Developmental Science

Developmental Science (2014), pp 1–14 DOI: 10.1111/desc.12231

PAPER

The development of adaptive conformity in young children: effects of uncertainty and consensus

Thomas J.H. Morgan,[1,2] Kevin N. Laland[1] and Paul L. Harris[3]

1. Centre for Social Learning and Cognitive Evolution, School of Biology, University of St Andrews, UK
2. Department of Psychology, University of California, Berkeley, USA
3. Harvard Graduate School of Education, Harvard University, USA

Abstract

Human culture relies on extensive use of social transmission, which must be integrated with independently acquired (i.e. asocial) information for effective decision-making. Formal evolutionary theory predicts that natural selection should favor adaptive learning strategies, including a bias to copy when uncertain, and a bias to disproportionately copy the majority (known as 'conformist transmission'). Although the function and causation of these evolved strategies has been comparatively well studied, little is known of their development. We experimentally investigated the development of the bias to copy-when-uncertain and conformist transmission in children from the ages of 3 to 7, testing predictions derived from theoretical models. Children first attempted to solve a binary-choice quantity discrimination task themselves using asocial information, but were then given the decisions of informants, and an opportunity to revise their answer. We investigated whether children's revised judgments were adaptively contingent on (i) the difficulty of the trial and (ii) the degree of consensus amongst informants. As predicted, older but not younger children copied others more on more difficult trials than on easier trials, even though older children also showed a tendency to stick with their initial, asocial decision. We also found that older children, like adults, were disproportionately receptive to non-total majorities (i.e. were conformist) whereas younger children were receptive only to total (i.e. unanimous) majorities. We conclude that, whilst the mechanism for incorporating social information into decision-making is initially very blunt, across the course of early childhood it converges on the adaptive learning mechanisms observed in adults and predicted by cultural evolutionary theory.

A video abstract of this article can be viewed at http://youtu.be/Qb6JINGYqVk

Research highlights

- Older children, but not younger children, use the decisions of others to improve their performance on number judgments.
- Children are poor at using task difficulty to decide when to copy others.
- Older children are highly sensitive to small majorities, whilst younger children are only influenced by unanimity.
- Children have a tendency to stick with their own initial decisions no matter what others say.

Introduction

Cultural Evolutionary theory suggests that individuals should be selective with respect to when they adopt the decisions of others (Boyd & Richerson, 1985; Rogers, 1988), and that natural selection will lead to the use of adaptive learning strategies that guide the use of social information (Boyd & Richerson, 1985; Henrich & McElreath, 2003; Laland, 2004). Such 'social learning strategies' (also known as 'transmission biases'; Boyd & Richerson, 1985) have been primarily examined through population genetic and game theory modeling (Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Rogers, 1988; Feldman, Aoki & Kumm, 1996; Schlag, 1998, 1999; Wakano & Aoki, 2007; Enquist, Eriksson & Ghirlanda, 2007; Kendal, Giraldeau & Laland, 2009; Nakahashi, Wakano & Henrich, 2012; Kandler & Laland, 2013), and through experiments with human adults (McElreath, Lubell, Richerson, Waring, Baum, Edsten, Efferson & Paciotti, 2005; Efferson, Lalive, Richerson, McElreath & Lubell, 2008; Mesoudi, 2008, 2011; Toelch, Van Delft, Bruce, Donders, Meeus &

Address for correspondence: Thomas J.H. Morgan, Tolman Hall, Hearst Avenue, Department of Psychology, University of California, Berkeley, CA 94720, USA; e-mail: thomas.morgan@berkeley.edu

Reader, 2009; Toelch, Bruce, Meeus & Reader, 2010; Morgan, Rendell, Ehn, Hoppitt & Laland, 2011).

One such bias – a tendency to copy others when uncertain as to how to solve the task at hand – has been a central assumption of theoretical models of cultural evolution. Boyd and Richerson (1988) modeled individuals in a spatially and temporally variable environment. They postulated than when asocially acquired information left individuals uncertain, they should adopt the decisions of others. Enquist *et al.* (2007) considered a related rule called 'conditional social learning', by which individuals first learn asocially, but go on to learn socially if the result of their asocial learning is unsatisfactory, an outcome that is likely on more difficult tasks. Their analysis found this rule to be a successful strategy across a range of conditions – particularly when asocial learning is relatively cheap (i.e. energetically undemanding and/or low risk) (Enquist *et al.*, 2007). Evidence for a bias to copy others when uncertain also comes from empirical studies with non-human animals (Van Bergen, Coolen & Laland, 2004; Galef & Whiskin, 2008). In adult humans, across multiple tasks, individuals' confidence ratings in their performance strongly predicted whether they would revise their decision when presented with conflicting social information (Morgan *et al.*, 2011; See Morrison, Rothman & Soll, 2011; Soll & Mannes, 2011; Minson & Mueller, 2012). Furthermore, individual confidence ratings were shown to predict accuracy, supporting the notion that this strategy increases performance (Morgan *et al.*, 2011).

Another well-studied learning rule is 'conformist transmission' – not to be confused with conformity more generally (i.e. the adoption of majority decisions). As defined by Boyd and Richerson (1985), conformist transmission refers to the *disproportionately* large influence of majorities on an individual's decision-making. According to this strict definition, an individual is only defined as conformist if, given that they are otherwise naïve, the probability that they adopt the majority decision is greater than the size of the majority when considered as a proportion of the group of potential informants (Boyd & Richerson, 1985). To illustrate, consider a naïve individual choosing between options A and B who observes seven informants advocating option A and three informants advocating option B – thus, the (non-total) majority represents 70% of the group. In this case, if the probability that the individual chooses option A is greater than 0.7, they would be described as a conformist. If the probability that an individual adopts the majority decision is less than the size of the majority relative to the group, the individual is described as anti-conformist. In the hypothetical case, an anti-conformist would have a probability less than 0.7 (though potentially still > 0.5) of choosing option A. Hence our use of the term 'anti-conformist' need not imply a preference for the minority behavior. Finally, if the probability of adoption is equal to the relative size of the majority (i.e. equal to 0.7 in the hypothetical scenario), then proportional or unbiased transmission will occur. Accordingly, conformists, proportional copiers and (some) anti-conformists are all more likely to go along with the majority than the minority. However, the critical difference between them is in precisely how likely they are to do so. This difference is of importance because popular ideas and beliefs will spread to fixation in a population of conformists, whilst proportional transmission does not change the popularity of ideas and an anti-conformist population can either heterogenize, with all beliefs being equally frequent, or oscillate, with an endless succession of fads. Theoretical models suggest that conformist transmission, as defined above, is a highly effective strategy (Boyd & Richerson 1985), particularly favored in spatially variable environments, where there are errors in learning, and a greater number of options between which individuals choose. Nonetheless, conformist transmission can be disadvantageous in temporally variable environments because it hinders the initial spread of innovations (Nakahashi *et al.*, 2012).

Despite this theoretical background, the empirical evidence for conformist transmission in adults is mixed (Mcelreath *et al.*, 2005; Efferson *et al.*, 2008; Morgan *et al.*, 2011; Morgan & Laland, 2012). A plausible explanation for this is that whereas models have considered the effect of social information separate from any other information sources, experimental work has typically studied the decisions of individuals following both social and asocial information and so theoretical predictions are less likely to hold. In support of this explanation, when other sources of influence are controlled for, there is strong evidence for a conformist response to consensus underlying human decision-making (Morgan *et al.*, 2011). Thus while cultural evolutionary work has explored these issues using mathematical models and experimental studies involving adult participants, it has not greatly investigated the learning strategies of children.

