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Decontextualised Minds: Adolescents with Autism are Less Susceptible to the Conjunction Fallacy than Typically Developing Adolescents

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Abstract The conjunction fallacy has been cited as a classic example of the automatic contextualisation of problems. In two experiments we compared the performance of autistic and typically developing adolescents on a set of conjunction fallacy tasks. Participants with autism were less susceptible to the conjunction fallacy. Experiment 2 also demonstrated that the difference between the groups did not result from increased sensitivity to the conjunction rule, or from impaired processing of social materials amongst the autistic participants. Although adolescents with autism showed less bias in their reasoning they were not more logical than the control group in a normative sense. The findings are discussed in the light of accounts which emphasise differences in contextual processing between typical and autistic populations.

Keywords Autism · Conjunction fallacy · Contextualisation · Developmental disorders · Heuristics and biases · Judgment and decision making

The conjunction fallacy violates a fundamental rule of probability, that the likelihood of two independent events occurring at the same time (in "conjunction") should always be less than, or equal to the probability of either one occurring alone ($p(A) \geq p(A \,\&\, B)$). People who commit the conjunction fallacy assign a higher probability to a conjunction than to one or the other of its constituents. In the most famous demonstration in the literature (Tversky and Kahneman 1983) people read a description of Linda, a 31-year-old, smart, outspoken woman who was a philosophy major, concerned with discrimination and social justice, and a participant in antinuclear demonstrations. When asked to judge a number of statements about Linda according to how likely they are, people usually rank the statement "Linda is a bank teller and is active in the feminist movement" above the statement "Linda is a bank teller," thus committing the fallacy. In the past 26 years around a hundred scientific papers have been published on the conjunction fallacy, and the "Linda problem" has been a key topic in the debate on human rationality.

According to Hertwig and Gigerenzer (1999) rather than being a reasoning error, the conjunction fallacy is based on an intelligent inference (see also Hertwig et al. 2008; Politzer and Noveck 1991). These researchers emphasize that norms should not be content blind, and they also highlight the possible role of linguistic ambiguity in performance on the task. Specifically, they proposed that people inferred that "Linda is a bank teller" implicitly negated the possibility that "Linda is a feminist" when participants were asked to compare the statement with "Linda is a bank teller and is active in the feminist movement" (see e.g., Politzer and Noveck 1991). In this case, considering the latter statement as more likely is no longer a fallacy. There is, however, evidence to show that removing the ambiguity (that is, in the present example to include a response option that contains explicit negation, i.e., "Linda is a bank teller and is *not* active in the feminist movement") is not sufficient to eliminate the fallacy (Tentori et al. 2004).

According to Kahneman and Frederick (2002) the reason for this bias is that when people are confronted with a difficult question, they tend to answer an easier question instead—a process called attribute substitution. For example, at a job interview for a junior academic position,

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the choice of a candidate is often based on the simple question of "How impressive was the candidate's talk?" instead of the hard question of "How likely is it that this candidate could be tenured in the department?" Similarly, in the case of the Linda problem, the hard question of "How likely is it that the statement is true about Linda?" is substituted with the easier "How representative is the statement to Linda?" question. In fact, when a group of participants were asked to rate the statements according to their probability, and another group of participants were asked to rate them according to their representativeness, the correlation between these rankings was almost perfect (.99—Tversky and Kahneman 1982).

The intuitive appeal of a response that is in conflict with the rules of probability has led some authors to cite the conjunction fallacy as a prototypical case of dual processes at work (Sloman 1996), whereby the rapid, automatic and intuitive processes of the heuristic system (System 1) deliver up responses which are often in conflict with the 'rational' or analytic responses associated with the deliberative processing system (System 2; Stanovich 1999). System 2 can sometimes override the heuristic responses offered by System 1. However, this process requires conscious, effortful reasoning. Under dual-process accounts System 1 processes are responsible for what has been termed the fundamental computational bias—the tendency for people to automatically contextualize presented information (Evans et al. 1996; Stanovich 1999). For example, in the case of attribute substitution, the intent to judge a target attribute initiates a search for a reasonable response. Sometimes this search ends quickly, because the response is readily available in memory, or it can be easily inferred from a current experience. However, if this does not happen, the search process will continue with the evaluation of concepts which were activated by the context of the task (Kahneman and Frederick 2002). The effect of contextually cued concepts on choosing a response is arguably very similar to that involved in generating a coherent situation model of a piece of text, where text continuations that are consistent with pre-activated knowledge are processed rapidly (see, for example, Hess et al. 1995) and inconsistencies are readily detected (for a review, see Zwaan and Radvansky 1998).

