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 Probability errors in children's judgements about the likelihood of social characteristics

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Abstract

The studies reported here investigated mechanisms underlying children's tendency to commit the conjunction fallacy (judging that a conjunction of two events is more likely than one of the events in isolation) when judging people's characteristics. Study 1 investigated these errors in 4- and 5-year-olds (N=58) using a newly-developed social judgement task in which children judged whether a conjunction or one of its elements would apply to a protagonist. Children made conjunction fallacy errors at chance level. Study 2 (N=71) replicated these findings using an adapted version of the task, in which children separately judged the likelihood of the conjunction and each of its events. Study 3 investigated age-related changes in conjunction fallacy errors in a sample of 148 4- to 11-year-olds and 130 adults. This study also investigated how providing background information on the protagonist influenced error rate. Unlike younger children, 10- and 11-year-olds committed the conjunction fallacy at chance level in the absence of background information, but providing information consistent with the likely component of the conjunction significantly increased their error rate. Adults' error rate also significantly increased after the introduction of background information. Across all three studies, conjunction fallacy errors were unrelated to cognitive and social-cognitive abilities, such as verbal ability, theory of mind, and inhibitory control (Studies 1 and 2), and prejudice and hindsight bias (Study 3). These findings suggest that it is only in the second decade of life that children use social information to inform their judgements about people, and that social decision-making errors are not determined by core aspects of cognitive and social-cognitive development.

Probability Errors in Children's Judgements about the Likelihood of Social Characteristics

We make numerous decisions every day, all of which are potentially subject to poor reasoning. Evaluating statistical probabilities is particularly prone to error, and these illogical reasoning strategies are consistent and common in even the simplest probabilistic problems. According to Bayesian reasoning, the probability that A and B are both true [P(A&B)] will be equal to the probability of A happening [P(A)] multiplied by the probability of B happening [P(B)] (Howson & Urbach, 1991). This is known as the conjunction rule, described by Tversky and Kahneman (1983, p. 294) as "the simplest and most fundamental qualitative law of probability". As Tversky and Kahneman (1983) pointed out, it is logically impossible for the probability of the conjunction, P(A&B), to be greater than the probability of either of its components, P(A) and P(B).

The conjunction rule can be illustrated using the example of drawing a playing card from a standard deck. Consider the probabilities of the following statements: "The card you drew is black" (1/2 chance, .50), "The card you drew is an ace" (1/13 chance, .08)*,* or "The card you drew is black and is an ace". The conjunction of the two statements will always be less probable than either of its component statements because multiplying the two probabilities (0.5 x 0.08 = 0.04) will always result in a lower value than that of each individual statement. It may seem highly unlikely that someone will judge more specific conditions as more probable than more general conditions, especially when considering an example with such clearly defined objective probabilities as a deck of cards. However, when we are required to make judgements about people, we frequently violate the conjunction rule, and are prone to the conjunction fallacy: judging the conjunction of two statements to be more probable than one of the component statements in isolation.

Conjunction fallacies were first studied by Tversky and Kahneman (1983), who investigated how adults make judgements about people based on simple statements about their characteristics and behavior. For example, participants were presented with the following short description: "Linda is 31 years old, single, outspoken and very bright. At university she studied philosophy. As a student she was deeply concerned with issues of discrimination and social justice and also participated in anti-nuclear demonstrations" (Tversky & Kahneman, 1983, p. 297). Participants were then asked to rank various statements from most likely to least likely. Crucially, the statements included "Linda is active in the feminist movement" (assumed to be likely, given the description), "Linda is a bank teller" (assumed to be unlikely), and the conjunction of these statements, "Linda is a bank teller and is active in the feminist movement". In light of the conjunction probability rule explained above, the conjunction should always be ranked lower than both of its component statements.

Interestingly, Tversky and Kahneman (1983) found that 85% of participants ranked the conjunction as being more likely than its unlikely component (Linda is a bank teller). An almost identical conjunction fallacy rate was observed for judgements about a character called Bill, with 87% of participants rating the conjunction "Bill is an accountant who plays jazz for a hobby" as more likely than "Bill plays jazz for a hobby" based on his staid description. Thus, when we have no objective data on which to base the perceived probabilities, there is a strong tendency for social stereotypes to influence decision-making, leading us to deem the combination of likely and unlikely statements to be more probable than the unlikely statement in isolation, and hence we commit the conjunction fallacy.

Tversky and Kahneman's (1983) original task required participants to rank the component and conjunctive statements according to their perceived likelihood, but conjunction fallacies have subsequently been observed when participants give each statement

a probability rating. Under these conditions, the conjunction fallacy is present when the participant judges the conjunction as more probable than either or both of its component statements (Tversky & Koehler, 1994). When presented with the probability version of the conjunction problem, there was a reduction in the fallacy rate, but it was still a substantial 70% (Fisk, 1996). Tversky and Kahneman (1983) attributed conjunction fallacies to the representativeness heuristic, according to which people judge the likelihood of a variable by how much it matches traits typically associated with a particular category (Kahneman & Tversky, 1972).

Compared with the substantial literature on adults, research into the conjunction fallacy during childhood is scarce. Using a social judgement task modelled on that used by Tversky and Kahneman (1983), Davidson (1995) reported a progressive increase in the conjunction fallacy between the ages of 7 and 12 years. Similarly, Jacobs and Potenza (1991) assessed children's self-reported decision-making processes during a social judgement task and found that the use of the representativeness heuristic increased with age from 6 to 11 years. While these two studies suggest that children become more prone to conjunction fallacy errors on social judgement tasks as they get older, research has not yet investigated the earliest age at which children make such errors, or what might account for this age-related shift in performance. Exploring these questions was the main aim of the three studies reported here. The studies were preregistered on the Open Science Framework (https://osf.io/t64m7/), and data from the studies are available via this platform.

Study 1

Previous research has investigated the conjunction fallacy only in children from age 6 upwards (Davidson, 1995; Jacobs & Potenza, 1991); we therefore do not know whether younger children are susceptible to the conjunction fallacy. Study 1 thus investigated whether 4- and 5-year-olds were prone to social conjunction fallacy errors. In order to explore these

errors in children of this age, we adapted the standard social conjunction task in order to make it more age appropriate. In Davidson's (1995) study, children were told stories about characters and then had to judge the likelihood of a series of statements using a 1 to 5 scale. In Study 1, the social vignettes were accompanied by interactive drawings, and rather than judging the likelihood of multiple statements, children simply had to choose between one of the two components versus the conjunction in making a decision.

Study 1 also investigated potential correlates of children's social conjunction fallacy errors. Our selection of potential correlates was based on aspects of core cognitive and social-cognitive development that undergo marked change across the early years of life, and could *a priori* be predicted to relate to children's judgements about others' social characteristics. An obvious construct that meets these criteria is theory of mind (ToM). Children's ToM abilities develop across the first decade of life, with children gradually beginning to grasp how people's beliefs and emotions influence their behavior (Wellman & Liu, 2004). As children acquire the ability to understand that others have thoughts and feelings that differ from their own and appreciate how internal states govern people's behavior and decision-making, they may be more influenced by information on a person's social characteristics and increasingly use this information to draw conclusions about how this person is likely to behave. The tendency to infer a person's characteristics based on a brief description, and then to rely on such characteristics in making judgements about the person, lies at the heart of conjunction fallacy errors in social judgement tasks. These errors may therefore be dependent on ToM abilities. In support of this proposal, the ability to understand others' mental states is important in various aspects of social decision-making, including understanding the intentions behind actions and social norm conformity (Frith & Singer, 2008; Rilling & Sanfey, 2011). The acquisition of more sophisticated understanding of others' internal states may thus account for the observed age-related increase in conjunction fallacy errors when

making social judgements (Jacobs & Potenza, 1991; Davidson, 1995). Study 1 investigated

for the first time whether children's conjunction fallacy errors and ToM abilities were

positively related.