In contrast, there have been numerous recent studies on social learning in children within developmental psychology (Koenig & Harris, 2005; Corriveau & Harris, 2009a; 2009b; Corriveau, Fusaro & Harris, 2009a; Corriveau, Harris, Meins, Fernyhough, Arnott, Elliott, Liddle, Hearn, Vittorini & de Rosnay, 2009b; Harris & Corriveau, 2011; Kinzler, Corriveau & Harris, 2011; Chen, Corriveau & Harris, 2013; Fusaro & Harris, 2013), with findings germane to the development of these learning biases. First, there is evidence of uncertainty guided social learning in infants (Harris & Lane, 2013) and young children (Sobel & Kushnir, 2013). For example, infants are more likely to rely on guidance from others when they encounter an uncertain as opposed to an unambiguous situation. Thus, 12- and 16-month-olds look more rapidly and more often at nearby adults, and copy the emotional reactions of those adults (e.g. make a negative response following fearful signals) when presented with an unfamiliar or strange toy, as opposed to a familiar toy (Kim & Kwak, 2011). When 18-month-olds face a slope of intermediate steepness, whether they walk down the slope or remain immobile depends on whether their mother's affective signals are positive or negative. Yet if the slope is either unambiguously gentle or steep, maternal input has little impact on their behavior (Tamis-LeMonda, Adolph, Lobo, Karasik, Ishak & Dimitropoulou, 2008). Similarly, 5- to 8-year-olds are more likely to endorse category labels that conflict with their own judgments when their prior knowledge is weak rather than strong (Chan & Tardif, 2013).

Despite these findings, other studies have found that the confidence ratings of 7–12-year-olds correlate poorly with accuracy unless children are given feedback to help them calibrate their ratings (Newman & Wick, 1987). However, recent work with 5-year-olds suggests that the effect of feedback was not to improve calibration, but simply to prompt children to evaluate how well they were doing, which they do not do otherwise (Odic, Hock & Halberda, 2012). Accordingly, it is clear that young children are sensitive to whether or not they have received any information but it is less clear whether they are able to estimate the strength of their information (i.e. how certain they can be) and whether they can use such estimates to guide their social learning such that their accuracy is increased.

There is also good evidence that children can use a consensus to guide their decision-making. For instance, when given conflicting names for a novel object by two different informants, if two bystanders signal agreement (via head nods and smiles) with the name supplied by one informant and disagreement (via head shakes and frowns) with the name supplied by the other informant, 4-year-olds overwhelmingly endorse the name eliciting bystander agreement (Fusaro & Harris, 2008). Similarly, if three informants all point to the same object as the referent of a novel name whereas a single informant points to a different object as the referent, 3- and 4-year-olds select the former when asked to identify the named object (Corriveau *et al.*, 2009a). Such sensitivity to informant agreement is seen in both Western and East Asian children, regardless of the culture of the informants (Chen *et al.*, 2013). Furthermore, 3- and 4-year-olds, having correctly identified the biggest line of a trio, will defer to a consensus of three informants who disagree with what the children can see for themselves (Corriveau & Harris, 2010) at rates similar to those observed in classic studies of conformity in adults (Asch, 1956; Bond & Smith, 1996). Similarly, 4-year-olds will defer to an obviously incorrect group of three peers, even if they later revert to their original decision in the absence of the informants (Haun & Tomasello, 2011). Thus, children often endorse a consensus when they lack relevant perceptual cues (as in learning names for novel objects) but they will even do so despite the availability of perceptual cues. Finally, 3–6-year-olds copy a behavior with higher fidelity when shown it performed once by each of two demonstrators than when they see it performed twice by a single demonstrator (Herrmann, Legare, Harris & Whitehouse, 2013).

Taken together, these findings show that young children are more reliant on the decisions of others when they feel uncertain and when informants are in agreement. Nevertheless, this body of research displays two key limitations, which we seek to address. First, the ability of young children to use uncertainty to successfully guide their use of social information and to improve the accuracy of their decision-making – a prediction of evolutionary theory – remains unclear. In particular, the relative certainty of the information made available to children has not been systematically varied. Second, the degree of consensus has also not been systematically varied, leaving it unclear whether children can be characterized as conformist, using the strict definition set out above (i.e. disproportionately sensitive to less than unanimous examples).

To resolve these questions, we present an experimental study in which children (aged 3 to 7) were given a task that they first attempted to solve themselves, but were then informed of the decisions of a group of adults and given the opportunity to revise their decision. We chose a task – selecting the more numerous of two dot arrays – in which task difficulty could be systematically varied. We also employed a large number of informants so that the number of informants who agreed/disagreed with the children's initial asocial decisions could also be systematically varied. We predicted that, with age, children's behavior would approach the adaptive behavior of adults expected by cultural evolutionary theory, with children becoming more adept at using uncertainty and consensus to guide decision-making with age. Specifically, we predicted that, with age, children would increasingly show the conformist transmission pattern defined by Boyd and Richerson (1985). Thus, we anticipated that older, but not younger, children would show an exaggerated receptivity to a less than unanimous majority.

Methods

General methods

Children took part in a computer-based, two-alternative forced-choice game using asocial and social information to make relative quantity judgments concerning pairs of arrays of dots. Children gained asocial information through direct observation of the arrays, and social information by watching a video of 10 adult informants. Each child completed five trials, taking 5 minutes, and was rewarded with a sticker for taking part, irrespective of their performance.

Participants and apparatus

One hundred and twenty-two children (55 males) took part, aged between 2 years 11 months and 8 years 11 months (mean age = 5 years 7 months, median = 5 years 5 months). The experiment took part in the 'Discovery Center' in the Museum of Science, Boston, and children were recruited from visiting families. Children played the game individually, although a parent/guardian was present throughout.

The task

We used the 'who-has-more' two-alternative, forced-choice, numerical discrimination task in which the child briefly sees two arrays of dots (each array belonging to a television character; Big Bird or Grover) and must decide who has more dots (see Figure 1a). This task was used because previous work has established that the difficulty of the task for young children varies with the degree of similarity between the number of dots that each character has (Halberda & Feigenson, 2008). This can be expressed as a dot ratio, calculated as the difference between the numbers of dots each character has, divided by the lesser number. For example, given 15 versus 25 dots, the dot ratio would be 0.66. As the dot ratio tends to 0, the trial becomes increasingly difficult. In adults, confidence ratings associated with decisions are robustly related to difficulty, with decisions on more difficult trials made with lower confidence (Pleskac & Busemeyer, 2010). Young children have also been shown to be sensitive to their performance, but only when prompted by the presence of feedback (and irrespective of the accuracy of the feedback itself; Odic *et al.*, 2012). Thus, we inferred that, if feedback in the form of the decisions of informants was sufficient to cause children to assess their state of knowledge, their uncertainty would vary across trials, depending on the dot ratio.

On each trial, each character had a random number of dots between 10 and 30 such that the dot ratio was between 0 and 1 (although there was always at least 1 dot difference between the two characters). The minimum of 10 dots was used because for numbers >10, dot ratio correlates with difficulty, whereas for lower numbers (< 5) individuals use different enumeration mechanisms (Lipton & Spelke, 2004; Feigenson & Carey, 2005; Carey, 2009). The location of each dot on its panel was randomized, no dots overlapped and the dot arrays were shown for 3.5s. We re-sized dots using an area

