Title
Individual consistency and flexibility in human social information use

Journal
Proceedings of the Royal Society B, 281(1776)

ISSN
0962-8452

Authors
Toelch, Ulf
Bruce, Matthew J
Newson, Lesley
et al.

Publication Date
2014-02-07

DOI
10.1098/rspb.2013.2864

Peer reviewed

PROCEEDINGS OF THE ROYAL SOCIETY B

rspb.royalsocietypublishing.org

Research

Cite this article: Toelch U, Bruce MJ, Newson L, Richerson PJ, Reader SM. 2014 Individual consistency and flexibility in human social information use. *Proc. R. Soc. B* **281**: 20132864.
http://dx.doi.org/10.1098/rspb.2013.2864

Received: 1 November 2013
Accepted: 21 November 2013

Subject Areas:
behaviour, cognition

Keywords:
social learning, development, individual differences, personality, collectivism, culture

Authors for correspondence:
Ulf Toelch
e-mail: toelch@gmail.com
Simon M. Reader
e-mail: simon.reader@mcgill.ca

Electronic supplementary material is available at http://dx.doi.org/10.1098/rspb.2013.2864 or via http://rspb.royalsocietypublishing.org.

Royal Society Publishing

Individual consistency and flexibility in human social information use

Ulf Toelch[1,2,3], Matthew J. Bruce[1,4], Lesley Newson[5,6], Peter J. Richerson[5] and Simon M. Reader[1,7]

[1]Department of Biology and Helmholtz Institute, and [2]Department of Innovation and Environmental Sciences, Utrecht University, Utrecht, The Netherlands
[3]Berlin School of Mind and Brain, Humboldt University, Luisenstrasse 56, Berlin 10117, Germany
[4]Arthur Rylah Institute for Environmental Research, Department of Environment and Primary Industries, Heidelberg, Victoria, Australia
[5]Department of Environmental Science and Policy, University of California, Davis, CA 95616, USA
[6]School of Psychology, University of Exeter, Exeter EX4 4QG, UK
[7]Department of Biology, McGill University, 1205 avenue Docteur Penfield, Montréal, Québec, Canada H3A 1B1

Copying others appears to be a cost-effective way of obtaining adaptive information, particularly when flexibly employed. However, adult humans differ considerably in their propensity to use information from others, even when this 'social information' is beneficial, raising the possibility that stable individual differences constrain flexibility in social information use. We used two dissimilar decision-making computer games to investigate whether individuals flexibly adjusted their use of social information to current conditions or whether they valued social information similarly in both games. Participants also completed established personality questionnaires. We found that participants demonstrated considerable flexibility, adjusting social information use to current conditions. In particular, individuals employed a 'copy-when-uncertain' social learning strategy, supporting a core, but untested, assumption of influential theoretical models of cultural transmission. Moreover, participants adjusted the amount invested in their decision based on the perceived reliability of personally gathered information combined with the available social information. However, despite this strategic flexibility, participants also exhibited consistent individual differences in their propensities to use and value social information. Moreover, individuals who favoured social information self-reported as more collectivist than others. We discuss the implications of our results for social information use and cultural transmission.

1. Introduction

Humans constantly make decisions by integrating information from individual experience and social sources, which can be optimized by balancing these information sources according to prevailing environmental circumstances [1,2]. The complex of abilities underlying human social cognition has led to remarkable cultural evolution and unmatched capacities to adapt to novel environments, shape current surroundings and to cope with new circumstances [2–4]. However, despite the importance of socially biased decision-making to human daily life, as well as to diverse animal species [5–10], many questions remain on how individuals integrate different information sources. Theoretical evolutionary models have explored factors that influence the relative reliability of social information in both humans and non-human animals, and thus make predictions about how social information use will be modulated under various conditions [1,7,11–16]. For example, when the cost or difficulty of learning a task individually increases, reliance on social information is predicted to increase [7,17]. An assumption common to several of these theoretical models is that when personally gathered information ('individual' or 'personal' information) on the optimal choice is equivocal, individuals will copy others [11,16]. This has led to the proposal, tested here, that individuals may employ a so-called 'copy-when-uncertain' social learning strategy [7].

