogan fluency	**−0.20**	**0.38**	1	**0.37**	**0.55**
	<0.01	**<0.01**	0	**<0.01**	**<0.01**
	283	**268**	283	**281**	**283**
Alternate uses 'unusualness'	−0.01	**0.22**	**0.37**	1	**0.51**
	0.84	**<0.01**	**<0.01**	0	**<0.01**
	300	**280**	**281**	300	**300**

Bold $p < 0.05$ FDR adjusted

Table 4 Linear regression models with SATQ score (autistic traits) as dependent variable and Wallach–Kogan fluency, ambiguous figure reversals and Unusual responses to the alternate uses as predictor variables

	Univariable unadjusted models coefficient (95 % CI)	Multivariable model unadjusted* coefficient (95 % CI)	Multivariable model adjusted for age and gender** coefficient (95 % CI)
Wallach–Kogan fluency	**−0.31 (−0.55 to −0.06)**	**−0.46 (−0.73 to −0.19)**	**−0.47 (−0.73 to −0.20)**
Ambiguous figure total	−0.08 (−0.18 to 0 .01)	−0.07 (−0.17 to 0.04)	−0.08 (−0.18 to 0.03)
Alternate uses unusual ≥4	**16.81 (6.54 to 27.08)**	**28.14 (16.03 to 40.26)**	**30.55 (18.75 to 42.35)**

* n = 268 $F(3, 264) = 9.53$ $p < 0.001$

** n = 268 $F(5, 262) = 10.01$ $p < 0.001$

unusualness variable was initially added to the model as a continuous predictor to see if it was useful in predicting autistic traits once fluency was statistically controlled. It was significant but was found to be non-linear in its relationship to the dependent variable so was transformed into a categorical variable. The categorical measure of unusualness [coefficient 16.81 (95 % CI 6.54–27.08)] was a significant positive predictor of level of autistic traits. That is, people who generated 4 or more unusual responses in the divergent thinking task had higher levels of autistic traits. There was no univariate relationship between reversals of the ambiguous figures and autistic traits.

Divergent thinking fluency and unusualness were then included in the same model and this produced a small improvement in the model fit and magnitude of the coefficients (see Column 2 Table 4).

The model was adjusted for age and gender and this again produced a small improvement in the model fit and magnitude of the coefficients (see Column 3 Table 4).

In neither of the multivariable models did ambiguous figure reversal contribute to prediction of autistic traits. This is probably because of the high degree of correlation with divergent thinking fluency measure entailing that it would not add any further information to the model.

Exploratory analyses of the relationship between the subdomains of the SATQ and other measures.

No specific hypotheses were tested. Spearman's r_s values are given as an indication of effect size and *p* values for the correlations are corrected for False Discovery Rate using the Benjamini and Hochberg (1995) method. High subfactor scores indicate greater level of autistic trait. The participants' fluency score on the Wallach–Kogan figures negatively correlated with the expressive language, reading facial expressions, rigidity, and social interaction factors of the SATQ. Participants' score on the alternate uses test was only related to the expressive language factor of the SATQ. Ambiguous figure reversals were negatively correlated with expressive language and rigidity subdomains. The correlations are shown in Table 5.

Self-Report of ASD Diagnoses in the Sample

Seventy-five of our participants reported they had received a diagnosis of an autism spectrum disorder. Results were analysed by self-reported diagnosis. They are exploratory so no specific hypotheses were tested. The participants reporting a diagnosis of ASD had higher SATQ scores and produced fewer responses on the Wallach–Kogan figures. The mean number of ambiguous figure reversals in the 'diagnosis' group is higher than in the 'no diagnosis' group. However, the 95 % confidence interval of the difference between the means contains 0. This means that that the difference between groups on the ambiguous figures is no greater than would be expected due to sampling error and there is likely to be no 'true' difference in population means. The mean test scores of participants with and without a diagnosis of an ASD and the 95 % confidence intervals of the difference between means are shown in Table 6.