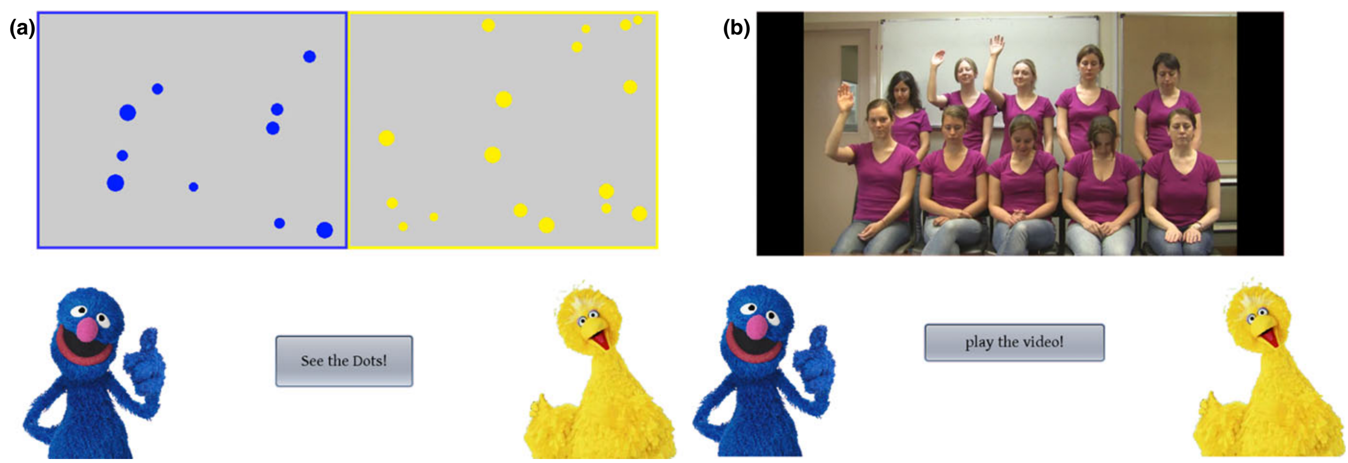

Figure 1 *(a) The 'who-has-more' task. Children were given a 3.5s viewing of the dots after which they were required to decide who had more. In this case, Big Bird has more. (b) The social information. After making an initial decision, children saw the decisions of 10 adult informants who were asked by a voice-over whether they thought each character had the most dots. In the still shown, three of the informants are agreeing with the character being suggested by the voice-over.*

anti-correlation procedure to prevent total area being a reliable cue to number (Halberda & Feigenson, 2008). Using this procedure, each trial had a 0.5 chance of being anti area-correlated in which case the relationship between the number of dots and the total area was reversed such that if one character had twice as many dots as the other character, the sum of their dots' areas was half that of the other character's dots. In addition, the diameter of each individual dot was multiplied by a number drawn from a uniform distribution ranging from 0.65 to 1.35 to add variation in size.

The social information

The social information was presented as a video of 10 informants, a random subset of whom claimed that Big Bird had more dots, whilst the others claimed that Grover had more dots (see Figure 1b). During each video, a voice-over asked the informants if they thought each character had more dots (e.g. 'Who thinks Grover has more? . . . . . . Who thinks Big Bird has more?'). At each asking, the informants who agreed with the voice-over nodded (a signal children are known to recognize) (Fusaro & Harris, 2013) and raised their right hand, whilst the others looked down and remained still in order to signal disagreement. We made four videos for each of the 11 possible levels of consensus (from 0 to 10 of the informants supporting each option, totaling 44 videos) with the spatial location of informants varying across videos such that each informant did not occupy a consistent location. All the informants were women and wore identical purple T-shirts without any identifying items (e.g. glasses). The intention was that children playing the game would not be able to recognize any informants across trials to prevent them from trusting specific individuals.

Procedure

Children joined the experimenter in the experimental area of the 'Discovery Center'. The experimenter explained how to play the game to children and then guided them through it, without leading their decision-making. For each trial, the child was first shown the dots (see Figure 1a), after which the child was asked which character they thought had more dots. Following their initial decision, a randomly selected video was played to provide social information (see Figure 1b). Note that because each video was randomly selected, children's initial asocial decision was sometimes endorsed by a majority of the informants and sometimes rejected – no matter whether that initial decision was wrong or right. After the video, children made a second, final decision and the trial was complete. The experimenter did not give children feedback on their final decisions during the experiment, both to see if children would assess their uncertainty without direct feedback, but also to avoid confidence hysteresis (Odic *et al.*, 2012). After all five trials, a final screen congratulated the child, informing them they had done 'really well' (irrespective of the child's actual performance), they were given a sticker and the experiment finished.

Analysis

We analysed the data with two Bayesian generalized linear mixed models (GLMMs), modeling the performance of children following asocial and all information, respectively, using Monte Carlo Markov Chain (MCMC) methods to estimate parameter values in OpenBUGS 3.2.1 (Lunn & Spiegelhalter, 2009; for a more detailed description of this approach, see Ntzoufras, 2009; for an accessible introduction to Bayesian methods for developmentalists, see Van de Schoot, Kaplan, Denissen, Asendorpf, Neyer & Van Aken, 2014). In this approach, several chains of values (Markov chains) are created for each parameter estimated by the model (we used three per parameter). Starting from arbitrary points, the chains converge and produce values according to the probability that they are the true value of the parameter. A large sample of these values is collected (we collected > 3000 per parameter), the median value of which can be considered the most likely estimate of the parameter. The uncertainty in this estimate is presented as a central credible interval (comparable to a confidence interval). The 95% central credible interval, for example, is the range of the sample excluding the top and bottom 2.5% of values, and there is a 95% chance that the true value of the parameter lies within this interval. A 95% central credible interval that does not include 0 has a similar implication to a p-value $< .05$ and we will describe this as strong evidence for that parameter having an effect. Although Bayesian approaches allow the combination of prior information with new data, to avoid the possibility that the deliberate selection of prior information could influence the results we used extremely vague priors throughout (see Supporting Information 1). Our final model was constructed by starting with a maximally complex model and removing all parameters for which the 90% central credible interval included 0 (i.e. parameters for which there was a < 90% probability of an effect). Unless otherwise stated, all graphs show median estimates and their 95% central credible intervals. For an illustration of how well our model was able to fit the data see Supporting Information 2.

We used this approach for several reasons. Firstly, our analysis incorporates several simultaneously varying parameters, some of which were modeled as linear (e.g. age, trial ratio) and others as categorical (e.g. sex), as well as random individual-level effects. For this type of analysis MCMC methods are recommended (Bolker, Brooks, Clark, Geange, Poulsen, Stevens & White, 2009). Secondly, the flexibility of the approach allowed us to build a model specifically tailored to the experiment that we carried out, for example, by including a parameter specifically testing for conformist transmission. Thirdly, *p*-values and confidence intervals produced by frequencist GLMMs are only approximations and are unlikely to be accurate without a very large dataset. Although MCMC methods also involve approximation, the accuracy of the approximation does not depend on the size of the dataset and these methods readily give very accurate approximations provided enough values are generated from the chains. Finally, analyses of this type can be used to generate quantitative expectations for children's behavior under all conditions modeled (e.g. what is the probability a child makes the correct initial decision given that trial ratio = 0.5 and they are 4 years 7 months old?). These estimates can be highly instructive in interpreting the values of parameters in the model and they are the values we show in our figures.

For some illustrative means and standard deviations of the raw data, see Tables 1–3. However, because the experiment involved several simultaneously varying factors and collected multiple data points from each child, we do not recommend relying on the numbers in the tables over those displayed in the graphs. As a test of the robustness of our finding, we repeated all analyses excluding data from children below 4 years old. This did not change our findings and so here we report results of the analysis involving all children. For a comparison of the results with and without data from children below 4 years old, see the Supporting Information.

Table 1 *Raw data averages, followed by standard deviations, for comparison with our model results*

Dot ratio	Initial accuracy	
	Mean	*SD*
0–0.2	0.69	0.46
0.2–0.4	0.64	0.48
0.4–0.6	0.84	0.36
0.6–0.8	0.84	0.37
0.8–1.0	0.86	0.35

Key: Initial Accuracy = the probability a child's initial answer (prior to hearing from the informants) was correct.