The second potential correlate of conjunction fallacy errors investigated in Study 1

was executive function abilities. These abilities emerge close to the end of the first year of

life, rapidly changing between 2 years and 5 years of age, and reach adult levels of

performance around 12 years of age (Zelazo & Muller, 2002). Studies show a positive link

between increased executive function and a wide range of abilities, such as emotion

regulation (Zelazo & Cunningham, 2007), mathematics achievement (Brock et al., 2009;

Nguyen et al., 2019), the acquisition of complex rules (Zelazo et al., 2003), and the ability to

apply decision rules even where fluid intelligence and numeracy are controlled (Del Missier

et al., 2012). Executive function abilities also include prioritizing and sequencing behavior,

inhibiting familiar or stereotyped behaviors, creating and maintaining an idea of what task or

information is most relevant for current purposes, resisting information that is distracting or

task irrelevant, switching between task goals, utilizing relevant information in support of

decision making, categorizing or otherwise abstracting common elements across items, and

handling novel information or situations (Banich, 2009; Pennington et al., 1996). These

abilities all appear highly relevant for avoiding conjunction fallacy errors on social judgement

tasks, and we therefore hypothesized that executive function abilities would be negatively

related to such errors.

Study 1 also investigated whether children's receptive and expressive verbal abilities

related to their tendency to make conjunction fallacy errors. The tasks used to assess these

errors in children are linguistically complex, but previous research has not included a

standardized measure of verbal ability. Study 1 was thus the first to investigate how

children's verbal ability related to their tendency to make conjunction fallacy errors.

Interestingly, adolescents with Autism Spectrum Disorders (ASD) are less susceptible than their typically developing counterparts to the conjunction fallacy (Morsanyi et al., 2010). Given the different profiles in ToM, executive function, and language processing associated with ASD, these findings support the hypothesized role of these cognitive abilities in social decision-making.

In summary, Study 1 was the first to investigate (a) whether 4- and 5-year-olds were prone to conjunction fallacy errors, and (b) potential correlates of conjunction fallacy errors in children. We hypothesized that conjunction fallacy errors would be positively correlated with ToM abilities and negatively correlated with inhibitory control and language abilities; analyses to test these hypotheses were therefore confirmatory.

Method

Participants

The 58 participants (31 girls, 27 boys; 51 White, 6 Asian, 1 Black) were recruited from two schools in North-West England. The age range was 50–71 months ($M = 60.2$ months, $SD = 6.68$ months); there were 28 4-year-olds and 30 5-year-olds. The recruitment target was not met, and the study was underpowered to detect a medium-sized effect for the correlation analyses (power = .64). Bayesian analyses were therefore used to confirm the findings. No child had any diagnosed learning or neurological disorder according to reports from their teachers. Children were rewarded with stickers for their participation.

The study was approved by the University of York Ethics Committee, and data were gathered in accordance with the ethical code of practice of the British Psychological Society and fully complied with the Data Protection Act 1998. Parental/guardian consent and child assent for participation were obtained.

Materials and Methods

An experimenter administered the tasks individually to the children in a quiet area of their school in the order described below. Children were video-recorded while completing the tasks.

Verbal Ability. Children completed the Renfrew (2010) Bus Story Test to provide a standardized measure of their receptive and expressive verbal ability. The child was read a short story with four accompanying picture panels. When the experimenter finished the story, the child was asked to tell the story back to the experimenter as accurately as they could. Each child's speech was transcribed and scored on various metrics, such as information, sentence length, and use of subordinate clauses. The score used in the analysis is known as the A5LS, which represents the average length of the longest five sentences produced by the child.

ToM was assessed using a battery of six well established tasks (Wellman & Liu, 2004): diverse beliefs, knowledge access, contents false belief (self and other versions), explicit false belief, and unexpected transfer. Each task was scored as either correct or incorrect, giving a range of potential scores between 0 and 6. For each task, all control questions had to be answered correctly for the child to be given credit for passing the test question. Internal reliability of the ToM battery was Cronbach's α = .64.

Inhibitory Control was assessed using a Stroop task (Gerstadt et al., 1994) and a dimensional change card sort (DCCS) task (Zelazo, 2006). The Stroop task was a day/night picture card game, which required the child to inhibit their intuitive response and instead respond in the opposite manner. For example, the child was instructed to respond "night" if the card depicted a sun, and "day" if the card depicted a moon. A practice run for each card was carried out to confirm the child understood the rules before beginning the task. There were 16 trials, and children's total inhibition errors were used in the analyses.

In the DCCS (Zelazo, 2006), the child was asked to help sort some picture cards into category boxes; the sorting criterion was either the color of the picture or the shape of the picture (the sorting rule order was randomized). After the first sorting rule had been established, practiced across 2 trials, and tested in 6 subsequent trials, it was changed for the next 6 trials with no practice trials given. Scores for the total number of perseverative errors on the DCCS were used in the analyses.

Decision-making. The decision-making task was a novel procedure created for this study to provide a functional equivalent of the adult version that would be appropriate for children aged between 4 and 6. The child was asked to imagine a local school which had a new teacher who was trying to learn about all the students in their class. To do this, the teacher decided to pull the students' names out of a hat and ask each selected student to come to the front of the class and tell everyone about themselves. The experimenter demonstrated this procedure by showing children a drawing of the teacher and classroom, and then picking a name out of the hat through a slot in the picture. When a name was pulled out, the experimenter read out the name and explained that the goal was to work out what the selected student would tell the class. The child was presented with a sheet containing two illustrations, one representing the component and one representing the conjunction. For example, if Chloe's name was pulled out of the hat, the child had to decide whether she would tell the class that her favorite color is pink (component) or that her favorite color is pink and she likes vegetables (conjunction). The child was asked to select the option they thought Chloe would say by pointing to or voicing the corresponding illustration.

The component events were chosen to be generally accepted as likely (plays computer games, plays sports for boys; likes dancing, favorite color is pink for girls) and unlikely (wears glasses and likes vegetables for both genders) for children of this age range according to previous research (Cooke & Wardle, 2005; Corcoran, 2019; Food Foundation, 2020;

Homer et al., 2012; Horwood et al., 2005; Leonhardt & Overå, 2021; LoBue & DeLoache, 2011; Sport England; Statistica; Tuero et al., 2014). There were four trials of the task (two girls and two boys) and each trial had a likely–unlikely conjunction. For two of the trials (Chloe and Jack), children had to choose between a likely component versus the likely–unlikely conjunction (e.g., likes dancing versus likes dancing and wears glasses); for the other two trials (Rick and Sally), children had to choose between an unlikely component versus the likely–unlikely conjunction (e.g., likes vegetables versus likes vegetables and favorite color is pink). For each vignette, children received a score of 1 if they made the conjunction fallacy error, or 0 if they did not make the error.

Results

Descriptive Statistics and Preliminary Analyses

Table 1 shows the mean scores for all variables. Stroop and DCCS scores were positively correlated, $r(56) = .34$, $p = .010$, and scores for the two tasks were combined to give a total inhibitory error score. Correlations between the ToM, inhibitory control, and language measures are reported in the Supplementary Materials.

Rates of Conjunction Fallacy Errors

The percentage of children who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 52%, 53%, 43%, and 59%. Binomial tests showed that performance did not differ from chance on any of the four vignettes (ps = .896, .694, .358, and .237, for the Rick, Chloe, Sally, and Jack vignettes respectively).

To investigate whether the likelihood of the component influenced the conjunction fallacy error rate, error scores were calculated separately for the two vignettes where the component was likely (Chloe and Jack) versus unlikely (Rick and Sally). Error scores on these two types of vignette were positively correlated, $r(56) = .41$, $p = .001$.

There was no significant gender difference in the conjunction fallacy error rate (girls M=1.81, SD=1.30; boys M=2.37, SD=1.31), $t(56) = 1.64$, $p = .106$, $d = .43$, although the difference represented a medium-sized effect. The gender difference was further explored using a Bayesian analysis, setting the Bayes factor to BF_{01} to indicate the strength of evidence in favor of the null hypothesis. The Bayes factor was 1.52, indicating only anecdotal support for the null hypothesis. To investigate whether the perceived likelihood of the component influenced the conjunction fallacy error rate, the analysis was run separately for the vignettes where the component was likely (Chloe and Jack) versus unlikely (Rick and Sally). There was no gender difference in fallacy error rate when the component was likely (girls M=1.03, SD=0.71; boys M=1.22, SD=0.75), $t(56) = 0.99$, $p = .163$, $d = .26$. The Bayes factor was 3.24 for the likely component comparison, indicating substantial support for the null hypothesis. However, boys' error rate was higher than that of girls when the component was unlikely (girls M=0.77, SD=0.84; boys M=1.15, SD=0.81), $t(56) = 1.76$, $p = .047$, $d = .45$. The Bayes factor was 1.38 for the unlikely component comparison, indicating only anecdotal support for the null hypothesis.