Discussion

This paper aimed to assess the relationship between autistic traits and divergent thinking in a non-clinical sample. It has previously been speculated that in order for a complex genetic disorder to remain within the population there must be advantages conferred on individuals who inherit some of the traits of the disorder but not the full-blown clinical syndrome (Happé and Vital 2009). The high incidence of special talent in some people with autism is consistent with this claim (Treffert 2014), and study of these special talents may cast light on what the advantages of autism-like traits are (Mottron 2011). There is good evidence that they include enhanced detail focussed processing (e.g., Happé and Vital 2009). The current study also suggests a difference in divergent thinking contributes to these advantages.

We began by considering the paradox that a condition diagnosed by impairments in imagination is nevertheless associated with some apparently very creative individuals. Consistent with Craig and Baron-Cohen (1999) and Turner (1999), we found evidence that divergent thinking fluency

Table 5 Non-parametric correlations between SATQ factors, divergent thinking scores and ambiguous figure reversals (Spearman's r_s, *p* value corrected for FDR, n)

	SATQ-social interaction and enjoyment	SATQ-oddness	SATQ-facial expression	SATQ-expressive language	SATQ-rigidity
Alternate uses fluency	−0.03	0.03	−0.07	**−0.20**	−0.08
	0.64	0.67	0.37	**<0.01**	0.30
	303	303	303	**303**	303
Wallach–Kogan fluency	**−0.16**	−0.09	**−0.20**	**−0.30**	**−0.26**
	0.03	0.27	**<0.01**	**<0.01**	**<0.01**
	283	283	**283**	**283**	**283**
Ambiguous figures	−0.09	−0.06	−0.13	**−0.21**	**−0.17**
	0.27	0.37	0.08	**<0.01**	**0.01**
	285	285	285	**285**	**285**
Alternate uses unusualness	0	0.06	0.03	−0.07	−0.05
	1	0.37	0.67	0.34	0.47
	300	300	300	300	300

Bold $p < 0.05$ after correction for FDR

Table 6 Mean scores of participants with and without a diagnosis of autism spectrum disorder (self-report) on SATQ, Wallach–Kogan figures, alternate uses, ambiguous figure reversals and divergent thinking unusualness score

	Participants reporting diagnosis mean (SD)	Participants without reported diagnosis mean (sd)	95 % confidence interval of difference between means
SATQ autistic traits	42.39 (14.4)	25.22 (13.7)	−20.78 to −13.56
Wallach–Kogan fluency	10.29 (8.33)	13.22 (7.14)	0.90 to 4.96
Alternate uses fluency	3.76 (4.41)	3.53 (3.06)	−1.15 to 0.68
Ambiguous figure reversals	26.13 (18.59)	23.17 (19.71)	−2.25 to 8.17
Alternate uses unusualness	0.72 (1.59)	0.50 (1.00)	−0.51 to 0.13

is negatively related to the presence of autistic traits. However, a novel finding is that, when fluency was statistically controlled for, people with high levels of autistic traits were more likely to produce unusual novel responses. This would be a potential cognitive advantage for creative problem solving.

This provides a clue to the solution of the apparent paradox. In typically developing samples, divergent thinking fluency and originality or unusualness of response are highly correlated (Silvia et al. 2008). Both associative and executive processes play a role in creative cognition (Beaty et al. 2014), and the relative contribution of these processes changes while the task progresses. Participants produce the most common responses first, and subsequently produce more unusual responses (Beaty and Silvia 2012). Initially, participants use episodic memory and semantic associations to derive alternate uses. Later, they use strategies that are more reliant on top-down executive process such as the strategy of decomposing the object into its constituent parts to produce more responses (Gilhooly et al. 2007).

Participants with autism, however, may approach creativity problems in a different way. Studies of linguistic processing in ASD have found that narrow semantic processing that takes place in the left cerebral hemisphere is unimpaired in ASD, but broader semantic processing that takes place in the right cerebral hemisphere is impaired (Gold et al. 2010). Participants with autism may therefore be selectively impaired in the broad semantic associations that underlie the fluency that typical participants initially rely on. As a result, they are more likely to use strategies that result in unusual responses. In other words, the associative or memory based route to divergent thinking fluency is impaired in ASD, whereas the executive strategies specific to production of unusual responses are relatively unimpaired or superior. This speculation awaits specific test.