Although empirical data have confirmed many theoretical predictions regarding the local conditions favouring social learning [7,18–20], striking variation between individuals in the degree of social information use has also been observed, results that were not predicted theoretically [21–23]. Such data raise the possibility that individuals may show consistent, context-independent differences in their propensity to learn from others, and that such differences may correlate with other personality traits. Individual differences in social learning propensities could potentially arise from multiple interacting sources, such as early life experiences, genetic differences or cultural influences [24,25]. There is a growing realization that such individual differences require theoretical attention and that individual differences in social learning may have crucially important effects on cultural evolution [23,26].

Our study pursued two goals. First, we tested the hypothesis that the reliability of individual information influences the propensity of participants to use social information. Second, we addressed the degree to which participants' use of social information in decision-making was context independent. We presented participants with two computer-administered tasks where participants could access information from other individuals completing the same tasks simultaneously. Both tasks required participants to make decisions based on the information they were given, and participants received monetary rewards based on the accuracy of their choices.

The first task, a 'stock-investment game', used a novel two-phase design to allow us to manipulate the reliability of personal information that participants received and to assess the confidence participants had in their decisions. Robust measures of the reliance on social information are critical to the field of social learning, but social learning studies typically rely on simple choices between acts. In many real-world situations, individuals can distribute investments between several alternatives instead of choosing exclusively one option, and thus we allowed participants to vary how much they invested in a choice based on how reliable they perceived their judgements to be. Moreover, the two-phase design allowed us to investigate the still untested 'copy-when-uncertain' assumption, namely that individuals assess the reliability of information gained by personal experience, and, if unreliable, exploit social information [7,16]. The second task was an established social learning task, the 'farming game' [22,27], which differed on multiple characteristics from the stock-investment game (see §2). The use of two tasks completed several days apart allowed us to test the prediction that individuals show some individual consistency in decision-making, with individuals favouring social information use to a similar degree in two different contexts. We also applied three established socio-psychological scales to address how social information use is linked to how individuals perceive themselves in relation to others. For this, we chose modified individualism and collectivism scales [28] and a narcissism scale (narcissistic personality inventory [29]). Collectivism has been linked to population differences in social transmission and markers of social sensitivity ([30–32], but see [33]), whereas narcissism has been linked to individualism [34]. We thus predicted that collectivist individuals would be more likely to employ social information, whereas individualist and narcissistic individuals would be less likely to do so.

2. Material and methods

(a) General procedure

Ninety undergraduate students of the University of California, Davis (all adults, age: mean $\pm$ s.d. $= 23.7 \pm 3.74$; 54 females) from various disciplines were recruited via posters and announcements to participate in two experiments ('games') that were played 2–5 days apart. Participants signed up for sessions online, and 4–10 participants took part in each experimental session. Experimental sessions took place in a computer laboratory, with computers separated by partitions and one participant per computer. Participants were asked not to communicate with each other during experimental sessions. After the first experimental session, the participants made a new appointment for a second session where they played the second game. We did not randomly assign participants to the second session but ensured that group composition was different from the first session. Participants knew that remuneration was performance dependent. However, participants were informed that they would receive a fixed amount ($10) after the first session with any remainder to be paid after the second session. This was to avoid the possibility that differential financial rewards in the first session influenced behaviour in the second session.

Prior to the first session, participants completed a questionnaire at home or in the laboratory. The questionnaire included the 40-item narcissistic personality inventory ([29], sample questions: 'I am an extraordinary person', 'I am more capable than other people'), a seven-item individualism scale ([28], sample items: 'I tend to do my own thing, and others in my family do the same', 'I am unique—different from others in many respects') and an eight-item collectivism scale ([28], sample items: 'Before making a decision, I always consult with others', 'I make an effort to avoid disagreements with my group members'), and questions on age, gender and other demographics.