This sort of automatic contextualisation, however, is not universal. According to an influential cognitive account of autism, the Weak Central Coherence (WCC) theory (Frith and Happé 1994; Happé 1999), typically-developing individuals tend to create global representations, and they process information in context, whereas autistic individuals engage in more detailed, local or piecemeal processing. The applicability of WCC theory to the processing of verbal material is supported by evidence that autistic people are less able than typical populations to benefit from sentence context in disambiguating the meaning of homographs (Frith and Snowling 1983; Jolliffe and Baron-Cohen 1999, although see Brock et al. 2008). Autistic people also have difficulty with understanding metaphors and other types of non-literal language, such as irony, especially when this requires picking up and integrating cross-modal cues (Pexman 2008). Importantly, it appears that these effects cannot be attributed to deficits in the automatic inferences involved in text comprehension or to the lack of activation of relevant knowledge (Saldana and Frith 2007).

The WCC theory has, however, been criticized based on evidence that in the general population various tasks that supposedly measure central coherence are not correlated with each other (Pellicano et al. 2005). López and Leekam (2003) found that children with high functioning autism were able to use contextual information to enhance their recognition and memory for stimuli when only single items of information needed to be connected. However, the autistic group performed less competently than age- and IQ-matched controls on a verbal task where multiple items of information needed to be integrated. Moreover, some studies suggest that people with autism are able to process information globally when they are instructed to do so, although they process information locally when no such instructions are offered (e.g., Mottron et al. 1999). A recent study using different versions of the block design task demonstrated that locally oriented processing in autistic participants did not imply a deficit in forming global representations (Caron et al. 2006). Additionally, not all studies looking at performance on the block design task have found an autistic advantage (see White et al. 2009 for a review). In fact, besides a number of studies reporting no difference between groups, one study found *impaired* rather than enhanced performance in autism on three visuospatial tasks (Burnette et al. 2005).

More recent versions of the WCC theory emphasize that autistic people are able to process information globally, but they only do it under specific circumstances. After reviewing a large number of empirical studies of coherence, Happé and Frith (2006) concluded that the finding of a local bias was robust, and it was not a side-effect of executive dysfunction or theory of mind deficits. Happé and Frith also proposed that in most cases the local bias can be overcome through conscious effort. Recently, it has also been suggested that the autistic advantage on these tasks might be carried by a significant minority of the autistic sample. For example, White et al. (2009) proposed that maybe only those with macrocephaly (i.e., increased head/brain size—which affects approximately 20% of all autistic individuals) exhibit weak central coherence.

To date there is virtually no research that has examined the use of reasoning heuristics in autistic individuals. Thus, the aim of the present study is to determine whether the fundamental computational bias, the tendency to automatically contextualise any given input, operates as powerfully amongst autistic individuals as in typical populations. In light of the theoretical account presented above, and especially considering the findings regarding contextual processing of complex verbal materials, we expected autistic participants to be less susceptible to the conjunction fallacy than non-autistic participants.

Experiment 1

Method

Participants

Twenty-two high functioning adolescents with autism took part in the study. Participants were between the age of 11 and 16 (mean age 14 years 3 months). They were recruited from four mainstream secondary schools around the Plymouth area with specialist units for individuals with autism. Diagnostic records of our participants showed that each of them received a diagnosis of autism by experienced clinicians using the guidelines of DSM-IV (American Psychiatric Association 1994). None of our participants had a diagnosis of Asperger's syndrome or Pervasive Developmental Disorder, and individuals with multiple diagnoses were not included in the sample.

Additionally, 45 adolescents between the age of 11 and 16 (mean age 13 years 10 months) from a Plymouth secondary school participated in the study as a control group of typically developing individuals. Participants in the control group had no known clinically significant impairment or diagnosis according to their school's records.

Instead of using pair-matching (where participants in the two groups are individually matched on certain characteristics) we compared the performance of our autistic participants to a relatively larger group of typically developing adolescents. Although pair-matching is widely used in the case of high functioning individuals, a potential problem with this method is that due to the fact that the control group does not consist of randomly selected participants, the sample gained this way might not be representative to the typically developing population. In order to avoid this problem we measured the performance of the two groups on a number of important indices of cognitive ability (see below), and we controlled for any differences statistically, using analyses of covariance (see Jarrold and Brock 2004).

As a measure of general verbal and nonverbal intelligence we used a short form of the Wechsler Intelligence Scale for Children (WISC-III, Wechsler 1991), consisting of the vocabulary and block design subtests. This short form is reported to have the highest validity and reliability compared to other two-subtest short forms of the WISC (used jointly, these two subscales have a reliability of $r_{tt} = .91$ and a validity of $r = .86$; Sattler 2001, Table A-16). As our participants were from different age groups, and we were interested in their absolute verbal and cognitive ability rather than their IQs, we used the raw scores on the tasks for our analyses and for matching the samples. We also used the stop-signal task which is a computerised measure of inhibition skills (for a detailed description see Handley et al. 2004). These particular tasks (i.e., the short form of the WISC, and the stop-signal task) were chosen for matching the samples, because they were previously found to be good indicators of reasoning performance in developmental samples (see Handley et al. 2004; Kokis et al. 2002; Morsanyi and Handley 2008). Additionally, we administered a computerised measure of set-shifting ability, which was based on Miyake et al. (2000). According to Miyake et al. (2000) both inhibition and set-shifting ability are important indicators of normal executive (or frontal lobe) functioning. Group scores on each of these measures are displayed in Table 1.