Comparing the 4- and 5-year-olds with regard to the number of vignettes on which the conjunction fallacy was committed, there was no age-related difference in fallacy errors (4-year-olds M=2.18, SD=1.31; 5-year-olds M=1.97, SD=1.35), $t(56) = 0.61$, $p = .547$, $d = .13$. This null finding was confirmed using a Bayesian analysis: the Bayes factor was 4.29, indicating substantial evidence for the null hypothesis. Investigating the error rate on the vignettes where the component was likely versus unlikely also indicated no age-related differences: for the likely component comparison (4-year-olds M=1.18, SD=0.72; 5-year-olds M=1.07, SD=0.74), $t(56) = 0.58$, $p = .218$, $d = .15$; for the unlikely component comparison (4-year-olds M=1.00, SD=0.86; 5-year-olds M=0.90, SD=0.84), $t(56) = 0.45$, $p = .329$, $d =$

.12. Bayesian analyses indicated substantial support for the null hypothesis in both comparison conditions (Bayes factors of 4.34 and 4.63, respectively).

Correlates of Social Conjunction Fallacy Errors

Table 2 shows the correlations between the number of vignettes on which conjunction fallacy errors occurred and children's performance on the ToM, inhibitory control, and language ability tasks. As shown in Table 2, correlations for all associations were non-significant. These null findings were confirmed using Bayesian analyses, which indicated substantial evidence for the null hypothesis for all three correlations (see Table 2). Investigating the error rate on the vignettes where the component was likely versus unlikely also resulted in null findings. For the likely component comparison, correlations ranged between -.09 and .10, $ps > .445$; for the unlikely comparison, correlations ranged between .003 and .12, $ps > .369$. Bayes factors for all correlations indicated substantial evidence for the null hypothesis (range = 6.49 to 9.17).

Discussion

The study reported here sought to establish whether 4- and 5-year-olds are prone to social conjunction fallacy errors and to investigate potential correlates of these errors. Children's decision-making in Study 1 showed fallacy rates that did not differ from chance. With regard to age-related changes in the conjunction fallacy, the error rates in 4- and 5-year-olds did not differ. Contrary to our hypotheses, there was little convincing evidence that ToM or inhibitory control abilities were associated with errors; children's tendency to commit the conjunction fallacy was unrelated to their performance on the ToM and executive function tasks. These findings give no indication that greater awareness or understanding of others' mental states or poorer ability to inhibit prepotent information underlie children's tendency to be biased by background information provided on a protagonist. Children's receptive and expressive verbal ability was similarly unrelated to their tendency to make conjunction

fallacy errors. There was, however, a non-significant, medium-sized effect for gender differences in fallacy errors in the child participants, with boys scoring more highly than girls. Additional analyses investigating whether the perceived likelihood of the component influenced the conjunction fallacy error rate showed that boys made more errors than did girls specifically on the vignettes where the comparison was between the conjunction and the unlikely component.

While the results of Study 1 may indicate that 4- and 5-year-olds are not prone to the conjunction fallacy, the chance-level performance in Study 1 may be due to the fact that the social judgement task required children to make a series of binary decisions rather than assign actual probabilities to rate the likelihood of the components and the conjunction. Study 2 therefore adapted the task methodology to explore this issue. The task used in Study 2 was designed to provide data on children's social judgements that were more comparable with the data in the adult literature. In order to do so, children were asked to rate the likelihood of both components and the conjunction using an age-appropriate scale for each of the social vignettes. If the testing format was responsible for the chance performance observed in Study 1, fallacy rates significantly different from chance would be expected in Study 2.

A further aim of Study 2 was to attempt to replicate the null findings of Study 1 with regard to associations between conjunction fallacy errors and children's ToM, inhibitory control, and verbal abilities. In addition, Study 2 investigated a further potential correlate of these decision-making errors in children: cognitive planning. Children's cognitive planning is typically assessed using the Tower of London (ToL; Shallice, 1982), which is a spatial problem-solving task based on the Tower of Hanoi. This task assesses facets of executive function that complement those measured by the Stroop and DCCS tasks and that can be hypothesized to be involved in making conjunction fallacy errors. For example, the ToL indexes children's working memory and cognitive flexibility in devising and enacting

solution strategies. To succeed in solving the ToL problems most efficiently, children must mentally plan out their strategy and evaluate whether it is logical. Cognitive planning as assessed by the ToL shows continued development across childhood and into adolescence (e.g., Injoque-Ricle et al., 2014), and thus ToL performance meets the criteria outlined in Study 1 for selecting potential correlates of children's conjunction fallacy errors. If cognitive planning plays a role in social decision-making, conjunction fallacy errors would be hypothesized to relate negatively to ToL performance. Study 2 tested this hypothesis.

In summary, Study 2 built on the findings of Study 1 in a number of ways. Children's conjunction fallacy errors on the social task were assessed in a more fine-grained manner to investigate whether 4- and 5-year-olds were prone to these errors. Study 2 also investigated how children's probabilistic judgements related to core aspects of their cognitive and social-cognitive development, including cognitive planning abilities. We expected to replicate the null findings for associations between conjunction fallacy errors and children's ToM, inhibitory control, and language abilities. We hypothesized that cognitive planning would be negatively correlated with conjunction fallacy errors. The analyses to test these predictions were therefore confirmatory.

Study 2

Participants

The 71 participants (39 girls, 32 boys; 63 White, 7 Asian, 1 Black) were recruited from three schools in North-West England. The age range was 48 to 66 months, and the mean age was 57.9 months, $SD = 3.84$ months; 44 of the children were age 4 and 27 were age 5. The study was appropriately powered to detect medium-sized effects for the correlational analyses (power = .84); nevertheless, Bayesian analyses were used to confirm the findings. No child had any diagnosed learning or neurological disorders according to reports from their

teachers. Children were given stickers both during testing as an incentive, and a bag of stickers to take home as a reward.

The study was approved by the University of York Ethics Committee, and data were gathered in accordance with the ethical code of practice of the British Psychological Society and fully complied with the Data Protection Act 1998. Parental/guardian consent and child assent for participation were obtained.

Materials and Methods

The procedure and measures for the ToM, inhibitory control, and language assessments were identical to Study 1. Internal reliability of the ToM battery was Cronbach's $\alpha = .82$.

Decision-making. The social decision-making task materials were identical to those used in Study 1, but instead of making a binary choice between a component (e.g., likes vegetables) and the conjunction (e.g., likes vegetables and favorite color is pink), children rated the likelihood of both components and the conjunction for each of the four vignettes. The complete stimuli are provided in the Supplementary Materials. Before completing the task, children were introduced to the scale, which consisted of a range of faces stretching its full length, with the poles depicting a frowning sad face on the far left and a smiling happy face on the far right. The scale was numbered 0–7 in order to quantify children's judgements.

The experimenter explained that the far left (sad face) was for things the person was definitely not going to say; in probabilistic terms, it represents zero at the unlikely pole. Children were then shown a marker than could be stuck on the scale. It was explained that if the child was definitely sure the person was not going to say the sentence then the marker would go on the sad face; if they were not sure but thought the person would not say it, then it would still stay on the 'sad' side of the scale, but would not go all the way to the left. Likewise, the same process was explained for attributes which they were definitely sure the

person would say, with the happy face representing the likely probabilistic (1) pole of the scale. The children were instructed that if they did not know where one of the components should go, or were not sure if it should go on one side or the other, they should put the marker on the neutral face (representing .5 probability). Three practice trials tested the child's understanding of the happy and sad absolutes and the neutral ground; these took the form of simple qualifying questions such as "Can you show me where the marker goes if you are definitely sure the person does/does not do X?" and "If you are not sure if the person does X, where do you put the marker?"