Asocial performance

We modeled the probability that a child's initial decision (prior to receiving social information) would be correct (p_1) as a Bernoulli variable (appropriate for binary data, in this case correct = 1 and incorrect = 0) and logit link function (which translates the probability of success into a continuous linear predictor). The linear predictor contained a baseline value (β_1), a function of dot ratio (DR), and an effect of which side of the screen the character with the most dots was displayed on, such that:

$$logit(p_1) = \beta_1 + DR + \beta_2{}^{*} side\ of\ screen, \quad (1)$$

where $\beta_{1,2}$ are coefficients, the values of which were estimated by the analysis. The function of dot ratio (DR) included age, sex, whether the trial was area-correlated or not and random individual level effects, such that:

Table 2 *Raw data averages, followed by standard deviations, for comparison with our model results*

Age	Initial accuracy		Switch*		Final accuracy**	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
3	0.71	0.46	0.35	0.49	0.53	0.5
4	0.69	0.46	0.42	0.5	0.68	0.47
5	0.78	0.41	0.36	0.49	0.79	0.41
6	0.79	0.41	0.4	0.5	0.88	0.33
7	0.91	0.28	0.6	0.5	0.91	0.3

Key: Initial Accuracy = the probability a child's initial answer (prior to hearing from the informants) was correct; Switch = the probability a child's final answer was different from their initial answer; Final Accuracy = the probability a child's final answer (after hearing from the informants) was correct. *Given that a majority, but not all, of the informants disagreed with the child. **Given that the majority of informants gave the correct response.

Table 3 *Raw data averages, followed by standard deviations, for comparison with our model results*

Proportion of informants who disagree	Switch	
	Mean	*SD*
0–0.2	0.12	0.33
0.2–0.4	0.23	0.42
0.4–0.6	0.29	0.46
0.6–0.8	0.47	0.5
0.8–1	0.59	0.49

Key: Switch = the probability a child's final answer was different from their initial answer.

$$DR = dot\ ratio^{*}(\beta_3 + \beta_4{}^{*}age + \beta_5{}^{*}sex + \beta_6{}^{*}area\ correalation + individual\ effects), \quad (2)$$

where $\beta_{3:6}$ are coefficients, the values of which were estimated by the analysis. Accordingly, the complete model is:

$$logit(p_1) = \beta_1 + dot\ ratio^{*}(\beta_3 + \beta_4{}^{*}age + \beta_5{}^{*}sex + \beta_6{}^{*}area\ correalation + individual\ effects) + \beta_2{}^{*}side\ of\ screen, \quad (3)$$

The calculation of DR allows the effect of dot ratio on performance to depend upon age, sex, area-correlation and individual. The baseline value (β_1) is intended to check the success of the model; a non-zero value of β_1 would indicate that the function of dot ratio cannot fully explain children's performance. The value of $logit(p_1)$ can be considered as a measure of the asocial information children were able to collect. The greater the magnitude of this value, the more certain children should feel in their decision. The screen side effect allows children, as a group, to have a bias towards choosing the character on a particular side of the screen. As part of the backwards elimination procedure, the following parameters were removed from the final model: the screen side bias, the baseline value, the interaction between area correlation and dot ratio and the interaction between sex and dot ratio (i.e. $\beta_{1,2,5,6} = 0$). This left the final model as:

$$logit(p_1) = dot\ ratio^{*}(\beta_3 + \beta_4{}^{*}age + individual\ effects), \quad (4)$$

Social performance

Next, we modeled the probability that a child's final decision (after receiving social information) would be correct (p_2) as a Bernoulli variable (1 = correct, 0 = incorrect) using a logit link function. The linear predictor contained additive effects of the child's asocial information (i.e. $logit(p_1)$, which interacted with age), the child's initial decision (1 = correct, 0 = incorrect, which interacted with age) and a function of the social information the child had received (*SI*, which interacted with age, sex, dot ratio and random individual level effects), such that:

$$logit(p_2) = (\beta_7 + \beta_8{}^{*}age)^{*}logit(p_1) + (\beta_9 + \beta_{10}{}^{*}age)^{*}intial decision + (\beta_{11} + \beta_{12}{}^{*}age + \beta_{13}{}^{*}sex + \beta_{14}{}^{*}dotratio + individual effects)^{*}SI, \quad (5)$$

where $\beta_{7:14}$ are coefficients, the values of which were estimated by the model. Including children's asocial information takes into account the differing levels of accuracy across ages and individuals, and is a measure of how certain children *should* be in their judgments. The effect of the child's initial decision serves as a measure of children's tendency to stick with their initial decision, regardless of the asocial information in its favor. The effect of the social information was calculated such that:

$$SI = q^s/(q^s + (1 - q)^s) - 0.5, \quad (6)$$

where q is the proportion of informants who are correct and s is the shape parameter, which interacted with age, such that:

$$s = exp(\beta_{15} + \beta_{16}{}^{*}age), \quad (7)$$

where $\beta_{15,16}$ are coefficients, the values of which were estimated by the analysis. $SI = 0$ when there is no majority ($q = 0.5$, i.e. 5 vs. 5 informants). If the value of the shape parameter (s) is greater than 1, the response to the degree of consensus is conformist as defined earlier. If it is less than 1, the response to the degree of consensus is anti-conformist (for graphs of this function see Supporting Information 3). If the value equals 1, then the response to consensus is proportional to the relative size of the majority. As part of the backwards elimination procedure, the following parameters were removed from the final model: the interaction between age and the asocial information, and the interactions between sex and *SI*, dot ratio and *SI* and age and *SI* (i.e. $\beta_{8,12,13,14} = 0$). This left the final model as:

$$logit(p_2) = \beta_7{}^{*}logit(p_1) + (\beta_9 + \beta_{10}{}^{*}age)^{*}intial\ decision + (\beta_{11} + individual\ effects)^{*}SI, \quad (9)$$

Results

Asocial performance

After receiving only asocial information, children performed much better on trials with a high (i.e. easier) rather than low dot ratio ($\beta_3 = 3.16$, [2.53, 3.95]) and the gradient of this improvement increased with age ($\beta_4 = 0.89$, [0.50, 1.38], see Figure 2a). This means that although children 4 years and up clearly perform above chance at higher dot ratios, the evidence that 3-year-olds do so is weaker (see Figure 2a). There was no evidence of a difference in performance between girls and boys ($\beta_5 = -0.15$, [−1.26, 0.96]) and only very weak evidence that area correlation helped performance ($\beta_6 = 0.75$, [−0.19, 1.71]). There was also no baseline performance independent of dot ratio ($\beta_1 = 0.25$, [−0.13, 0.62]) suggesting that the effect of dot ratio and its interactions were able to account for performance. Children did not, as a group, show a side preference ($\beta_2 = -0.13$, [−0.34, 0.08]). Finally, there was considerable individual variation in asocial performance (precision of population distribution: 0.33, [0.14, 1.32]).

Social performance

There is strong evidence that children's asocial information had less-than-expected influence when children made their final decision, consistent with them forgetting or undervaluing this initial information ($\beta_7 = 0.29$, [0.11, 0.50]). Thus, children displayed only a relatively weak increment in their tendency to stick with their initial decision on trials with a high (i.e. easier) as opposed to a