The two games, the 'stock-investment game' and the 'farming game', differed on several characteristics. The games involved different contexts (stock-investment decisions versus crop-planting on a virtual farm), different rewards (financial pay-offs versus crop yields), different user interfaces, different forms of social information (information from one person versus multiple individuals; information on the current versus the previous round; information in the form of a hint another received versus an act they performed), different forms of individual information (hint versus yield) and different kinds of performance feedback (no versus immediate feedback). We counterbalanced game order so that approximately half experienced the stock-investment game first and half the farming game first. After the second session, participants answered a short questionnaire comparing the two games and were paid their remaining earnings. Participants each earned mean $\pm$ s.d. $= \$24.3 \pm 6.3$ in total.

(b) The stock-investment game

Participants played 150 rounds, each round consisting of two phases. A *click the square phase* (click-phase) was followed by an *investment phase* (investment-phase). Click-phase performance determined the accuracy of a personal hint for the investment-phase of that same round. We varied the difficulty of the click-phase to manipulate the reliability of this hint.

(i) The click-phase

Participants were asked to use the computer mouse to click on a square as soon as possible after it appeared on the screen. A trial began with a message to press any key to begin. The mouse pointer was locked to the upper left corner of the screen until a square appeared in a random location. We manipulated the difficulty of the click task by varying the square's location, colour and size. Participants initially played 20 training rounds of the click

rspb.royalsocietypublishing.org *Proc. R. Soc. B* **281**: 20132864

game that did not count towards the 150 rounds. At the end of this training phase all participants were told that they would receive information to help with their investment decisions ('stock tips') but the accuracy of these tips would be based on how quickly they had managed to click on the square. Participants were informed that, based on their performance in the training rounds, they would receive an accurate hint about 50% of the time.

(ii) The investment-phase

Participants had to invest 1–100 points in one of four options. This phase was framed as a stock-investment game and options had fictional company names. Participants were told that only one option was profitable and investing in this option would triple the invested points, while points invested in any other option would be lost. All points not invested were retained by the participant without modification. Participants did not see their winnings each round and were not informed whether they had chosen the correct option. We could thus assess participants' confidence in their investment decision, assuming that players would invest many points when they were confident, and fewer points when they were not. In every round, participants received a personal hint for the correct option (their 'individual information'), the accuracy of which was based on their speed in the previous click game round. If their speed was faster than their median response time during training, the hint was always accurate, but if their speed was slower than their median response time, the hint was a random pick of the four options. Participants were not informed whether their response time would result in an accurate hint but had to judge for themselves based on their past performance. To assess whether and for how long participants accessed the hints, hints were only visible when participants hovered their mouse above a box on the screen (figure 1*a*). In two-thirds of the rounds, participants could also access social information in the form of the hint of a randomly chosen player from the room, by hovering their mouse over another box on the screen. Players were not informed whether their hint was shown to another participant. This set-up created three situations for the participants: (i) only individual information available, (ii) matching ('confirming') individual and social information and (iii) conflicting individual and social information (figure 1*a*). In summary, participants did not receive feedback on their pay-offs but were informed that the performance in the click game had a direct impact on the reliability of their individual information.

(c) Farming game

Participants played a modified version of a well-studied farming game [22,23,27] in groups of four. In cases where the total number of participants was not a multiple of four, remaining participants were allocated to one group and saw decisions of three randomly selected players from the initial group of four participants. Participants made planting decisions on a virtual farm, choosing between four different crops (wheat, potatoes, barley and tomatoes) each season. Their aim was to maximize crop yields. Two crops, determined randomly but balanced across farms, had a higher mean yield than the other two (13 versus 10 units). Participants played 10 seasons (i.e. made 10 decisions) per farm. Participants were then given a new farm with new conditions and no connection to the previous farm. Players were informed of the shift to the new farm and that it was not connected to previous farms. Farms differed in the crops yielding high rewards and the variance associated with each option. In total, participants played on eight farms, and the variance was low on four farms (s.d. = 0.5) and high (s.d. = 4) on the remaining four. All members of each group experienced identical farms and social information was available as a box for each player on the screen. Hovering the mouse pointer over this box revealed which crop this particular player had chosen on the previous round but not the yield achieved from this crop. Players received information on the yields achieved by the crop they chose after they made their choice, but this was not visible to other participants. Thus, contrary to [27], social information on choice pay-offs was not available.