Having established that children understood the scale, the social decision-making task began. After a name was pulled out of the hat, the child was required to judge the likelihood of the likely and unlikely components and the conjunction. Each was described and the child was then asked "Now think about the scale we have been using and look at the things that [Vignette name] might tell the class. Where do you think [component/conjunction] goes on the scale?" After having made the likelihood judgement, the marker was removed from the scale before the child was asked to make the next judgement. The children's judgements on the numerical scale were converted to probability values (e.g., 3.5 on a 0–7 numerical scale = .5 in probability), which were used in the analyses. After the components and the conjunction are converted to probability estimates, they are equivalent to the probabilities obtained in the adult literature. The comparative probabilities assigned to the two components and the conjunction were used to calculate whether the conjunction fallacy had been committed for each vignette, and the resulting error rate was used in the analyses.

Problem solving was assessed using the ToL task (Shallice, 1982). The set up included three beads (red, white, blue) and three pegs of varying sizes (space for 3, 2, and 1 beads) on a fixed board. The instructions were tailored to encourage the use of planning; the children were instructed to solve the problem in their heads before they committed to moving

any of the beads. Children were given two practice trials with simple 2 move problems before moving on to a total of eight trials of increasing difficulty: two 2 move, two 3 move, and four 4 move problems. Each trial was counted as a 'pass' only if it was completed in its minimum number of moves; therefore, a score of 0 indicated that none of the problems had been completed in the minimum number of moves and a score of 8 indicated that all of the problems had been solved in the minimum number of moves.

Results

Descriptive Statistics and Preliminary Analyses

Table 3 shows the descriptive statistics for all variables. Scores on the Stroop and DCCS tasks were not significantly correlated, $r(69) = .22$, $p = .070$, and were therefore analyzed separately. Correlations between the ToM, inhibitory control, language, and cognitive planning measures are reported in the Supplementary Materials.

Rates of Conjunction Fallacy Errors

Mean probability scores for each of the components and their conjunction across the four vignettes are presented in Table 4 and show that, for all vignettes, the likely component received the highest probability score, followed by the conjunction, and then the unlikely component. These data indicate that children's probability ratings were not random and that they interpreted the characteristics as likely versus unlikely in the expected way.

The percentage of children who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 65%, 66%, 56%, and 63%. Children committed fallacy errors above chance for the Rick ($p = .017$), Chloe ($p = .009$), and Jack ($p = .032$) vignettes, but performance on the Sally vignette did not differ from chance ($p = .342$).

Boys' conjunction fallacy error rate was higher than that of girls (girls $M=2.28$, $SD=1.15$; boys $M=2.78$, $SD=1.04$), $t(69) = 1.90$, $p = .031$, $d = .45$. A Bayesian analysis indicated anecdotal support for the null hypothesis, Bayes factor = 1.08. Comparing the 4-

and 5-year-olds, the fallacy error rate was non-significantly higher in the 5-year-olds (4-year-olds M=2.34, SD=1.16; 5-year-olds M=2.78, SD=1.01), $t(69) = 1.61$, $p = .056$, $d = .40$. A Bayesian analysis indicated anecdotal support for the null hypothesis, Bayes factor = 1.66.

Correlates of Conjunction Errors

Table 5 shows the correlations between conjunction fallacy errors and children's cognitive abilities. As shown in Table 5, fallacy errors were unrelated to inhibitory control, ToM, language, and cognitive planning. These null findings were confirmed using Bayesian analyses, which indicated strong evidence for the null hypothesis for the correlations with ToM and language ability, and substantial evidence for the null hypothesis for the correlations with DCCS Task errors, Stroop Task errors, and cognitive planning (see Table 5).

Discussion

The initial aim of Study 2 was to explore whether the binary choice format of the social decision-making task used in Study 1 accounted for the finding that children made conjunction fallacy errors at chance level. There were notable differences in fallacy rates between Studies 1 and 2. While children's tendency to make the conjunction fallacy did not differ from chance in Study 1, the fallacy was committed significantly above chance on three of the four vignettes used in Study 2. These findings suggest that Study 1's binary choice format may have been responsible for the observed chance-level performance. Moreover, they provide the first evidence that children younger than age 6 are prone to conjunction fallacy errors. With regard to age differences in conjunction fallacy error rates, there was some suggestion in Study 2 of an age-related increase in conjunction fallacy errors, with 5-year-olds having a non-significantly higher error rate than 4-year-olds.

Study 2 also attempted to replicate the findings of Study 1 regarding relations between conjunction fallacy errors in children and core aspects of development. Study 2

replicated Study 1's null findings for associations between children's conjunction fallacy errors and their inhibitory control, ToM, and language abilities. Study 2 also found that children's fallacy errors were unrelated to their cognitive planning abilities. These findings indicate that children's core cognitive and social-cognitive abilities do not relate to their tendency to make fallacy errors, both when they make binary decisions about whether the conjunction or one of its components is more likely (Study 1), and when they rate the probabilities of the conjunction and both of its components (Study 2). The results of Studies 1 and 2 do, however, suggest that children's gender is related to fallacy errors. There was a significant gender difference for (a) the binary comparison between the conjunction and the unlikely component in Study 1, and (b) the conjunction fallacy error rate in Study 2. In both studies, boys were more prone than girls to commit conjunction fallacy errors.

The main aim of Study 3 was to explore in greater detail how the design of the social task may influence the tendency to make the conjunction fallacy. It seems reasonable to assume that the nature of the background information provided plays a critical role in inducing the stereotypical judgements that may lead to conjunction fallacy errors. One way of testing the extent to which the background information plays a role in fallacy errors is to assess whether these errors are made in the absence of any information about the protagonist. Tversky and Kahneman (1983) reported that almost all of their adult participants avoided the conjunction fallacy error when no background information other than age and gender was provided on an individual. However, previous research has not explored how the presence or absence of background information relates to children's tendency to make these errors. Study 3 included a wider age range of children than that of Studies 1 and 2, as well as a sample of adults, whose data enabled us to attempt to establish the point in development when children's social judgements become adult-like. We hypothesized that, as they get older, children would become increasingly prone to conjunction fallacy errors when background

information was provided. We expected that adults would make logical probabilistic judgements in the absence of background information, but would be significantly more likely to commit conjunction fallacy errors when provided with information on the protagonists. Analyses to test these predictions were therefore confirmatory. Exploratory analyses investigated the age at which children's performance became more adult-like.

If the background information is instrumental in inducing fallacy errors, other types of stereotypical thinking or decision-making errors may relate to conjunction errors on social tasks. Study 3 investigated two such potential correlates of social fallacy errors: prejudice and hindsight bias. Research shows that stereotypes relating to gender are established by 3 years of age, as demonstrated by children distinguishing between objects and toys stereotypically associated with a particular gender (Banse et al., 2010). Racial stereotypes are also present as young as age 3 and further develop across the first decade of life (Aboud, 1988; Augoustinos & Rosewarne, 2001). Prejudice is an obvious measure of individuals' tendency to rely on stereotypes in making judgements about people and in shaping attitudes and behaviors toward different groups. As such, it may relate to both children's and adults' tendency to draw the stereotypical conclusions about people's social characteristics that are likely to make them more prone to conjunction fallacy errors. We therefore hypothesized that prejudice scores would be positively associated with children's and adults' tendency to commit the conjunction fallacy when they were provided with background information on the protagonists; analyses to test this prediction were confirmatory.

Hindsight bias specifically indexes the extent to which individuals revise their judgements based on their acquisition of new knowledge. Assessing hindsight bias in children typically involves measuring an informed child's estimates of a naïve individual's knowledge of the contents of toy boxes or the identity of visually degraded/obstructed objects (Harley et al., 2004). For example, Bernstein et al. (2004) presented line drawings of objects

and asked 3- to 5-year-olds to identify each object as fast as possible; the objects were visually obstructed in a number of ways such as blurring, pixel noise, or cropping, and gradually became clearer over time. Children then repeated the task and were asked to estimate the point at which another individual would be able to identify each object. Their results showed that children overestimated the naïve individual's ability to recognize the objects, stating that they would be able to identify the objects at a more degraded level than that at which they themselves had identified them. The adult participants in this study were also prone to hindsight bias, although to a lesser degree than the child participants. Hindsight bias is argued to be a by-product of the updating of knowledge (Hoffrage et al., 2000), and can therefore be hypothesized to play a role in individuals' tendency to be influenced by the background information provided in the social decision-making task. We thus hypothesized that hindsight bias would be positively correlated with conjunction fallacy errors in the standard version of task, in which participants are presented with background information; analyses to test this prediction were confirmatory.