Table 1 Mean chronological age in months, performance on the vocabulary and block design subscales of WISC-III, accuracy on the stop signal task and shift cost on the set shifting executive function task for each group in Experiment 1

	Autistic	Typically developing
Age in months	171 (17.6)	166 (14)
Vocabulary	33.4 (9.2)	37 (6.4)
Block design	48.7 (9.8)	54 (9.6)
Inhibition (stop signal)	42.5 (12.4)	42 (10)
Set-shifting cost	1.10 (.12)	1.12 (.12)

There were no significant differences between the groups in chronological age ($t(65) = 1.3$, n.s.), scores on the block design ($t(65) = .68$, n.s.) or vocabulary subtests of the WISC ($t(65) = 1.62$, n.s.), nor were there any differences on either of the executive function measures (ts < 1).

Materials and Procedure

We used two problems (previously used by Morsanyi and Handley 2008; adapted from Tversky and Kahneman 1983) to measure the conjunction fallacy. The problems have been designed to be appropriate for a developmental sample. Each problem was presented on a PowerPoint slide show, which included illustrations and accompanying text that was read out by the experimenter. Each task consisted of a description of a young person followed by a set of options which participants were asked to rank in order of likelihood. The full text of one of the problems used is shown below:

Tim is 10-year-old. He lives in a house with a garden. He has many friends and he likes to play sports in the park and he collects football cards.

Now read the following statements. Your task is to mark the statement which is the most likely to be true with number 1, the next one with number 2, and so on. Mark the statement which is the least likely to be true with number 4.

(a) Tim has a rabbit.
(b) Tim has a sister.
(c) Tim has a rabbit and he often plays football.
(d) Tim goes to chess competitions.

Participants were given a booklet with the response options in order to record their answers. Participants who ranked option (c) as more likely than option (a) committed the conjunction fallacy and were allocated a fallacy point. We administered two problems to measure the conjunction fallacy, thus, scores ranged from 0 to 2.

The conjunction fallacy tasks were administered together with some other reasoning tasks (not reported here) in a group session. The control measures were administered in a separate, individual session.

Results

The mean number of times that the control group committed the conjunction fallacy was 1.91 (SD = .28) compared to 1.72 (SD = .45) for the autistic group. In percentage terms, the control group committed the fallacy 96% of the time, whilst the autistic group committed the fallacy 86% of the time. As we used a small number of problems, and the assumption of normality was not met, we used a Mann–Whitney *U*-test to compare fallacy rates in the two groups. The difference was significant ($z = -1.97$; $p < .05$). The effect size for this statistic was $\theta = .69$ (which corresponds to a Cohen's d of .4, according to Newcombe 2006, which is a medium effect). This indicates that the autistic group were less susceptible to the conjunction fallacy than the control group. We also compared the rates of the conjunction fallacy against the chance rate of 50%. Both the control group ($t(44) = 21.23$, $p < .01$) and the autistic group ($t(21) = 7.48$, $p < .01$) committed the fallacy at rates significantly above chance.

Discussion

The findings of Experiment 1 are in line with the predictions; autistic participants are less susceptible to the conjunction fallacy than matched controls. This suggests that autistic individuals may be less influenced by contextual factors in their reasoning. On the other hand, fallacy rates were high in both groups.

One problem with interpreting the data from Experiment 1 is that a reduction in conjunction fallacies in autism may occur for one of two reasons. It might arise because autistic participants are more sensitive to the underlying logical structure of the decision options and consequently resist the fallacy because they successfully apply the conjunction rule. Alternatively, it could be the result of a reduction in contextual processing, without any accompanying increase in the recognition of the normative status of the decision options. One of the primary aims of Experiment 2 was to evaluate whether the reduction in conjunction fallacy responses in the autistic group could be attributed to higher rates of normative responding on these probabilistic reasoning problems.

Another important question is the actual meaning of the 86% fallacy rate in the autistic group. In both groups fallacy rates were high (although significantly lower in the autistic group) which allows for the interpretation that autistic participants rely on contextual processing, although not as much as the control group. Additionally, fallacy rates in both groups were at a level above chance. However, chance responding might not be the most appropriate comparison for deciding whether autistic participants rely on their background knowledge (specifically, the representativeness of response options) when deciding about the probability of a conjunction of events. It would be more appropriate to compare fallacy rates when the conjunction consists of a representative and a non-representative item (e.g., Tim has a rabbit and he often plays football), with fallacy rates when the conjunction consists of two non-representative items (e.g., Tim has a rabbit and he goes to chess competitions). If participants' responses are affected by representativeness, then fallacy rates in the two cases should differ. Nevertheless, if autistic participants are unaffected by the representativeness of the conjuncts then we can expect similar fallacy rates in both cases. This issue was addressed in Experiment 2.