(d) Analysis

(i) Stock-investment game

We modelled the factors that influenced players' investment in a linear mixed model (LMM) in R v. 2.15.0 [35,36]. We transformed the invested amount by subtracting the median investment of each player from each investment. We tested for the influence of click-phase performance, gender and the three possible conditions (no, confirming and conflicting social information), and their two-way interactions on the median centred investment. Click-phase performance was z-transformed within subjects. We modelled player identity as a random effect on the three possible factor levels of the available social information and on the random slope of click-phase performance. Model selection was based on the deviance information criterion (DIC [37]). We explored several models with different combinations of independent variables and report the model with the lowest DIC, although other models with fewer predictors were similar in DIC. Including gender in the models did not yield a reduction in DIC and was thus omitted from the final model. The final model was inspected for deviations from assumptions by a qq-plot of the residuals and a plot of the residuals versus the fitted values [35].

(ii) Individual consistency

To test whether participants had a context-independent predisposition to use social information, we derived a measure describing the extent to which a player used social information from each game. For the farming game, we used s_f from the electronic supplementary material, equation S3, as an estimate of the extent of social information use. For the stock-investment game, we made use of the random effects estimates for each individual in our LMM. The specification of the fixed effects in our final model for the stock-investment game led to an estimate of a separate intercept for each social information condition (confirming, conflicting and no social information). The specification of a random effect led to varying estimates for each individual for each social information condition. That is, the random effects provide an estimate of how much each individual adjusted their investment for each social information condition relative to the model population estimate. We combined the random effects estimates when social information was confirming and when social information was conflicting to arrive at an estimate for social information use for each participant, termed s_i (see the electronic supplementary material for further details). The two factors from the experimental games together with three scores from psychological scales (narcissism, collectivism and individualism) were entered into a principal component analysis (PCA) using the principal function from the psych package under R v. 2.15.0. Data are archived online in the dryad repository (http://datadryad.org).

3. Results

(a) Stock-investment game

Participants finished within 20–25 min, collecting mean ± s.d. = 18 647 ± 4223 points with mean latencies of mean ± s.d. = 1.01 ± 0.24 s in the click-phase. Each participant differed