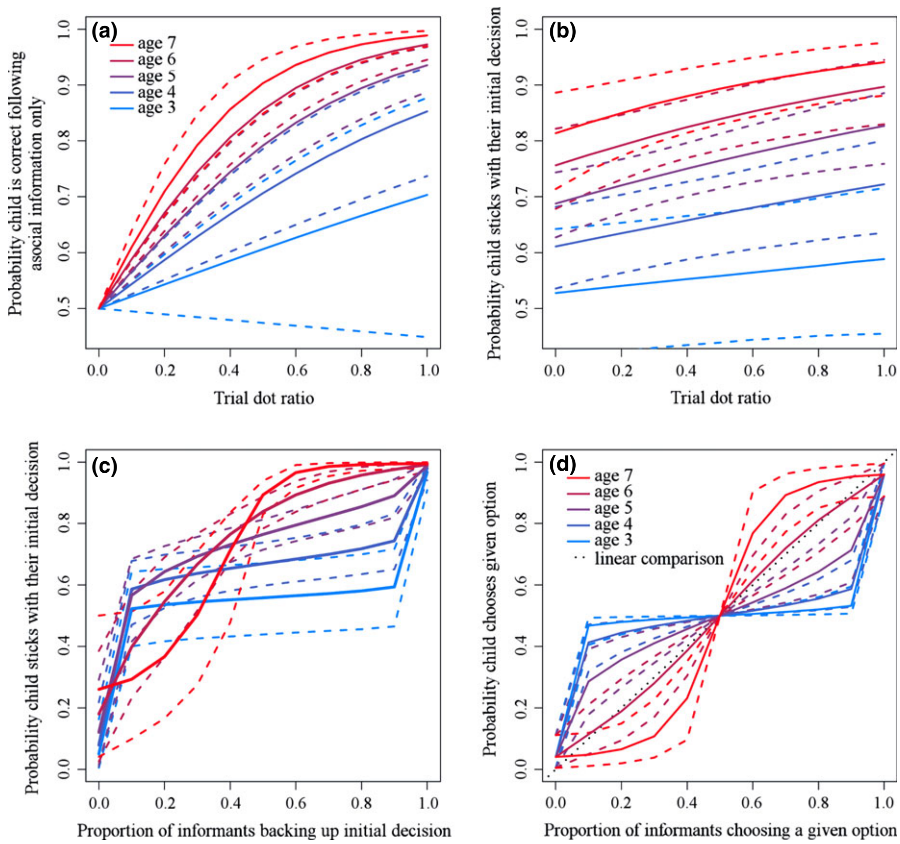

Figure 2 *Figures show median estimates (solid lines), and 95% central credible intervals (dashed lines). (a) Children's performance improved with dot ratio and with age. Six- and 7-year-olds start to hit ceiling performance at intermediate dot ratios, whilst there is not strong evidence that 3-year-olds perform above chance levels. (b) The probability that a child sticks with their initial decision for the case of 5 vs. 5 informants (i.e. no net social influence), such that whether or not a child sticks is based solely upon their asocial information and sticking tendency. Children showed a blunt tendency to stick with their initial decision across all dot ratios and hence irrespective of their asocial information. This tendency to stick increased with age; 7-year-olds always have a > 80% chance of sticking, whilst the behavior of 3-year-olds is consistent with sticking or switching at random. Nevertheless, children did show some sensitivity to how much asocial information they had collected, being more likely to stick on trials with a high, as opposed to low, dot ratio. (c) The probability that children stick with their initial decision for a trial with the intermediate dot ratio of 1.5. Three- and 4-year-olds are only affected by social information when there is unanimity amongst informants. However, 6- and 7-year-olds show a more nuanced response to social information and respond differently to the various possible levels of consensus in non-total majorities. (d) The response of children to social information alone (i.e. statistically controlling for asocial information). The black dotted line has a gradient of 1 (representing unbiased copying) and is for comparison with the other lines. Three-, 4- and 5-year-olds are anti-conformist in that they are at least somewhat insensitive to non-total majorities. Six-year-olds show a roughly proportionate response to the size of the majority. Seven-year-olds, by contrast, are conformist in that they show an over-proportionate sensitivity to small majorities.*

low dot ratio; compare gradient of lines in Figure 2b with Figure 2a). Moreover, this weak impact of asocial information did not appear to change with age (β_8 = 0.10, [−0.03, 0.24]). In addition to the somewhat muted effect of asocial information, children also showed a blunt tendency to 'stick' with their initial decision (β_9 = 1.96, [1.30, 2.61]), a tendency that increased with age (β_{10} = 0.68, [0.25, 1.12], see Figure 2b). The effect of asocial information and the sticking tendency are additive, such that children are less likely to change their mind on easier trials (in which they are likely to have collected more asocial information). Nevertheless, when considered across all cases, children show an overall tendency to stick with their initial decision.

Finally, despite their overall tendency to stick with their initial decision, children were clearly influenced by the information provided by the informants (β_{11} = 0.32, [0.21, 0.53], see Figure 2c). Their response to total majorities (i.e. when all 10 informants unanimously agreed with their initial asocial decision or unanimously disagreed with that decision) was considerable, and did not change with age (β_{12} = 0.05, [−0.02, 0.14]), sex (β_{13} = 0.05, [−0.17, 0.29]) or dot ratio (β_{14} = 0.11, [−0.17, 0.40]). However, their response to lower levels of consensus (i.e. less than unanimity) did change with age (β_{15} = −0.84, [−1.49, 0.14], β_{16} = 1.00, [0.62, 1.50]); children under 6 were 'anti-conformist', being relatively insensitive to the presence of less than unanimous majorities; 6-year-olds displayed a proportionate response, the extent to which the informants biased them towards a particular option was linearly related to the number of informants choosing that option; 7-year-olds were conformist, displaying a disproportionate response to less than unanimous majorities (see Figure 2d). Thus, there is a marked age change. Whilst, 3-year-olds do not distinguish between any intermediate levels of consensus and are only influenced by total majorities, 7-year-olds, by contrast, do distinguish between differing levels of consensus, and less than unanimous majorities have a relatively large influence.

There was little individual variation in the response to social information (precision of population distribution: 11.0, [3.37, 31.8]).

Discussion

Asocial performance

Our results provide good evidence that the experiment worked as intended, with children beginning to perform above chance from age 3, and accuracy increasing with both dot ratio and age, as has been found elsewhere (Halberda & Feigenson, 2008). Such findings are intuitively plausible because dot ratio corresponds to trial discriminability (the easiness of the trial) and because the ability to discriminate is likely to increase with age. Furthermore, all effects remaining in the model dealing with the initial decision were part of the function of dot ratio, which suggests that our model was able to explain the variation in performance well. It is of note that there was only very weak evidence for an interaction between area-correlation and ratio, suggesting that children were able to see past the area covered by dots and focus solely on the number of dots. We also find convincing evidence that there is no gender difference in performance on our task.

Consensus

The social information had a large effect on children of all ages. In the hypothetical absence of prior information, a child of any age exposed to a total majority (i.e. 10 vs. 0) has a 90% chance of endorsing the judgment of that total majority (see Figure 2d). However, the shape of the response to the consensus amongst informants changed sharply with age. Children aged 3–4 showed strong anti-conformism; total majorities had a strong effect, but levels of consensus that were less than totally unanimous had no systematic effect on their judgments. (Note, our use of the term 'anti-conformist' does not imply that young children exhibit a preference for minority positions, or a tendency to rebel, and is descriptive as opposed to mechanistic). Children aged 6 showed a broadly proportionate response; the probability of their being swayed by a less than unanimous majority was proportionate to the relative size of the majority. Finally, children aged 7 were conformist; they showed an enlarged or disproportionate response to non-total majorities (although not as strong as their response to a total majority). The conformism of 7-year-olds corresponds very closely to the adaptive decision-making mechanism predicted by the theoretical cultural evolution literature (Boyd & Richerson, 1985; Nakahashi *et al.*, 2012; Kandler & Laland, 2013). Moreover, it is the same response to a consensus that is seen in empirical studies of adults (Morgan *et al.*, 2011).