It is also well documented that autism often results in profound difficulties with everyday social interaction. It has been claimed that such deficits arise because autistic people have very specific problems reasoning within the social domain (see, for example, Adolphs 1999). The judgment problems used in Experiment 1 included descriptions of young people that were designed to activate stereotype-based knowledge. Whilst recent evidence suggests that stereotypes are activated and used as readily for autistic as typical populations (Hirschfeld et al. 2007), it seems prudent to evaluate whether the effect observed in Experiment 1 also extends to problems with non-social content. This question was also examined in Experiment 2.

Experiment 2

In this study we included two traditional conjunction fallacy problems (here we called them conflict problems, because they elicit a conflict between the underlying logical structure and intuitions), and two control (non-conflict) problems. Instead of the conjunction of a representative and a non-representative statement, the control problems included the conjunction of two non-representative statements (see Fig. 1 for examples of the types of problems that we used). This allows a direct comparison between the two groups in terms of their capacity to resist the conjunction fallacy when the conjunction does not contain a representative conjunct. Note that the conjunction of a representative and a non-representative statement in itself (e.g., somebody being a doctor and a mechanic) is quite implausible, just as the conjunction of two non-representative events (e.g., somebody being a plumber and a mechanic). Rating the “doctor and mechanic” conjunct as more likely than the person being a mechanic makes sense only in the light of the description, which is representative to a doctor. Thus, we expected that if participants with autism commit the conjunction fallacy less often than the control group because they disregard the description, their performance on the conflict and non-conflict problems should be indistinguishable.

In order to avoid content effects we used two (a conflict and a non-conflict) versions of each problem. These two versions were administered to different groups of participants (that is, we had two sets of problem, with four different tasks in each, and each participant only solved one set of problems). Half of the participants in each group

Fig. 1 Examples of conflict and non-conflict problems with social and non-social content. (Note that all participants were presented with four problems which corresponded to one of each type. Set 1 and Set 2 were administered to two different groups of participants)

Conflict/social content (Set 1) *Sue is a very intelligent woman, who works in a hospital. She wears glasses and a green uniform. Her bookshelves in her office are full of medical books. Mark the following statements with number 1 to 4 according to how likely they are. (1: most likely, 4: least likely)* ______*Sue is a plumber.* ______*Sue is a doctor.* ______*Sue is a doctor and a mechanic.* ______*Sue is a mechanic.*	***Non- conflict/social content (Set 2)*** *Sue is a very intelligent woman, who works in a hospital. She wears glasses and a green uniform. Her bookshelves in her office are full of medical books. Mark the following statements with number 1 to 4 according to how likely they are. (1: most likely, 4: least likely)* ______*Sue is a plumber.* ______*Sue is a doctor.* ______*Sue is a plumber and a mechanic.* ______*Sue is a mechanic.*
Conflict/non-social content (Set 1) *This object is usually made of wood, and it has four legs. You can put plates and cutlery on it and people can sit around it. Most families have one at home. Mark the following statements with number 1 to 4 according to how likely they are (1: most likely, 4: least likely).* --------*This object is sometimes made of glass.* --------*This object is usually in the dining room.* --------*This object is usually in the dining room and it is used for keeping animals on it.* --------*This object is used for keeping animals on it.*	***Non- conflict/non-social content (Set 2)*** *This object is usually made of wood, and it has four legs. You can put plates and cutlery on it and people can sit around it. Most families have one at home. Mark the following statements with number 1 to 4 according to how likely they are (1: most likely, 4: least likely).* --------*This object is sometimes made of glass.* --------*This object is usually in the dining room.* --------*This object is used for keeping animals on it and it's sometimes made of glass.* --------*This object is used for keeping animals on it.*

(i.e., in the autistic and in the control group) solved Set 1, and the other half solved Set 2. We also investigated whether the difference between the two groups in committing the conjunction fallacy was specific to the social domain (when participants had to reason about people), or whether this difference would also hold with non-social (object/animal) content. Finally, the response options for all of the problems included the representative option alone. This allows us to compare the rank order assigned to this option for the two groups in order to evaluate whether likelihood judgments are similarly affected by background knowledge in each group.

Method

Participants

Twenty-three high functioning adolescents with autism took part in the study. Participants were between the age of 11 and 16 (mean age 14 years). Nine of these adolescents also took part in Experiment 1. Diagnostic records of participants showed that each of them had received a diagnosis of autism by experienced clinicians using the guidelines of DSM-IV (American Psychiatric Association 1994). No participant had a diagnosis of Asperger's syndrome or Pervasive Developmental Disorder, and adolescents with multiple diagnoses were not included in the sample.