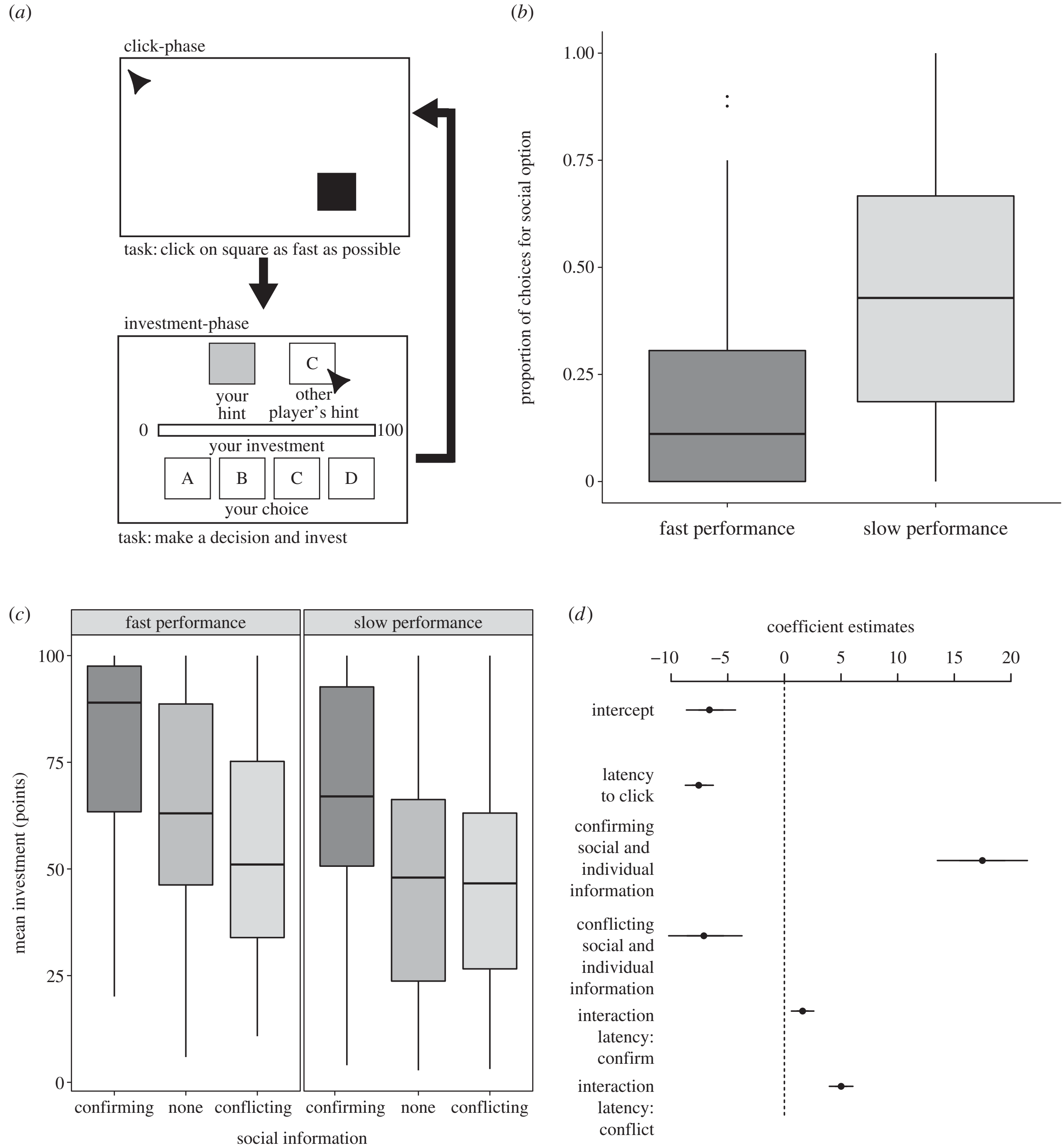

Figure 1. The stock-investment game. (*a*) Schematic of the task. Participants attempted to click a square on the computer screen as fast as possible. Performance in this click-phase determined the accuracy of a personal hint ('individual information') for the subsequent investment-phase, where participants chose how much to invest in one of four available stock options with fictitious company names (abbreviated here). Fast performance was likely to lead to an accurate personal hint, whereas slow performance was likely to result in an inaccurate hint. On two out of three trials, participants could also access the hint provided to another participant in the room ('social information'). Participants made hints visible by hovering the mouse over the boxes. (*b*) When personal and social hints conflicted, players were more likely to choose the social hint when they had performed relatively slowly in the click phase. (*c*) Participants made higher investments when their click-phase performance was fast versus slow. Participants reduced investment when they experienced conflicting social information compared to no social information, and increased investment with confirming social information. Boxplots cover the 1.5 interquartile range, with the box containing 50% of the data points. The horizontal line gives the median. (*d*) Results of a LMM examining the difference between each player's investment and median investment (see also the electronic supplementary material, figure S2). Coefficients of the LMM are depicted, with error bars showing the 95% CI. Effects are significantly different from zero if the error bars do not cross the broken vertical line at zero. Click-phase performance was analysed as a continuous variable; for exposition, (*c*) presents click-phase performance divided by the median into fast and slow. Residual analysis revealed no violations of assumptions, and a comparison with an intercept-only model revealed a lower DIC for the displayed model (displayed model DIC = 72396.5; intercept only DIC = 72640.5). A model including gender did not yield a reduction in DIC.

considerably in their click-phase performance from round to round (mean within-participant standard deviation of latencies = 0.58 s). Thus, the manipulation of click-phase difficulty and hence the reliability of individual information from round to round were successful.