Study 3

Participants

The adult participants consisted of 130 psychology undergraduate students (108 women, 22 men; 104 White, 14 Asian, 2 Black; mean age 19.8 years, $SD = 1.83$, range 18–27) who volunteered via the University's online participant recruitment website; participants were rewarded with course credit. Power to detect a medium-sized effect for a paired samples t test was .99; power to detect a medium-sized correlation was .97. The youngest age group of child participants consisted of 69 children (31 girls, 38 boys; 58 White, 9 Asian, 2 Black) recruited from two schools in North-West England; mean age 58.6 months, $SD = 2.97$, range 53–65 months. The middle age group of children, $n = 46$ (22 girls, 24 boys; 40 White, 6 Asian) was recruited from schools in North-East and North-West England; mean age 102.2

months, $SD = 8.70$, range 90–119 months. The eldest group of children, $n = 33$ children (19 girls, 14 boys; 29 White, 4 Asian) was recruited from two schools in North-West England; mean age 129.4 months, $SD = 4.40$, range 120–135 months. Note that the two older groups are smaller than the youngest group due to testing having been abandoned early because of the COVID-19 pandemic. Power to detect a medium-sized effect for a repeated measure ANOVA with three groups was .99; power to detect a medium-sized correlation was .81, .66, and .53 for the youngest, middle, and oldest age groups, respectively. As was the case with Studies 1 and 2, Bayesian analyses were used to confirm findings. No child across any of the age samples had any diagnosed learning or neurological disorders according to reports from their teachers. Children were rewarded for their participation with stickers.

The study was approved by the University of York Ethics Committee, and data were gathered in accordance with the ethical code of practice of the British Psychological Society and fully complied with the Data Protection Act 1998. Fully informed written consent was gained for adult participants; parental/guardian consent and child assent were obtained for child participants.

Materials and Methods

The tasks were completed individually; adult participants completed them alone in a testing room at the University, and the experimenter administered the tasks to the child participants in a quiet area of their school. All tasks were administered to both adults and children in computerized format.

Child Procedure

Decision-making. The social decision-making task was an adaption of that administered in Study 2, and used the same vignette materials and response scale. Children were first asked to decide on the likelihood of the two components and their conjunction for each of the four characters before being presented with any background information other

than their name. When the child had made initial judgements on the likelihood of both components and the conjunction, the experimenter provided the child with background information on each character. The child was told a short story, accompanied by a storyboard (presented on a laptop) regarding a day in the life of each of the characters. These stories were designed to further strengthen the perceived likelihoods of the component probabilities. For example, the description of Chloe was stereotypically feminine, and involved going shopping with her mother for clothes and toys (all of which were shown in pink colors on the storyboard). The child was then asked to judge the two components and the conjunction using the scale as before. The experimenter recorded the children's pre- and post-information judgements on a laptop. As in Study 2, the children's judgements were converted into probabilities. The comparative probabilities assigned to the two components and the conjunction in the pre- and post-information conditions were used to calculate whether the conjunction fallacy had been committed for each vignette. Scores for the number of vignettes on which the fallacy occurred were used in the analyses.

Prejudice was measured using an adaption of tasks to assess attitudes towards the in-group and the out-group within the literature (Cameron & Rutland, 2006; Stathi et al., 2014). Children were shown headshots of 10 children matching the participant's gender and approximate age. The headshots were standardized to make sure the expression in every photo showed the child smiling, with head position/size similar, eyes looking forward, on a white background with a red border. Of the ten total stimuli, four were photos of White children, four were children of Asian or Black ethnic origin, and the remaining two children had visible disabilities (Down syndrome and Cerebral Palsy). The White or Asian/Black group was scored as the outgroup depending on the individual child participant's ethnicity. The visible disabilities group was always scored as the out-group because none of the participating children had any disability.

Participants were presented with the photos in a random order via a computer presentation and asked to indicate on a 4-point scale (1- No way, 2- Not much, 3- Slightly, 4- Very much) for each photo how much they would like to make friends with the child. The wording of the question was based on the intergroup bias measure used by Abrams et al. (2015). A quantified prejudice score was calculated by subtracting the mean score for the out-group from the mean score for the in-group; a higher number therefore indicates more favorable attitudes toward the in-group than the out-group (i.e., higher scores index higher prejudice).

Hindsight bias. The task was based on the computer hindsight task used by Bernstein et al. (2004). A total of eight line drawings of common objects served as stimuli: aeroplane, bicycle, chair, clock, glasses, keys, scissors, and telephone. Each object was degraded in one of two ways: (a) by pixel noise, or (b) by cropping. Pixel noise was achieved by changing proportions of the image pixels into random grayscale; this was done in 10% intervals, decreasing from 100% pixilation. Likewise, the cropping procedure started in the middle of the image and expanded in 10 equal intervals to reveal the full image. Both degrading procedures therefore included 10 stages, from fully degraded to fully visible. The images were displayed via a computer program, which provided complete standardization across object size (240x240 pixels, screen resolution 1024x768), time (1,200 ms per image), and presentation order (alphabetical, as listed above).

Participants were seated approximately 60cm from the screen. Two practice trials were used, one of each degradation, with stimuli and degradation combinations which were not repeated during the remaining task. The first eight trials provided the baseline condition as none of the participants were aware of the object's real identity at the outset of these trials. For each trial, the child was asked to identify the object as soon as possible, and then watched the screen as the object appeared. The time taken to identify each object correctly was

recorded automatically by the experimenter pressing the space bar. Close synonyms of the object name (e.g., 'bike', 'cycle' for bicycle) were scored as correct.

Following the baseline measure, children were asked to estimate when a same-age peer would be able to identify the object. The 4- and 5-year-olds were provided with a toy character (Ernie from Sesame Street) and asked to estimate Ernie's answer. All other participants were asked to use an imaginary person called Ernie for their 'other person' perspective. It was reinforced that Ernie did not have prior knowledge of the objects, much in the same way the children approached their own baseline measure. At the outset of each trial in the hindsight condition, the object was shown in full and named by the children before running the trial. The verbal instructions were: "Tell me when Ernie might know what the picture is". Regardless of which trials were being completed, be it baseline or hindsight, degradation type (pixel noise/crop) and object presentation order remained constant.

Hindsight bias was expressed as a simple difference score: the hindsight score was deducted from the baseline score. A positive result indicated a hindsight bias and a negative result indicated inhibition (no hindsight bias).

Adult Procedure

Decision-making. Four vignettes were used in the social decision making task: the Linda and Bill scenarios (Tversky & Kahneman, 1983), the Ollie scenario (Tentori et al., 2013), and a new Ashleigh scenario created for this study. Adults first gave a baseline judgement on the probability of each component and the conjunction in the absence of any information on the vignette character, other than their name. The participants were asked to judge the perceived probability (by giving an integer between 0 and 100, where 0 is highly unlikely and 100 is highly likely) of the typically likely component, the typically unlikely component, and the conjunction of the two components. After completing these judgements, participants were provided with background information about the vignettes' characters.

Having read this information, participants were then asked to make the same judgements about the probabilities of the two components and the conjunction for each vignette. The complete vignettes are provided in the Supplementary Materials. As was the case for the child participants, the comparative probabilities assigned to the two components and the conjunction in the pre- and post-information conditions were used to calculate whether the conjunction fallacy had been committed for each vignette, and the resulting error rate was used in the analyses.

Prejudice was assessed using a battery of eight questions taken from a number of standardized questionnaires: the Collective Narcissism Scale (Golec de Zavala et al., 2009, 2013), the Right Wing Authoritarianism Scale (Altemeyer, 1998, Zakrisson, 2005). the Social-Dominance Orientation Scale (Pratto et al., 2013), the Centrality subscale of the Social Identity Scale (Cameron, 2004), and Perceived Threat of Immigrants in the United Kingdom. Each item was scored on a 7-point scale (1= strongly disagree, 7= strongly agree), and scores were averaged to give a total prejudice score ranging from 1 (low prejudice) to 7 (high prejudice). The battery had acceptable internal reliability, Cronbach's $\alpha = .61$.