Additionally, 41 adolescents between the age of 11 and 16 (mean age 13 years 2 months) from two Plymouth secondary schools participated in the study as a typically developing control group. None of these participants took part in Experiment 1. Adolescents in the control group had no known clinically significant impairment or diagnosis according to their schools' records.

As a measure of general verbal and nonverbal intelligence we used the same short form of the WISC-III (Wechsler 1991), as in Experiment 1 (consisting of the vocabulary and block design subtests). Additionally, we used Set 1 of the Raven Advanced Progressive Matrices (APM—Raven et al. 1998) consisting of 12 items, together with 3 practice items taken from the Raven Progressive Matrices (Raven 1938), as a measure of fluid intelligence. We also administered the counting span task, a typical measure of working memory designed for developmental samples, which incorporates a processing (counting aloud) and storage component (see Handley et al. 2004 for full details). Due to a technical problem we failed to collect data on this task from three participants in the control group and two participants in the autistic group.

Group scores on each of these measures are shown in Table 2. There was no significant difference between the groups on either the vocabulary ($t(62) = 1.04$, n.s.) or the block design subtest of the WISC ($t(62) = .21$, n.s.). There was also no significant difference between the groups on the APM ($t(62) = .21$, n.s.). However, there was a marginally significant difference on the working memory measure ($t(57) = 1.89$, $p = .062$) indicating a trend for the autistic participants to score lower on this task. There was also a significant difference in the mean age of the two samples, the autistic group being significantly older than the control group ($t(62) = 2.06$, $p < .05$). In order to take account of these differences, we included age and working memory separately as covariates in our main analysis. None of the effects were moderated by either of these variables. Consequently, we report the simpler ANOVA model below.

Table 2 Mean chronological age in months, performance on the vocabulary and block design subscales of WISC-III, accuracy on the Raven's Advanced Progressive Matrices, and scores on the working memory task for each group in Experiment 2

	Autistic ($n = 23$)	Typically developing ($n = 41$)
Age in months	172.4 (19.10)	161.5 (20.9)
Vocabulary	28.2 (9.7)	30.4 (7.6)
Block design	45.9 (12.9)	46.6 (11)
Raven	7.1 (2.2)	7.2 (2.5)
Working memory	20.5 (10) ($n = 21$)	25.1 (8.1) ($n = 38$)

Materials and Procedure

We designed two sets of four problems measuring the conjunction fallacy which were administered to two separate groups of participants (i.e., half of both the autistic and the control participants were administered Set 1, and the other half of the participants were administered Set 2). In each set two problems had a social content, and two problems had a non-social content. In each task participants had to rate four statements according to how likely they thought that the statements were true. One statement was representative (based on the description), two statements were non-representative, and the fourth statement was either a conjunction of a representative and a non-representative statement (in the case of conflict problems) or a conjunction of two non-representative statements (in the case of non-conflict problems). The two sets of problems were designed in a way so that participants in one group solved the conflict version, and the other half of participants solved the non-conflict version of the same problem. This was to ensure that fallacy rates on conflict and non-conflict problems were not affected by content effects. In the *conflict* tasks the measure of the conjunction fallacy was whether participants judged the probability of the conjunction of a representative and a non-representative statement as more likely to be true than the non-representative statement alone. In the *non-conflict* tasks the dependent measure was whether participants judged the conjunction of two non-representative statements as more likely to be true than one of the non-representative statements alone (this was always the same non-representative item which was included in the representative—non-representative conjunction in the other set of problems). These manipulations resulted in a 2 × 2 × 2 mixed design with content (social/non-social) and conflict (conflict/non-conflict) as within-subjects variables, and group (autistic/control) as a between-subjects variable. Each participant solved four problems altogether (i.e., one of each type).

Participants solved the conjunction fallacy tasks together with some other reasoning tasks as part of a group session. The problems were presented in a booklet, with one problem on each page. The experimenter read out the instructions and the participants worked through the problems individually, at their own pace. The control measures were administered individually in a separate testing session.