We can think of two possible explanations for children's increasing sensitivity to a less than unanimous majority: reflecting children's improving numerical abilities, or, alternatively, their developing appreciation of how to respond in the face of disagreement among informants. According to the first interpretation, children's developing ability to count the number of informants who agreed or disagreed with their initial asocial decision led to their placing increasing weight on the size of the majority with age. However, close inspection of the data suggests that this account is unlikely. Note that 3–4-year-olds responded similarly to any kind of disagreement among the informants; for example, they responded similarly whether nine of the ten informants agreed with their initial response or disagreed with their initial response. Yet, it is unlikely that younger children were unable to register that the majority (of nine) was numerically greater than the minority (of one) (Halberda & Feigenson, 2008). We believe that the second interpretation is more plausible. We may assume that all children, no matter what their age, were sensitive to whether there was a unanimous majority that agreed versus disagreed with their initial decision. Indeed, inspection of Figure 2d confirms that children in all five age groups sharply differentiated between these two cases, typically sticking to their initial decision following unanimous agreement and switching their initial decision following unanimous disagreement. Thus, developmental change is limited to cases where the informants disagreed. A plausible interpretation is that children develop an increasingly nuanced response to such disagreement. More specifically, 3–4-year-olds respond in a simple all-or-none fashion; they register whether or not there is disagreement but if it is present they ignore its direction and its magnitude. Thus, having registered any level of disagreement among the informants they are unsure whether to stick or switch. By the age of 6 years, children display a proportionate reaction; their tendency to stick or switch is calibrated to both the direction and magnitude of the majority. Finally, older children, notably 7-year-olds begin to treat all majorities in a similar fashion so that, for example, a majority of 7 to 3 is likely to impact their final decision almost as much as a majority of 9 to 1. The broader implication of this interpretation is that young children become disproportionately sensitive to the existence of a majority. The finding that conformist transmission appears at age 7, whereas many biases in trust appear considerably earlier, suggests that conformist transmission, at least in humans, relies on a comparatively complex appraisal of disagreement among informants. Accordingly, a prediction of this interpretation is that conformist transmission should be limited in its taxonomic distribution. Consistent with this, there is currently little evidence for conformist transmission in non-human animals (Hoppitt & Laland, 2013).

Other nuanced social behaviors also develop across a similar age range. For example, 3- and 4-year-olds do not discriminate between two choices with identical rewards to themselves, but different payoffs to a partner. However, above the age of 5, children do discriminate and also show contingent reciprocity in rewarding partners who previously behaved cooperatively but punishing those who did not (House, Henrich, Sarnecka & Silk, 2013). Similarly, although children between the ages of 3 and 8 endorse norms for sharing, only 7- and 8-year-olds actually share when the opportunity arises. Younger children even predict that they will not share, ruling out the possibility that their lack of sharing is due to a last-minute failure of willpower (Smith, Blake & Harris, 2013). These results, along with our own, illustrate an increasing social modulation of behavior between the ages of 3 and 8. Whilst the behaviors described are sufficiently dissimilar to make it unlikely that they are underpinned by the same cognitive mechanisms, they nonetheless have qualitative similarities, similar developmental trajectories and may be influenced by similar experiential factors. Collectively they illustrate a general increase in the complexity of children's social behavior.

Uncertainty

We varied trial difficulty in order to manipulate children's uncertainty – a variable predicted by cultural evolutionary theory to influence social learning and observed to do so in adults as well as non-human species (Boyd and & Richerson, 1988; Van Bergen *et al*., 2004; Morgan *et al*., 2011). However, going against this prediction, we found that children show little sensitivity to the magnitude of their initial asocial information when making their final decision (see Figure 2b). Furthermore, there was only very weak evidence that their sensitivity to that magnitude increases with age, suggesting that it was not part of a developmental trajectory. This suggests that children were not accurately monitoring their own initial uncertainty. In the context of other work which found that children only assessed their own performance when prompted to do so by the presence of feedback (Newman & Wick, 1987; Odic *et al*., 2012), a possible explanation is that the indirect feedback from informants did not trigger such evaluation. However, going against this interpretation, similar behavior has also been observed in adults. For example, although adults are known to copy others depending on their own confidence (Morgan *et al*., 2011), their confidence is imperfectly related to accuracy (Morgan *et al*., 2011; Luna & Martín-Luengo, 2012). Accordingly, the weak effect of prior asocial information that we found could be the result of children inaccurately translating their asocial information into confidence. Perhaps the most plausible interpretation is some combination of the two; both adults and children are imperfect estimators of their certainty, but children are the poorer of the two,

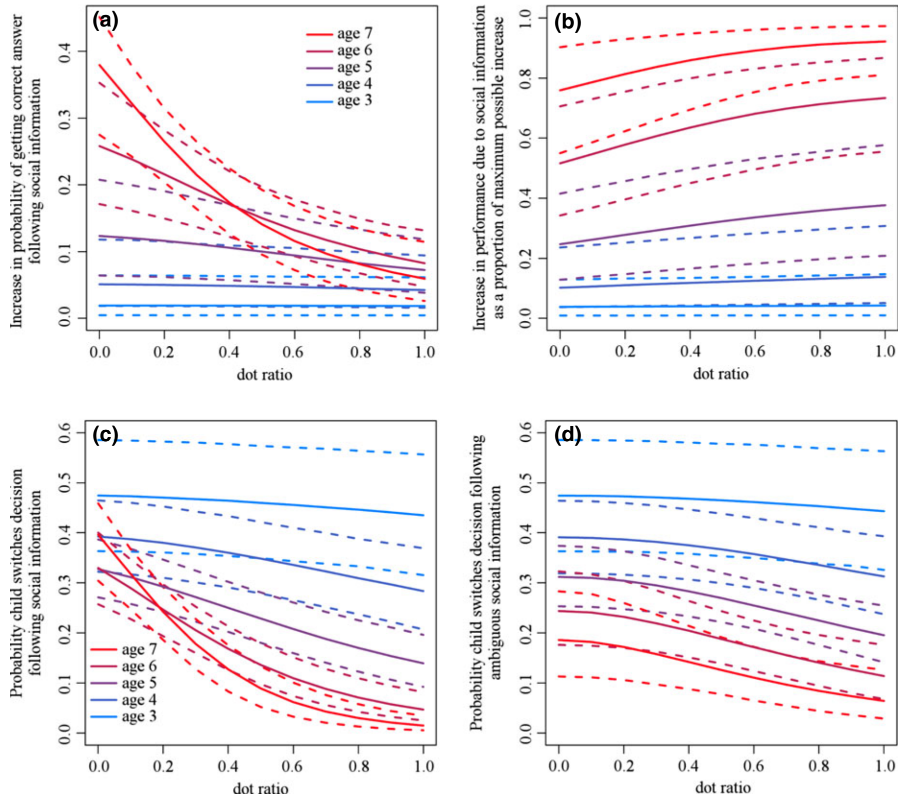

Figure 3 *Figures show median estimates (solid lines), and 95% central credible intervals (dashed lines). (a) Given that 8 out of the 10 informants give the correct answer, with age children were increasingly able to take advantage of the social information to improve their accuracy, particularly on the more difficult trials. For easier trials, the increase in performance due to social information was similar across ages. However, this is because on such trials older children are close to ceiling performance and so there is little room for further improvement. (b) In support of this, 7-year-olds nearly maximized their performance following social information, particularly on easier trials, whereas 3-year-olds take minimal advantage of the social information. (c) This graph is shows the effect of 8 out of the 10 informants disagreeing with the child on the probability the child switches. With age, children become more likely to switch following conflicting social information on more difficult trials relative to less difficult trials. Three-year-olds (in the absence of a total majority) are no more likely to stick than to switch, irrespective of trial difficulty. (d) This graph shows the effect of social information without a majority (i.e. 5 vs. 5 informants) on the probability a child switches. With age children are still more likely to change their decision on more difficult trials relative to less difficult trials. This tendency is much smaller than when the informants disagree with the children (panel c) and is likely due to children doubting their decisions on harder questions. The extent to which this sensitivity to difficulty dictates switching matches the extent to which difficulty affects asocial performance (Figure 2a).*

particularly if not prompted to evaluate their state of knowledge. A direct comparison between children and adults would be able to quantify this difference and may yet identify developmental changes.