Hindsight bias. The task was identical to that administered to the child participants, except for the adults pressing the spacebar themselves to indicate when they had recognized the object and being asked to respond in the second set of trials on the basis of when a naïve peer would recognize the objects. Hindsight bias scores were calculated in the same way as for the child participants: total response time in the second condition was deducted from the baseline response time; a positive result indicated a hindsight bias.

Results

Descriptive Statistics and Preliminary Analysis

Table 6 shows the descriptive statistics for all variables as a function of age group. For adults, a paired samples t test revealed no significant difference between object

identification time in the first ($M = 6.48$, $SD = 0.92$) and the second ($M = 6.51$, $SD = 1.50$) set

of hindsight task trails, $t(129) = 0.29$, $p = .773$, $d = .02$, indicating that adults did not show

hindsight bias. With regard to the different age groups of children, paired samples t tests

showed that identification time was significantly faster in the second set of trials compared to

the first set for the 4- to 5-year-olds (first set $M = 8.96$, $SD = 0.78$; second set $M = 7.19$, $SD =$

1.28), $t(68) = 12.88$, $p < .001$, $d = 1.72$, there was no difference in identification time for 7- to

9-year-olds (first set $M = 6.68$, $SD = 1.92$; second set $M = 6.45$, $SD = 1.64$), $t(45) = 0.99$, $p =$

.330, $d = .13$, and 10- to 11-year-olds were significantly faster in the first set of trials (first set

$M = 5.61$, $SD = 2.11$; second set $M = 6.23$, $SD = 2.03$), $t(32) = 3.79$, $p < .001$ $d = .58$. The

youngest age group was thus the only one to demonstrate hindsight bias. Prejudice and

hindsight bias scores were unrelated in adults, $r(128) = -.12$, $p = .194$, and in all three age

groups of children, rs .01 to -.22, ps .224 to .951.

Mean probability scores for each of the components and their conjunction across the

four vignettes in the post-information condition are presented in Tables 7 and 8 and show

that, for all age groups and all vignettes, the likely component received the highest

probability score, followed by the conjunction, and then the unlikely component. These data

indicate that children's and adults' probability ratings were not random and that they

interpreted the characteristics as likely versus unlikely in the expected way given the

background information provided.

Rates of Conjunction Fallacy Errors

In the pre-information condition, the percentage of adults making the conjunction

fallacy was as follows for the Linda, Bill, Ollie, and Ashleigh scenarios respectively: 19%,

19%, 13%, 21%. Binomial tests were used to investigate whether performance on each of the

vignettes was different from chance level. For all four vignettes, participants committed the

conjunction fallacy significantly lower than chance (all ps < .001). In the post-information

condition, the percentage of adults making the conjunction fallacy was as follows for the Linda, Bill, Ollie, and Ashleigh scenarios respectively: 45%, 40%, 43%, 49%. Committing the conjunction fallacy was no different from chance for the Linda ($p = .254$), Ollie ($p = .136$), and Ashleigh ($p = .930$) vignettes, but the fallacy error was significantly lower than chance for the Bill vignette ($p = .028$).

In the pre-information condition, the percentage of 4- and 5-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 44%, 42%, 46%, and 48%. Performance did not differ from chance on any of the four vignettes (ps = .336, .228, .630, and .810, for the Rick, Chloe, Sally, and Jack vignettes respectively). In the post-information condition, the percentage of 4- and 5-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 46%, 41%, 51%, and 45%. Performance did not differ from chance on any of the four vignettes (ps = .630, .148, 1.00, and .470, for the Rick, Chloe, Sally, and Jack vignettes respectively).

In the pre-information condition, the percentage of 7- to 9-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 83%, 59%, 70%, and 80%. Children made the conjunction error significantly above chance for the Rick, Jack (ps < .001), and Sally ($p = .011$) vignettes, but performance did not differ from chance for the Chloe vignette ($p = .302$). In the post-information condition, the percentage of 7- to 9-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 78%, 85%, 89%, and 74%. Performance was significantly above chance for all of the four vignettes (ps < .001 for Rick, Chloe, Sally, $p = .002$ for Jack).

In the pre-information condition, the percentage of 10- to 11-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively:

67%, 58%, 64%, and 61%. Performance did not differ from chance on any of the four vignettes (ps = .080, .487, .163, and .296, for the Rick, Chloe, Sally, and Jack vignettes respectively). In the post-information condition, the percentage of 10- to 11-year-olds who made the conjunction fallacy was as follows for the Rick, Chloe, Sally, and Jack vignettes respectively: 76%, 94%, 79%, and 91%. In the post-information condition, 10- to 11-year-olds made the conjunction error significantly above chance for all vignettes (ps < .001 for Chloe, Sally, and Jack, p = .005 for Rick).

In all three age groups of children, there were no gender differences in the rate of conjunction fallacy errors in either the pre-information (ts < 1.27, ps > .210) or post-information (ts < 0.99, ps > .330) conditions. Bayesian analyses were used to confirm these null findings. In the pre-information condition, there was substantial evidence for the null hypothesis for the 4- to 5-year-olds, Bayes factor = 5.39, and 10- to 11-year-olds, Bayes factor = 3.05, but anecdotal evidence for the null hypothesis for the 7- to 9-year-olds, Bayes factor = 2.24. In the post-information condition, there was substantial evidence for the null hypothesis for the 4- to 5-year-olds, Bayes factor = 4.87, and 10- to 11-year-olds, Bayes factor = 3.86, but anecdotal evidence for the null hypothesis for the 7- to 9-year-olds, Bayes factor = 2.97.

Does the Presentation of Background Information Lead to an Increase in Social Conjunction Fallacy Errors?

Table 6 shows the mean conjunction fallacy error rates in the pre- and post-information conditions for the different age groups. The adult and child data were analyzed separately. A paired samples t test showed that adults' fallacy error rate increased after the introduction of evidence $t(129)$ = 7.53, p < .001, d = .84. For children, the effect of introducing background information on the fallacy rate was investigated with a repeated measures general linear model, with fallacy error scores for the pre- and post-information

conditions entered as dependent variables and age group added as a fixed factor. There was a main effect of age group, $F(2, 145) = 31.07$, $p < .001$, $\eta^2 = .428$, a main effect of condition, $F(1, 145) = 14.24$, $p < .001$, $\eta^2 = .099$, and a significant age group x condition interaction, $F(2, 145) = 4.96$, $p = .008$, $\eta^2 = .069$. The interaction is shown in Figure 1. Post hoc paired samples t tests showed that pre- and post-information fallacy error rates did not differ in 4- to 5-year-olds ($p = .849$), that there was a non-significant increase in 7- to 9-year-olds' conjunction fallacy errors after the introduction of background information ($p = .084$), and that 10- to 11-year-olds' fallacy rate was significantly higher in the post-information condition than in the pre-information condition ($p = .001$).

Do Prejudice and Hindsight Bias Relate to Social Conjunction Fallacy Errors?

Given that we aimed to explore how prejudice and hindsight bias relate to a bias toward stereotypical or new information increasing proneness to conjunction fallacy errors, these analyses were run using the data only from the post-information condition. In adults, conjunction fallacy scores were unrelated to prejudice $r(128) = .05$, $p = .606$, and to hindsight bias, $r(128) = .01$, $p = .886$. In all three age groups of children, conjunction fallacy scores were unrelated to prejudice (rs $< .16$, ps $> .189$) and to hindsight bias (rs $< .15$, ps $> .246$). Bayesian analyses were used to confirm these null findings. In adults, there was strong evidence for the null hypothesis for the relations with prejudice and hindsight bias (Bayes factor 12.61 and 14.25, respectively). There was substantial evidence for the null hypothesis in all age groups of children for relations with both hindsight bias (Bayes factor 5.33–7.36) and prejudice (Bayes factor 4.49–7.64).