Results

Table 3 shows the mean proportion of conjunction fallacies committed for each of the contents, problem types and groups. Our first analysis aimed to address two questions. First we wanted to determine whether, as in Experiment 1, the conjunction fallacy was more common amongst the control group than the autistic group. The second aim was to evaluate whether autistic participants show greater sensitivity to the conjunction rule. We conducted a 2 (group) × 2 (problem type) mixed ANOVA to compare fallacy rates on the conflict and non-conflict problems for the two groups (see Fig. 2). The analysis revealed a main effect of problem type ($F(1,62) = 36.96$, $p < .001$, $\eta_p^2 = .37$) showing, as expected, higher rates of conjunction fallacy for the conflict compared to the non-conflict problems (82 vs. 40%). There was no effect of group ($F < 1$) which indicates that the autistic participants are not in any general sense more sensitive to the conjunction rule than the control group. There was also a significant interaction between group and problem type ($F(1,62) = 5.16$, $p < .05$, $\eta_p^2 = .08$). We analysed the nature of this interaction further by running ANOVAs with problem type as a between-subjects variable separately for the two groups. This indicated that the control group made more conjunction errors on the conflict problems (88%) than on the non-conflict problems (35%; $F(1,40) = 60.33$, $p < .001$, $\eta_p^2 = .60$). Although there was a similar trend in the autistic group, the difference in the number of conjunction fallacies made on the conflict (72%) and non-conflict problems (48%) did not reach significance ($F(1,22) = 4.17$, $p = .06$, $\eta_p^2 = .16$). That is, although task context (i.e., the description provided) had an effect on autistic participants' ratings of the conjunctive response options, this effect was much weaker than in the control group, and it was not reliable (although it approached significance). As in Experiment 1, the control group were significantly more likely to commit the conjunction fallacy than the autistic group on the conflict problems ($F(1,62) = 4.06$, $p < .05$, $\eta_p^2 = .06$). However, there was no difference between groups in the case of non-conflict problems ($F(1,62) = 1.60$, $p = .21$, $\eta_p^2 = .03$).

Table 3 Mean proportion of conjunction fallacies committed for each type of problem, content and group

	Conflict		Non-conflict	
	Non-social	Social	Non-social	Social
Autistic	.61 (.50)	.83 (.39)	.52 (.51)	.43 (.51)
Typically developing	.83 (.38)	.93 (.26)	.44 (.50)	.27 (.45)

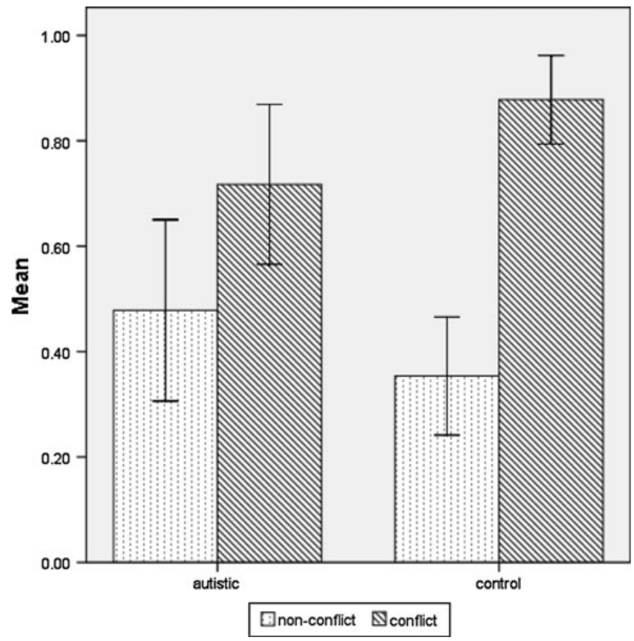

Fig. 2 Mean proportion of conjunction fallacies across conflict and non-conflict problems, and groups (*error bars* ±2 standard error of mean)

The second analysis focuses on the content manipulation. One possibility is that our autistic sample does not show the conjunction fallacy, because they do not activate the relevant social stereotype; that is the effect may be limited to materials that have a social content. In order to evaluate this possibility we analysed the proportion of fallacies on the conflict problems for each group and each type of content. In this analysis there is only one item per cell, so we employed non-parametric analyses to evaluate the effect of content (using a sign test), the effect of groups, and the interaction between these two factors (using Mann–Whitney *U* tests). The analysis showed an effect of content ($z = 2.5$, $p < .05$), indicating that the social content elicited higher conjunction fallacy rates than the non-social content (89 and 75%, respectively). There was also an effect of group, showing higher rates of conjunction fallacy in the control group, in line with the ANOVA analysis reported above ($z = 2.04$, $p < .05$). There was no interaction between content and group ($z = .37$, n.s.) indicating that the difference between autistic and typically developing participants extended to problems with both social and non-social content.

In the case of the non-conflict problems a similar analysis yielded no effect of group ($z = 1.18$, n.s.), a marginal effect of content ($z = 1.8$, $p = .07$, with slightly higher fallacy rates in the case of non-social problems), and no group by content interaction ($z = .63$, n.s.).

Finally, we compared the proportion of participants in each group who rated the representative item as the most likely option on the non-conflict problems (where there were no group differences in the conjunction fallacy rates). The purpose of this analysis was to evaluate whether both groups identified the representative item as the most likely to the same degree. This would indicate that similar knowledge was activated and employed in making judgments about the simple options. The analysis revealed no significant differences in the proportion of participants from the control and the autistic groups ranking the representative item as the most likely for either the non-social content (82 vs. 61%, $\chi^2(1) = 2.27$, n.s.) or the social content (90 vs. 83%, $\chi^2(1) = .79$, n.s.). We also compared the mean rank given to the representative option for each group and content. There was a marginally significant difference for the non-social content (1.24 vs. 1.69, $t(62) = 1.92$, $p = .06$), but no difference for the social content (1.22 vs. 1.22, $t(62) < 1$, n.s.).