In addition to the diminished effect of asocial information, children also show a tendency to ‘stick’ with their initial decision. Unlike the effect of asocial information, the sticking tendency does change across childhood, becoming more powerful with age. For 3-year-olds it is sufficiently weak as to be negligible. Above this age, however, it becomes an increasingly powerful influence (see Figure 2b). Again, similar patterns can be observed in the behavior of adults, where numerous experiments have documented that adults consistently give greater weight to their own decisions than they do to the decisions of others (Yaniv, 2004; Bonaccio & Dalal, 2006; Weizsäcker, 2010; Mesoudi, 2011; Soll & Mannes, 2011). There are several possible explanations for this developmental change. For example, a developing understanding of third parties having false beliefs or a desire to deceive the observer could lead children to increasingly rely on their own opinions. Another possible explanation is that children could inflate their sense of their own ability, over-riding the opinions of others, in order to maintain a positive self-image. Both these possibilities are considered in the adult literature (Soll & Mannes, 2011), and further work is necessary to understand the role they play in the development of the sticking tendency that we have observed.

Concluding remarks

A central prediction of this work, derived from Cultural Evolutionary theory, is that social learning should become more adaptive with age. The increasing strength of a sticking tendency might seem to contradict this, but direct examination of children's performance shows that, even with this increasing sticking tendency, the adaptive value of social learning increases across childhood (see Figures 3a and b), with the sticking tendency of over 5s being overcome by their increased sensitivity to non-total majorities. Thus, the behavior of 7-year-olds may not be optimal, but it is more adaptive than that of 3–4-year-olds and, as described above, it shows marked similarities to adult behavior.

A possible criticism of our design is that, because children always heard from the informants, we cannot differentiate between children changing their mind due to social influence or due to doubt about their initial decision. However, the experiment did include cases where the informants were equally divided (i.e. 5 vs. 5). Accordingly any change in the rate of switching when presented with a greater level of consensus than an equal split can be appropriately attributed to social influence. Such differences can be seen by comparing Figures 3d (which shows the response to 5 vs. 5 informants) and 3c (which shows the response to eight of the informants disagreeing with the child). In this case, for children under 6, the rate of switching is unchanged (this is to be expected given that children under 6 show little sensitivity to variation in the size of non-total majorities). By contrast, children over 6 (who are sensitive to non-total majorities) show an increase in switching, particularly on the harder trials. Accordingly, we can be confident that the decisions of the informants did influence children's behavior.

In sum, the effect of asocial and social information on children's decision-making changes with age towards the adaptive (though not optimal) decision-making mechanisms observed in adults. Three-year-olds' judgments are indistinguishable from random behavior unless they are presented with a total (i.e. unanimous) majority, in which case they are very likely to follow the informants. By age 6, children display a more nuanced pattern. They perform above chance, recall their previous decision and are biased in its favor even if the trial is extremely hard. They also switch or stick strategically depending on the size of the majority favoring one or the other. By age 7, children exhibit an adult-like pattern of disproportionate responding to a non-total majority. Overall, the findings show that the mechanism for incorporating social information into decision-making is initially very blunt and only sensitive to overwhelming social signals. Across the course of early childhood, however, it increasingly responds to small majorities, converging on those learning mechanisms observed in adults and predicted by Cultural Evolutionary theory.

Acknowledgements

We would like to thank Justin Halberda, Lisa Feigensen, Darko Odic, Thomas Schultz and Alison Gopnik for advice on the task and manuscript. Ethical approval for this study was given by the 'Committee on the Use of Human Subjects in Research' of Harvard University. This work was supported by an ERC Advanced Investigator grant (EVOCULTURE, Ref: 232823) to KNL and by a grant to the Museum of Science, Boston for 'Creating Communities of Learners'.

References

Asch, S.E. (1956). Studies of independence and conformity:a minority of one against a unanimous majority. *Psychological Monographs*, **70**, 1–70.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., & White, J.S. (2009). Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution*, **24**, 127–135.

Bonaccio, S., & Dalal, R.S. (2006). Advice taking and decision-making: an integrative literature review, and implications for the organizational sciences. *Organizational Behavior and Human Decision Processes*, **101**, 127–151.

Bond, R., & Smith, P.B. (1996). Culture and conformity: a meta-analysis of studies using Asch's (1952b, 1956) line judgment task. *Psychological Bulletin*, **119**, 111–137.

Boyd, R., & Richerson, P.J. (1985). *Culture and the evolutionary process*. Chicago, IL: University of Chicago Press.

Boyd, R., & & Richerson, P.J. (1988). An evolutionary model of social learning: the effects of spatial and temporal variation. In T.R. Zentall & B.G. Galef (Eds.), *Social learning: Psychological and biological perspectives* (pp. 29–48). Mahwah, NJ:Lawrence Erlbaum.

Carey, S. (2009). *The origin of concepts*. Oxford: Oxford University Press.

Cavalli-Sforza, L.L., & Feldman, M.W. (1981). *Cultural transmission and evolution: A quantitative approach*. Princeton, NJ: Princeton University Press.

Chan, C., & Tardif, T. (2013). Knowing better: the role of prior knowledge and culture in trust in testimony. *Developmental Psychology*, **49**, 591–601.

Chen, E.E., Corriveau, K.H., & Harris, P.L. (2013). Children trust a consensus composed of outgroup members: but do not retain that trust. *Child Development*, **84**, 269–282.

Corriveau, K.H., Fusaro, M., & Harris, P.L. (2009a). Going with the flow: preschoolers prefer nondissenters as informants. *Psychological Science*, **20**, 372–377.

Corriveau, K.H., & Harris, P.L. (2009a). Choosing your informant: weighing familiarity and recent accuracy. *Developmental Science*, **12**, 426–437.

Corriveau, K.H., & Harris, P.L. (2009b). Preschoolers continue to trust a more accurate informant 1 week after exposure to accuracy information. *Developmental Science*, **12**, 188–193.

Corriveau, K.H., & Harris, P.L. (2010). Preschoolers (sometimes) defer to the majority in making simple perceptual judgments. *Developmental Psychology*, **46**, 437–445.

Corriveau, K.H., Harris, P.L., Meins, E., Fernyhough, C., Arnott, B., Elliott, L., Liddle, B., Hearn, A., Vittorini, L., & de Rosnay, M. (2009b). Young children's trust in their mother's claims: longitudinal links with attachment security in infancy. *Child Development*, **80**, 750–761.

Efferson, C., Lalive, R., Richerson, P.J., McElreath, R., & Lubell, M. (2008). Conformists and mavericks: the empirics of frequency-dependent cultural transmission. *Evolution and Human Behavior*, **29**, 56–64.

Enquist, M., Eriksson, K., & Ghirlanda, S. (2007). Critical social learning: a solution to Rogers's paradox of nonadaptive culture. *American Anthropologist*, **109**, 727–734.

Feigenson, L., & Carey, S. (2005). On the limits of infants' quantification of small object arrays. *Cognition*, **97**, 295–313.

Feldman, M.W., Aoki, K., & Kumm, J. (1996). Individual versus social learning: evolutionary analysis in a fluctuating environment. *Anthropological Science*, **104**, 209–231.

Fusaro, M., & Harris, P.L. (2008). Children assess informant reliability using bystanders' non-verbal cues. *Developmental Science*, **11**, 771–777.

Fusaro, M., & Harris, P.L. (2013). Dax gets the nod: toddlers detect and use social cues to evaluate testimony. *Developmental Psychology*, **49**, 514–522.

Galef, B.G., & Whiskin, E. (2008). 'Conformity' in Norway rats? *Animal Behaviour*, **75**, 2035–2039.

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the 'number sense': the approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology*, **44**, 1457–1465.

Harris, P.L., & Corriveau, K.H. (2011). Young children's selective trust in informants. *Philosophical Transactions of the Royal Society, London B: Biological Science*, **366**, 1179–1187.

Harris, P.L., & Lane, J. (2013). Infants understand how testimony works. *Topoi*, doi: 10.1007/s11245-013-9180-0

Haun, D.B.M., & Tomasello, M. (2011). Conformity to peer pressure in preschool children. *Child Development*, **82**, 1759–1767.

Henrich, J., & McElreath, R. (2003). The evolution of cultural evolution. *Evolutionary Anthropology*, **12**, 123–135.