Players looked longer at the available information (total mouse hover times) when social information conflicted with their individual information (the 'personal hint') compared to when social and individual information matched (confirming: mean $\pm$ s.d. = 0.5 $\pm$ 0.2 s; conflicting: mean $\pm$ s.d. =

0.9 ± 0.4 s; paired Wilcoxon signed-rank test with continuity correction: $V = 170$; $n = 90$; $p < 0.001$). Overall, players accessed the initially hidden social information on mean ± s.d. = 96.4 ± 0.7% of the trials by moving their mouse over the square containing this information.

Click-phase performance determined the reliability of the personal hint, and participants knew this from their instructions. We thus examined how click-phase performance affected the option chosen, dividing click-phase response times via a median split (i.e. fast versus slow responses). With only the personal hint available, participants almost exclusively copied this hint when they responded fast (percentage of choices for personal hint mean ± s.d. = 95 ± 13%), but significantly reduced choices for their personal hint when they responded slowly (mean ± s.d. = 85 ± 24%; paired Wilcoxon signed-rank test with continuity correction: $V = 718$; $n = 90$; $p < 0.001$; both proportions were higher than the 25% of choices expected if participants were choosing options at random). When the personal and social hints matched, participants copied the hints almost exclusively regardless of whether their click-phase performance was fast or slow (matching choices mean ± s.d. = 98 ± 10% versus 95 ± 18%, respectively; paired Wilcoxon signed-rank test with continuity correction: $V = 224$; $n = 90$; $p = 0.23$; electronic supplementary material, table S2). When the personal and social hints conflicted, participants were more likely to copy the social hint when their click-phase performance was slow than fast (matching social choices mean ± s.d. = 44 ± 30% versus 19 ± 23%, respectively; paired Wilcoxon signed-rank test with continuity correction: $V = 150$; $n = 90$; $p < 0.001$; figure 1*b*; analysis treating click-phase performance as a continuous variable rather than using a median split confirmed these results: electronic supplementary material, table S1). Copying of the social hint was significantly greater than the 25% chance expectation when click-phase performance was slow but not when it was fast (Wilcoxon signed-rank tests; $V = 3125$; $p < 0.001$; $V = 1223$; $p = 0.90$, respectively). Participants who copied the social hint more frequently, regardless of whether it was confirming or conflicting, had higher total scores. In summary, participants were aware of their performance in the click-phase and modified their reliance on both the personal and social hints accordingly.

(i) Investment

Further insight into participant behaviour comes from their investment decisions. Assuming that players invest more when they are confident of choosing the profitable stock option, the points invested provides a measure of choice confidence. Confirming this, participants invested considerably more points in correct than incorrect stock choices (investment when correct: mean ± s.d. = 90.1 ± 20.3 points; incorrect: mean ± s.d. = 55.9 ± 20.0; paired Wilcoxon signed-rank test with continuity correction: $V = 64$; $n = 90$; $p < 0.001$).

Participants' investment decisions were influenced by click-phase performance: slow performance generally resulted in reduced investment (figure 1*c*,*d*; see also the electronic supplementary material, figure S3 for individual decisions). When social information was available, a confirmatory match between personal and social hints increased investment over no social information available, while conflicting social information reduced investment (figure 1*c*,*d*). Confirmatory social information had a marginally stronger effect on investment when click-phase performance was slow versus fast, while conflicting social information had a weaker effect on investment when click-phase performance was slow versus fast (interaction effects, figure 1*d*). The latter interaction may be the result of a floor effect because investment was already low when click-phase performance was slow, thus limiting the possibility to decrease investment further. In summary, participants combined individual and social information to make investment decisions.

Table 1. Loadings of variables on the two components in a PCA (orthogonal solution) with scores for collectivism (COL), individualism (IND), narcissism (NARC) and two measures for social information use by participants in the farming game (s_f) and the stock-investment game (s_i). Component 1: eigenvalue = 1.44, variance contribution = 0.29; component 2: eigenvalue = 1.26, variance contribution = 0.25.

	component 1	component 2
s_f	0.76	0.06
s_i	0.70	−0.12
COL	0.61	0.12
IND	−0.01	0.78
NARC	0.01	0.78

(ii) Farming game

Participants learned the optimal crops for each farm over time, with superior performance on the low-variability farms (see electronic supplementary material). Virtually all players accessed the available social information at very high rates (see electronic supplementary material, figure S1*b*). However, there was considerable individual variation in the use of this social information in planting decisions, and for many participants the observed social information had little influence on their planting decisions (see electronic supplementary material, figure S1*c*).