General Discussion

The main aims of the three studies reported here were to investigate whether children are prone to the conjunction fallacy on social decision-making tasks and to explore potential correlates of children's fallacy errors. Across the three studies, there was little convincing

evidence that 4- and 5-year-olds make the conjunction fallacy when judging people's characteristics. Children of this age made fallacy errors at chance levels in Study 1 using a binary choice format for the social decision-making task. The results of Study 2, in which children made probability judgements about the conjunction and component statements, showed that 4- and 5-year-olds made the conjunction fallacy above chance levels for three of the four vignettes. The discrepancy in results across the two studies therefore suggested that the binary format of the task used in Study 1 may have been responsible for children's chance level performance. However, 4- and 5-year-olds performed at chance level in Study 3, despite the fact that this study used the probability format of the social decision-making task used in Study 2, rather than the binary decision format used in Study 1. The probabilities that 4- and 5-year-olds assigned to the unlikely component also varied widely between Studies 2 and 3 (see Tables 4 and 7). Counterintuitively, higher probabilities were assigned to the unlikely component is Study 3 even though the extended background information used in this study should have further reinforced the likelihood of the likely component. The findings across the studies thus do not provide consistent evidence for very young children using social background information to inform their judgements about people's characteristics. This conclusion is underlined by Study 3's finding that 4- and 5-year-olds' probability ratings of the conjunction fallacy did not change when they were provided with background information on the story protagonists.

Study 2 indicated a non-significant increase in conjunction fallacy errors from 4 to 5 years of age, but the results of Study 3 showed that the tendency to make such errors in social decision-making changes considerably between the ages of 4 and 11 years. The 10- and 11-year-olds made logical decisions and were no more likely than chance to commit the conjunction fallacy in the absence of background information, but committed the fallacy when the information provided was consistent with the likely component of the conjunction.

The adults also performed in this manner, achieving a significantly higher rate of conjunction fallacy errors in the post-information condition compared with the pre-information condition. These findings suggest that, by the beginning of their second decade of life, children use social information to inform their judgements about people and arguably start to make these judgements in an adult-like manner. Like adults—but not like younger children—10- and 11-year-olds' tendency to make conjunction fallacy errors significantly increased when background information was provided on the protagonists in the vignettes.

Turning to the potential correlates of children's conjunction fallacy errors, our three studies failed to identify any aspect of cognitive or social-cognitive abilities that was related to children's decision-making errors. In Study 1, 4- and 5-year-olds' conjunction fallacy errors were unrelated to their ToM, inhibitory control, and language abilities. These findings were replicated in Study 2, using a refined version of the social decision-making task. Study 2 also found no association between conjunction fallacy errors and children's cognitive planning. In Study 3, we extended our search for potential correlates to children's tendency to be prejudiced or engage in hindsight bias; once again, there was no evidence that these cognitive biases related to conjunction fallacy errors. Neither was there any relation between conjunction fallacy errors and prejudice and hindsight bias in the adults who participated in Study 3. In all three studies, we confirmed our null findings using Bayesian analyses. These results suggest that children's social decision-making errors are not determined by these core aspects of cognitive and social-cognitive development, and that prejudice and hindsight bias cannot explain conjunction fallacy errors in either children or adults.

Advances in these core cognitive and social-cognitive abilities typically seen by age 5 prompted us to investigate whether 4- and 5-year-olds are prone to conjunction fallacy errors, given that previous research had not included children younger than age 6. However, the results of Studies 1 and 2 overwhelmingly suggest that the processes involved in 4- and 5-

year-olds' decision-making errors are orthogonal to core aspects of development—young children's tendency to avoid or make these errors thus does not appear to be determined by their increasingly sophisticated ToM, executive function, or language abilities. As discussed in the Introduction, conjunction fallacy errors are less commonly made by adolescents with ASD compared with their typically developing counterparts (Morsanyi et al., 2010). The fact that Studies 1 and 2 found no associations between conjunction fallacy errors and children's ToM, inhibitory control, or language abilities suggests that different processing in these areas cannot explain the superior performance of the ASD adolescents.

Our findings also suggest that there may be gender differences in children's tendency to make conjunction fallacy errors. The results of Studies 1 and 2 indicated that boys were more likely than girls to make these errors. However, this gender difference was not replicated in Study 3; boys and girls in all of the three age groups studied did not differ with respect to conjunction fallacy errors. Further research is therefore required to establish whether gender is reliably associated with these errors in social decision-making.

Given our null findings regarding correlates of conjunction fallacy errors, what other factors might help explain why they occur? As discussed in the Introduction, Tversky and Kahneman (1983) stated that the conjunction fallacy is a product of the more likely component within the conjunction pair being representative of background information, which results in the probability of a conjunction containing this likely component being boosted above the likelihood of the single unlikely component, and the conjunction fallacy thus being committed. More recently, Tentori et al. (2013) stated that the likelihood of the conjunction fallacy increased in accordance with the amount of inductive confirmation given to the components by the background evidence. Davidson (1995) interpreted the observed increase in these errors between 7 and 12 years as evidence for children becoming reliant on the representativeness heuristic in decision-making as they get older. However, the results of

Study 3 do not appear entirely consistent with these views. When children were required to

judge the probabilities of the components and the conjunction in the absence of any

background information, substantial probability scores were still assigned to the conjunctions.

These findings are therefore difficult to explain if the representativeness heuristic and

inductive confirmation are the decision-making processes that determine conjunction fallacy

errors.

In an alternative explanation for the occurrence of these decision-making errors, Fisk

and colleagues (Fisk, 2002; Fisk & Pidgeon, 1996) have demonstrated that it is the magnitude

of the unlikely (unrepresentative) component event that determines the probability assigned

to a conjunction of events in adults' decision-making. Fisk and Pidgeon (1996) investigated

different combinations of likely and unlikely statements, with the conjunctions consisting of

both likely, one likely and the other unlikely, or both unlikely statements. Consistent with

previous findings, the conjunction fallacy occurred most in the likely–unlikely pairs (64%),

followed by the likely–likely pairs (56%), and then unlikely–unlikely pairs (35%). A later

study by Fisk (2002) systematically varied the possible values assigned to the likely and

unlikely components to test how this influenced the value assigned to the probability for the

conjunction. For likely–unlikely combinations, no evidence was found for the more probable

component directly influencing the probability assigned to the conjunction. In Study 1,

children were required to choose between a component and a likely–unlikely conjunction,

with half of the trials involving a likely component, and half an unlikely component.

Interestingly, in all four vignettes, children in Study 1 made the conjunction error at rates that

did not differ from chance, and so their tendency to make the conjunction fallacy did not

appear to be influenced by the likelihood of the component. This suggests that young

children's evaluations of the relative probabilities of likely events versus likely–unlikely

conjunctions are markedly different from those of adults. Future research should investigate

in greater detail how manipulating the likelihood of the components of the conjunction influences children's tendency to make conjunction fallacy errors.

It would also be interesting to explore whether the source of the background information affects the extent to which it results in conjunction fallacy errors, given that young children have been found to be more likely to trust certain sources of information over others. For example, when judging the function of unfamiliar objects, children preferred to obtain information and were more likely to accept information if it was provided by a familiar rather than unfamiliar preschool teacher (Corriveau & Harris, 2009a). Preschoolers are also more likely to prefer information that is provided by informants who have been shown to be accurate rather than inaccurate (Corriveau & Harris, 2009b), and children's trust in the information provided by their mothers varies as a function of the security of the mother–child attachment relationship (Corriveau et al., 2009). Future research could therefore investigate whether conjunction fallacy errors differ if the familiarity, accuracy, and trustworthiness of the source of the information are manipulated.

Whether decision-making errors on social judgement tasks relate to the understanding of objective probabilities could also be explored. As discussed in the Introduction, the understanding of objective probabilities can be assessed in adults using tasks based on the likelihood of drawing particular cards from a standard deck. Fisk and Slattery (2005) designed a paradigm to assess 4- to 9-year-olds' objective probability judgements. The task involved three teddies who were split into two teams, and the child was required to judge which team was more likely to win a game where each teddy had to randomly draw out a specified color brick from their respective tubs. In the team with two teddies, both had to draw out the specified color in order for their team to win (this represents a conjunction). The ratio of colored bricks in each tub was manipulated to create an objective situation where the conjunction was always less likely than the component (i.e., the team with two teddies

winning should never be more likely than the teddy on its own winning). Fisk and Slattery found that the incidence of the conjunction fallacy fell as age increased.