Limitations

The ability of the present study to explain the 'real-world' creative talents of people with autism is limited. Although previous research on creativity in autism (Craig and Baron-Cohen 1999; Turner 1999) has employed fluency measures and they have a long history of use in creativity research, divergent thinking tasks are contested as a direct measure of creativity (Silvia et al. 2008; Runco and Acar 2012). The superior production of unusual responses by people with high autistic traits should be construed as indicating they have some of the cognitive skills that confers the potential for creative problem solving rather than as evidence for creativity per se.

Another limitation to this study is that we did not instruct participants explicitly to think of creative responses but to give as many as possible. Research has found that specific instruction leads to improvement in the creativeness of responses (Nusbaum et al. 2014). However the research was advertised to participants as involving, so they would have been primed to expect tasks requiring creative thought.

A further limitation of our study is the lack of a measure of participants' full scale IQ. However, the evidence suggests that divergent thinking is not related to age or IQ. Turner (1999) did not find a relationship using tasks similar to the present study with an autistic sample. A meta-analysis by Kim (2005) incorporating 21 studies of creativity concludes that the relationship between creativity test scores and IQ in the typical population is negligible. Guildford (1967) suggested that there is a threshold above which there is no effect of IQ, an idea for which there is considerable support (e.g., Jauk et al. 2013). If participants with higher SATQ scores had lower IQs, their poor performance on the divergent thinking tasks could have resulted from IQ rather than creativity deficits. However the different pattern of results across the two types of divergent thinking tests mitigates against this interpretation; one would expect both fluency and originality of performance to be affected by general effects of IQ.

Our results confirm the hypothesis that frequency of ambiguous figure reversal is related to autistic traits. The results also suggest that the cognitive skills that underlie facility in ambiguous figure reversal (i.e., inhibition and working memory) are also necessary for divergent thinking but in no way sufficient for either task. The Wallach–Kogan figures task discriminates the differences in cognition between people with high and low autistic traits better than the ambiguous figures do. The correlations shown in Table 5 suggest a broad association between the Wallach–Kogan fluency scores and most factors of the SATQ. This is in contrast to the ambiguous figure reversals which have more specific associations correlating only with the language and behavioural rigidity subdomains. Thus ambiguous figure reversals may be related to only some elements of the triad of impairments (Happé and Ronald 2008; Ronald et al. 2006; Robinson et al. 2011).

In contrast to Claridge and McDonald (2009) we did find a relationship between autistic traits and divergent thinking on the Wallach–Kogan figures, also in a non-clinical population. This may be because our sample size was more than three times larger than that obtained by Claridge and McDonald. However it should be noted that the magnitude of the predictive power of these regression models is small, indicating at most small to medium effect sizes (R^2 between 0.10 and 0.16). Divergent thinking tasks are complex and involve many different cognitive skills only some of which may be related to some elements of the autism phenotype. The utility of divergent thinking measures for predicting autistic traits or vice versa will be limited, but the detected relationship has the potential to help us understand more about the relationship between autistic traits and adaptive functioning in the general population (e.g., Nettle and Clegg 2006).

Our exploration of the relationship between self-reported diagnosis and the measures of divergent thinking was not the subject of any direct hypotheses. It is possible that the correlation between autistic traits (SATQ) and Wallach–Kogan fluency was largely driven by the group with an ASD diagnosis (see group difference on Table 6). However this was not the case for ambiguous figures or for unusualness where the relationship is clearest in relationship to autistic traits (SATQ) (see Table 3), not by diagnosis.

In conclusion, this study provides important information about the adaptive properties of the cognitive phenotype of autism. It suggests that although people with autistic traits may produce fewer responses to divergent thinking tasks, they are more likely to think of more unusual, rare responses. This difference may have positive implications for creative problem solving. We have speculated that differences in executive functioning may underlie qualitative differences in the process of divergent thinking. Further research is required to confirm the role of executive processes in the generation of unusual responses by people with high autistic traits.

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Author contributions CB and MD devised the study. CB wrote the first draft of the manuscript and CB and MD both revised it. FP developed and administrated the online survey. FP conducted initial data analysis. SA coded participant responses and completed further data analysis. All authors read and commented on the first draft of the manuscript.

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