Discussion

The evidence for reduced rates of the conjunction fallacy amongst autistic participants that we found in Experiment 1 has been replicated using a different set of problems and predominantly different groups of participants.

The comparison between the experimental and control problems demonstrates that autistic participants are not generally more sensitive to the conjunction rule; that is, they do not show superior normative performance on the non-conflict problems. In addition, the absence of an interaction between participant group and content indicates that the difference between the groups extends to problems with both social and non-social content. Finally, an examination of the likelihood judgments on the representative item alone indicates that the groups do not differ in the degree to which they are influenced by task context and their background knowledge in their ratings of the simple options. This is in line with Hirschfeld et al. (2007) who found that autistic children relied on stereotypes as much as typically developing children. This finding also suggests that contextualisation occurs as much in the autistic, as in the control group, when the task requires making a connection between a simple option and a description. However, in the case of the conjunction of two statements when the representations of the two statements have to be integrated with both each other, and a description, this process seems to break down in the case of autistic participants. This is similar to the pattern reported by López and Leekam (2003), who found that autistic children were able to use contextual information to enhance their recognition and memory of a single item, but they performed worse than controls when multiple pieces of information needed to be integrated.

The findings presented here suggest that the conjunction fallacy is less likely to occur with autistic participants. This effect was predicted because autism has been associated with deficits in contextual processing, the sort of automatic processing commonly claimed to underlie the conjunction effect (e.g., Kahneman and Frederick 2002; Stanovich 1999). The data here are consistent with the idea that autistic participants show a reduced sensitivity to global problem features. However, the reduced susceptibility to the conjunction fallacy amongst autistic participants does not occur because of greater sensitivity to the conjunction rule. So, although the data show that autistic participants are less 'biased' in their judgments, they are not any more 'rational' in a normative sense.

The evidence of reduced rates of conjunction fallacy is consistent with a number of findings relating to the impact of context on complex verbal processing (for a review, see Happé and Frith 2006). This evidence shows, for example, that autistic participants are less able to use sentence context to arrive at an appropriate understanding of sentence meaning (Jolliffe and Baron-Cohen 1999) or to make accurate context dependent inferences from short stories (Jolliffe and Baron-Cohen 2000). However, there is some evidence that autistic people can engage in global processing and show sensitivity to context if explicitly instructed to do so (Snowling and Frith 1986). Nevertheless, this process is not achieved automatically, instead it is relying on effortful processing (Saldana and Frith 2007).

Interestingly, we have recently shown that, amongst younger typically developing children (between 5 and 11 years of age), heuristic responding on a range of tasks (including the conjunction fallacy) is predicted by measures of processing capacity, such as working memory capacity (Morsanyi and Handley 2008), a pattern that reverses for adolescents and adults (Kokis et al. 2002). It is possible that amongst autistic participants contextual effects of the kind that underlie the conjunction fallacy depend upon effortful processing (cf. Happé and Frith 2006). Consequently they occur less often than amongst typically developing adolescents where these effects are the result of more automatic (i.e., System 1) contextualisation processes (Stanovich and West 1998, 2000). If this conjecture is right, then we would expect a relationship between working memory capacity (which is often used as an index of System 2 reasoning capacity—see e.g., Handley et al. 2004) and heuristic responding amongst the autistic group, but not amongst the control group. We collected data from the counting span task, a typical measure of working memory capacity. Using the data from Experiment 2, we computed the susceptibility to the conjunction fallacy for each individual by subtracting fallacy rates on conflict problems from fallacy rates on non-conflict problems. This way we gained an index of the difference that including a representative item makes to fallacy rates in the case of each individual (which is a measure of the relative contribution of context to reasoning performance). That is, a higher score indicates a stronger tendency to commit the fallacy when the conjunction contains a representative item, as compared to when it contains two non-representative items. Consistent with the analysis above, in Experiment 2 the correlation between this index of susceptibility to the conjunction fallacy in the autistic group and working memory score was significant and positive (r (19) = .63, $p < .01$), whilst the correlation in the typically developing group was negative and not significant (r (36) = −.23, n.s.). Additionally, susceptibility to the fallacy was positively correlated with vocabulary scores in the autistic group ($r(21) = .45$, $p < .05$), but it was unrelated with vocabulary scores in the control group ($r(39) = .01$, n.s.). There was no relationship between other measures of cognitive capacity (performance on the Raven test and on the block design test) and susceptibility to the conjunction fallacy (rs < .19, ps > .34). This analysis suggests that the absence of context effects with complex verbal stimuli often reported in the literature may arise, not because autistic participants do not engage in contextual processing, but because this processing is effortful and consequently more prone to failure (see Happé and Frith 2006 for a review of similar findings). However, the lack of relationship between performance on the block design test and susceptibility to the fallacy (together with the fact that our autistic participants did not show enhanced performance on the block design task) suggests that the performance of autistic participants cannot simply be described as exhibiting weak central coherence across the board.