Surprisingly, no study in either the adult or child literature has investigated how objective conjunction fallacy errors relate to the tendency to make such errors on social tasks. It may be that Study 3's finding that 10- and 11-year-olds tended not to commit the conjunction fallacy in the absence of background social information can be explained by their grasp of objective probability. Similarly, individual differences in understanding objective probability may underlie both adults' and children's tendency to make conjunction fallacy errors when judging people's likely characteristics. Investigating relations between objective and social decision-making errors in both adults and children is therefore a fruitful avenue for future research.

Finally, the results of Study 3 show how, as they get older, children increasingly use information on an individual's background to attribute social characteristics to that individual. While this type of heuristic thinking may be useful, it is also likely to increase children's tendency to make stereotypical attributions. It would be interesting to investigate how children would respond to our social decision-making task if the characteristics presented countered stereotypical attributes. Previous research has shown that 8- to 11-year-olds are less likely to make conjunction fallacy errors in judging social characteristics if they are provided with numerical information on the component and conjunction characteristics (Morsanyi et al., 2017); such numerical information was found to be more likely to reduce conjunction fallacy errors when presented in the form of pictorial cards rather than text-based descriptions (Schulze & Hertwig, 2022). Future research should explore whether these sorts of training procedures could be used to help children think logically and avoid stereotypes. If successful in doing so, such procedures have the potential to provide useful resources for

combatting stereotypes that could be used by schools, sports clubs, and other child-focused

organizations.

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Table 1

Descriptive Data for All Study 1 Variables

	M(SD)	Range
Theory of mind	3.24 (1.77)	0–6
Dimensional Change Card Sort Task errors	2.36 (2.91)	0–6
Stroop Task errors	7.93 (4.76)	0–16
Renfrew Language Assessment score	9.29 (3.85)	0–18
Conjunction fallacy errors total	2.07 (1.32)	0–4

Table 2

Correlations between Conjunction Fallacy Errors and Children's Cognitive Abilities

	Conjunction Fallacy Total	
	Pearson's *r*	Bayes factor
Theory of mind	.07	8.55
Inhibitory control errors	.13	5.92
Language ability	-.05	9.14

Table 3

Descriptive Data for All Study 2 Variables

	M(SD)	Range
Theory of mind	1.94 (1.60)	0–4
Dimensional Change Card Sort Task errors	3.61 (2.94)	0–6
Stroop Task errors	10.24 (4.91)	0–16
Renfrew Language Assessment score	8.78 (4.53)	0–22.60
Tower of London total score	3.17 (1.82)	0–8
Number of trials on which conjunction fallacy was made	2.51 (1.12)	0–4

Table 4

Descriptive Statistics for Probability Ratings for Each Component and their Conjunction for the Four Vignettes

	M (*SD*)	Range
Rick vignette		
Plays computer games (likely)	71.53 (38.38)	0–100
Wears glasses (unlikely)	49.80 (39.42)	0–100
Conjunction	58.45 (36.07)	0–100
Chloe vignette		
Favorite color pink (likely)	78.17 (29.89)	0–100
Likes vegetables (unlikely)	44.47 (40.82)	0–100
Conjunction	57.44 (34.62)	0–100
Sally vignette		
Likes dancing (likely)	79.68 (28.79)	0–100
Wears glasses (unlikely)	52.62 (37.14)	0–100
Conjunction	53.62 (37.14)	0–100
Jack vignette		
Plays sports (likely)	76.86 (30.03)	0–100
Likes vegetables (unlikely)	48.79 (41.22)	0–100
Conjunction	58.75 (37.28)	0–100

Table 5

Correlations between Conjunction Fallacy Errors and Children's Cognitive Abilities

	Conjunction Fallacy Average Probability	
	Pearson's *r*	Bayes factor
Theory of mind	.03	10.34
Dimensional Change Card Sort Task errors	.11	7.34
Stroop Task errors	.05	9.99
Tower of London score	.08	8.77
Language ability	.02	10.55

Table 6

Descriptive Data for Study 3 Variables as a Function of Age Group

	4- to 5-year-olds		7- to 9-year-olds		10- to 11-year-olds		Adult	
	M (SD)	Range	*M (SD)*	Range	*M (SD)*	Range	*M (SD)*	Range
Prejudice	0.33 (0.82)	-1.75–2.50	0.11 (0.56)	-1.00–1.58	0.02 (0.36)	-0.75–1.33	2.93 (0.64)	1.75–6.38
Hindsight bias	1.76 (1.13)	-0.87–5.63	0.30 (1.51)	-2.50–4.38	-0.69 (1.04)	-3.25–1.25	0.03 (1.37)	-2.50–3.13
CF pre-information	1.80 (1.05)	0–4	2.91 (1.19)	0–4	2.48 (1.46)	0–4	0.71 (1.04)	0–4
CF post-information	1.83 (1.26)	0–4	3.26 (0.98)	0–4	3.39 (0.86)	1–4	1.80 (1.47)	0–4

Note: CF = number of trials on which the conjunction fallacy error was made.

Table 7

Descriptive Statistics for Children's Probability Ratings for Each Component and their Conjunction for the Four Vignettes in the Post-Information Condition

	4- and 5-year-olds		7- to 9-year-olds		10- and 11-year-olds	
	M (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range
Rick vignette						
Plays computer games (likely)	74.50 (36.77)	0–100	69.80 (31.10)	0–100	71.11 (22.48)	0–100
Wears glasses (unlikely)	68.84 (39.98)	0–100	48.90 (36.50)	0–100	34.20 (30.82)	0–100
Conjunction	71.90 (35.71)	0–100	57.80 (27.50)	0–100	53.10 (26.15)	0–100
Chloe vignette						
Favorite color pink (likely)	87.43 (26.21)	0–100	93.89 (10.70)	44–100	93.76 (9.17)	63–100
Likes vegetables (unlikely)	73.20 (39.85)	0–100	35.20 (30.30)	0–100	39.80 (24.67)	0–100
Conjunction	74.10 (32.71)	0–100	57.50 (24.68)	1–100	70.60 (19.04)	0–100
Sally vignette						
Likes dancing (likely)	86.42 (27.37)	0–100	78.76 (25.90)	12–100	73.18 (25.31)	15–100
Wears glasses (unlikely)	54.30 (43.82)	0–100	29.70 (27.52)	0–100	35.30 (23.66)	0–80
Conjunction	69.00 (36.40)	0–100	57.80 (29.11)	1–100	55.50 (21.73)	0–100
Jack vignette						
Plays sports (likely)	81.87 (31.31)	0–100	94.26 (10.49)	55–100	93.00 (12.62)	52–100
Likes vegetables (unlikely)	69.20 (38.55)	0–100	45.00 (32.77)	0–100	51.30 (28.21)	0–100
Conjunction	72.20 (32.30)	0–100	60.60 (27.53)	0–100	74.80 (17.20)	4–100

Table 8

Descriptive Statistics for Adults' Probability Ratings for Each Component and their

Conjunction for the Four Vignettes in the Post-Information Condition

	M (SD)	Range
Linda vignette		
Active in feminist movement (likely)	78.28 (16.35)	10–100
Bank teller (unlikely)	35.63 (22.02)	0–100
Conjunction	41.91 (24.43)	0–100
Bill vignette		
Accountant (likely)	70.12 (18.15)	0–100
Plays jazz for a hobby (unlikely)	28.98 (23.01)	0–100
Conjunction	32.71 (25.07)	0–100
Ollie vignette		
Music lessons (likely)	71.92 (18.50)	20–100
Expert mountaineer (unlikely)	37.10 (20.64)	0–100
Conjunction	42.71 (24.43)	0–100
Ashleigh vignette		
Works at the zoo (likely)	72.12 (22.17)	1–100
Rides a motorbike (unlikely)	34.23 (27.18)	0–100
Conjunction	41.37 (26.94)	0–100

Figure Captions

Figure 1: Age-related changes in the influence of background information on children's

conjunction fallacy errors.