Herrmann, P.A., Legare, C.H., Harris, P.L., & Whitehouse, H. (2013). Stick to the script: the effect of witnessing multiple actors on children's imitation. *Cognition*, **129**, 536–543.

Hoppitt, W.J.E., & Laland, K.N. (2013). *Social learning: An introduction to mechanisms, methods, and models*. Princeton, NJ: Princeton University Press.

House, B., Henrich, J., Sarnecka, B., & Silk, J.B. (2013). The development of contingent reciprocity in children. *Evolution and Human Behavior*, **34**, 86–93.

Kandler, A., & Laland, K.N. (2013). Tradeoffs between the strength of conformity and number of conformists in variable environments. *Journal of Theoretical Biology*, **332C**, 191–202.

Kendal, J.R., Giraldeau, L.-A., & Laland, K.N. (2009). The evolution of social learning rules: payoff-biased and frequency-dependent biased transmission. *Journal of Theoretical Biology*, **260**, 210–219.

Kim, G., & Kwak, K. (2011). Uncertainty matters: impact of stimulus ambiguity on infant social referencing. *Infant and Child Development*, **20**, 449–539.

Kinzler, K.D., Corriveau, K.H., & Harris, P.L. (2011). Children's selective trust in native-accented speakers. *Developmental Science*, **14**, 106–111.

Koenig, M., & Harris, P.L. (2005). Preschoolers mistrust ignorant and inaccurate speakers. *Child Development*, **76**, 1261–1277.

Laland, K.N. (2004). Social learning strategies. *Learning and Behavior*, **32**, 4–14.

Lipton, J.S., & Spelke, E.S. (2004). Discrimination of large and small numerosities by human infants. *Infancy*, **5**, 271–290.

Luna, K., & Martín-Luengo, B. (2012). Confidence–accuracy calibration with general knowledge and eyewitness memory cued recall questions. *Applied Cognitive Psychology*, **26**, 289–295.

Lunn, D., & Spiegelhalter, D. (2009). The BUGS project: evolution, critique and future directions. *Statistics in Medicine*, **28**, 3049–3067.

McElreath, R., Lubell, M., Richerson, P.J., Waring, T.M., Baum, W., Edsten, E., Efferson, C., & Paciotti, B. (2005). Applying evolutionary models to the laboratory study of social learning. *Evolution and Human Behavior*, **26**, 483–508.

Mesoudi, A. (2008). An experimental simulation of the 'copy-successful-individuals' cultural learning strategy: adaptive landscapes, producer-scrounger dynamics, and informational access costs. *Evolution and Human Behavior*, **29**, 350–363.

Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, **32**, 334–342.

Minson, J.A., & Mueller, J.S. (2012). The cost of collaboration: why joint decision making exacerbates rejection of outside information. *Psychological Science*, **23**, 219–224.

Morgan, T.J.H., & Laland, K.N. (2012). The biological bases of conformity. *Frontiers in Neuroscience*, **6**, 1–7.

Morgan, T.J.H., Rendell, L.E., Ehn, M., Hoppitt, W.J.E., & Laland, K.N. (2011). The evolutionary basis of human social

learning. *Proceedings of the Royal Societyof London B: Biological Sciences*, **279**, 653–662.
Nakahashi, W., Wakano, J.Y., & Henrich, J. (2012). Adaptive social learning strategies in temporally and spatially varying environments : how temporal vs. spatial variation, number of cultural traits, and costs of learning influence the evolution of conformist-biased transmission, payoff-biased transmissi. *Human Nature*, **23**, 386–418.
Newman, R.S., & Wick, P.L. (1987). Effect of age, skill, and performance feedback on children's judgments of confidence. *Journal of Educational Psychology*, **79**, 115–119.
Ntzoufras, I. (2009). *Bayesian modeling using WinBUGS*. Hoboken, NJ: Wiley.
Odic, D., Hock, H., & Halberda, J. (2012). Hysteresis affects approximate number discrimination in young children. *Journal of Experimental Psychology, General*, **143**, 255–265. doi: 10.1037/a0030825
Pleskac, T.J., & Busemeyer, J.R. (2010). Two-stage dynamic signal detection: a theory of choice, decision time, and confidence. *Psychological Review*, **117**, 864–901.
Rogers, A.R. (1988). Does biology constrain culture? *American Anthropologist*, **90**, 819–831.
Schlag, K.H. (1998). Why imitate, and if so, how? A boundedly rational approach to multi-armed bandits. *Journal of Economic Theory*, **78**, 130–156.
Schlag, K.H. (1999). Which one should I imitate? *Journal of Mathematical Economics*, **31**, 493–522.
See, K.E., Morrison, E.W., Rothman, N.B., & Soll, J.B. (2011). The detrimental effects of power on confidence, advice taking, and accuracy. *Organizational Behavior and Human Decision Processes*, **116**, 272–285.
Smith, C.E., Blake, P.R., & Harris, P.L. (2013). I should but I won't: why young children endorse norms of fair sharing but do not follow them. *PLoS One*, **8**, e59510.
Sobel, D.M., & Kushnir, T. (2013). Knowledge matters: how children evaluate the reliability of testimony as a process of rational inference. *Psychological Review*, **120**, 779–797.
Soll, J.B., & Mannes, A.E. (2011). Judgmental aggregation strategies depend on whether the self is involved. *International Journal of Forecasting*, **27**, 81–102.
Tamis-LeMonda, C.S., Adolph, K.E., Lobo, S.A., Karasik, L.B., Ishak, S., & Dimitropoulou, K.A. (2008). When infants take mothers' advice: 18-month-olds integrate perceptual and social information to guide motor action. *Developmental Psychology*, **44**, 734–746.
Toelch, U., Bruce, M.J., Meeus, M.T.H., & Reader, S.M. (2010). Humans copy rapidly increasing choices in a multiarmed bandit problem. *Evolution and Human Behavior*, **31**, 326–333.
Toelch, U., van Delft, M.J., Bruce, M.J., Donders, R., Meeus, M.T.H., & Reader, S.M. (2009). Decreased environmental variability induces a bias for social information use in humans. *Evolution and Human Behavior*, **30**, 32–40.
Van Bergen, Y., Coolen, I., & Laland, K.N. (2004). Nine-spined sticklebacks exploit the most reliable source when public and private information conflict. *Proceedings of the Royal Society B: Biological Sciences*, **271**, 957–962.
Van de Schoot, R., Kaplan, D., Denissen, J., Asendorpf, J.B., Neyer, F.J., & Van Aken, M.A.G. (2014). A gentle introduction to Bayesian analysis: applications to developmental research. *Child Development*, **85**, 842–860.
Wakano, J.Y., & Aoki, K. (2007). Do social learning and conformist bias coevolve? Henrich and Boyd revisited. *Theoretical Population Biology*, **72**, 504–512.
Weizsäcker, G. (2010). Do we follow others when we should? A simple test of rational expectations. *American Economic Review*, **100**, 2340–2360.
Yaniv, I. (2004). The benefit of additional opinions. *Current Directions in Psychological Science*, **13**, 75–78.

Received: 16 September 2013
Accepted: 10 July 2014

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. & S2. A comparison of the average of the data (S1 shows initial asocial accuracy, S2 shows the rate of switching) with model predictions of those averages for trials of different dot ratios. The raw data averages are shown with the corresponding Wilson intervals, model estimates show the median estimate and the 95% central credible interval.

Figure S3. The effect of the social information on the probability a child adopts a particular option (SI, see equations 5 and 6) depends on the proportion of demonstrators supporting that option (q, see equation 6) and the shape parameter (s, see equations 6 and 7). Blue lines illustrate values of $s < 1$, red lines illustrate values of $s > 1$.

Table S1. A comparison of the results of analyses with and without data from 3-year-olds, showing the contents of the final model and the parameter estimates (showing median estimate and the 95% central credible interval).