According to Bowler et al. (2004) task support hypothesis, autistic individuals show greater difficulty in retrieving and integrating background knowledge with a problem context when retrieval is not directly cued by a task. In line with this claim, in a study investigating eyewitness memory in autism (McCrory et al. 2007) adolescents with Asperger syndrome mentioned less details of an event during free recall, and they were less likely to recall the most salient elements of the event than adolescents in the control group. However, general and specific questioning elicited the same amount of new information in the autistic and in the control group, and in this case both groups recalled the most salient elements of the scenario. An additional important finding of this study was that memory recall was correlated with executive functioning in the autistic, but not in the control group. A possible explanation for this is that participants with autism did not benefit from a spontaneous organization of the material, and, consequently, they had to rely on their executive resources during memory retrieval (that is, they had to retrieve relevant knowledge effortfully—see also Bennetto et al. 1996 for a similar finding).

Two other aspects of the results are informative. First it appears that the differences in heuristic responding between the two groups cannot be explained by a specific deficit in social reasoning. Whilst many examples of conjunction fallacy problems depend upon the activation of stereotypes, in the present study we introduced problems in which the content was based upon objects and animals rather than people. The difference between the groups was evident for both types of problem. Second, the ranked likelihood of the representative item alone did not differ significantly between the groups. This suggests, in line with recent findings (Hirschfeld et al. 2007; Saldana and Frith 2007), that autistic participants activate relevant world knowledge and can use this knowledge in making judgments concerning simple contingencies. The difference between groups appears to arise when contextual processing involves creating and maintaining multiple relations between concepts that are not explicitly presented. Although processing complex information *per se*, does not seem to be impaired in autism, as autistic people perform at a normal level on the Raven test, a formal reasoning test that requires the integration of complex relations (Dawson et al. 2007). This was also evident in our own sample—in Experiment 2 there was no difference between the autistic and the control groups in their performance on the Raven test. Autistic adolescents are also able to perform complex relational reasoning with thematic pictorial materials (Morsanyi and Holyoak 2009). However, autistic children seem to show a deficit in processing complex verbal material in context (López and Leekam 2003; Pexman 2008).

The ubiquitous nature of context effects in thinking is well documented across a broad range of problem structures and reasoning domains. This has led some authors to argue that the influence of context on thinking reflects a fundamental characteristic of our cognitive architecture; the tendency to automatically contextualise given input. In this paper we focused on the conjunction fallacy, perhaps one of the best known examples of this tendency and an effect that has probably generated more general interest, discussion and research investigation than any other context effect in reasoning and judgment. One reason for this is that, for most of us, the draw towards the conjunctive option is so powerful that even when we are aware that something is not quite right about our judgment, it is nevertheless very difficult to resist the powerfully compelling intuitive choice (Gould 1992). Our findings suggest that autistic individuals, in contrast, do not experience such a compelling intuition and the conjunction fallacy, when it does occur, arises through an effortful process of contextualisation. On the other hand, autistic participants were as likely to use contextual information as the control group when reasoning about a single item. Thus, it seems likely that they are susceptible to some reasoning biases that are based on a less complex contextualisation process.

The finding that heuristic reasoning is less prevalent in a non-typical group also poses interesting questions about the adaptive value of reasoning heuristics. As Hertwig and Gigerenzer (1999) in their famous critique of the conjunction fallacy noted, committing the conjunction fallacy is clearly not rational according to the rules of probability theory and logic. However, it can be perfectly rational in a social sense. In support of this claim they give the following example. According to the basic principle of internal consistency, the preference for one choice over another should be independent of the availability of other alternative choices (that is, the context in which a problem is presented). However, imagine that you are taking part in a dinner party, and it looks like there are fewer pastries than there are people. Although you would normally have dessert, in this situation you decide that you will not take the last remaining éclair from the tray, giving a chance to other people to take it. This behaviour is not rational according to probability theory. Nevertheless, it is polite and makes perfect sense socially. As this example illustrates, the relevance of contextual processing is not restricted to the domain of reasoning. In fact its importance is much more evident in everyday situations (and in social situations, especially).

To the best of our knowledge this study is the first one to investigate reasoning heuristics in autism. It has its limitations, as we only looked at one type of heuristic, and the number of problems we used was small. However, research into the use of reasoning heuristics seems to be a promising path to a better understanding of higher order cognition in autism. The fact that autistic participants display less sensitivity to contextual cues than typically developing individuals when they evaluate choice options can also have profound consequences to their everyday lives.

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