(iii) Consistency of individual differences

To assess whether players had a general, context-independent tendency to use social information, we used the social information measures for each player from the two games; the maximum-likelihood estimates for the parameter s_f from the farming game (see electronic supplementary material) and the stock-investment game measure derived from the random effects of our model, s_i. The social information measures from the farming and stock-investment game, s_f and s_i, were positively correlated (Pearson's correlation; $p < 0.01$; $r = 0.29$), and participants with above average values of s_f also scored above average on s_i (Fisher's exact test, $p < 0.01$), indicating individual consistency. Within the stock-investment game, the random effects estimated from the social information conditions were correlated (Pearson's correlation; $p < 0.01$; $r = 0.49$), indicating that players reacted consistently across the two conditions.

In a further exploratory step, we conducted a PCA to examine interrelations between variables, incorporating the scores from the psychological scales (narcissism, individualism and collectivism) and the two social information measures. Two components had eigenvalues greater than 1 that together explained 54% of the variance (table 1 and

rspb.royalsocietypublishing.org Proc. R. Soc. B 281: 20132864

electronic supplementary material, table S3 presents the underlying correlation matrix). s_f, s_i and collectivism all loaded positively on component 1, while individualism and narcissism loaded positively on the second component. This suggests that component 1 represents variation in a general tendency to use social information.

4. Discussion

We uncovered both flexibility and consistency in social information use. As predicted, participants flexibly adjusted their weighting of social information according to local conditions, moderating decisions according to the reliability of individual cues. Despite this flexibility, participants exhibited consistent interindividual differences in their reliance on social information, both within the investment task and across the two tasks. Our exploratory PCA revealed that this tendency to use social information was strongest in collectivist individuals, while there was no evidence for links to self-reported individualism or narcissism. Notably, many individuals did not use social information even when it would have benefited them. Furthermore, in both tasks, participants routinely observed other players but frequently did not use this information, stressing the need to carefully evaluate whether and how individuals use the information they observe.

(a) Social versus individual information use in the stock-investment task

In the stock-investment task, participants guided investment choices by combining and comparing individual and social information. In our experiment, the reliability of individual information was linked to performance on a task, and choice confidence could be assessed by measuring the amount invested. Our data emphasize the importance of giving participants the option of differential investment in acts, because this revealed not only choice preferences but also the associated confidence in the respective choice. Participants assessed their own performance and invested more when individual information was likely to be reliable, and used the available social information to modulate this decision. When social and individual information suggested an identical option, investment increased, while when social and individual information conflicted, investment decreased. These social effects on investment were also moderated by the perceived reliability of individual information, and participants were more likely to follow social information if individual information was likely to be unreliable. Our data thus confirm the influential theoretical assumption that social information will be used when individuals are left in doubt on the basis of their own experience [1,11,16]. This 'copy-when-uncertain' learning strategy has not been unambiguously demonstrated up to now [7]. Moreover, our investment data emphasize that individuals copy when uncertain but can do so cautiously, investing little. A growing literature, in humans and other animals, indicates that when individual information is costly, outdated or not available, individuals will use social information [7,9,17]. In certain cases, individuals may even disregard individually acquired information if social information is sufficiently compelling [17]. Thus, individuals of numerous species use and integrate individual and social information flexibly depending on the prevailing conditions.

Our findings aid understanding of how decision-making in social contexts is influenced by the reliability of individual information and under what conditions individuals will deviate from individual or social information. In the stock-investment task, we deliberately prevented participants from learning about the reliability of social cues by not providing trial-by-trial performance feedback. Often, the utility of social information can be rapidly assessed and learned by observation of the rewards others receive or the rewards obtained by copying [9,38]. However, in many cases, direct feedback is unavailable or is delayed for a long period. Our experimental game thus has parallels to choices where social and individual information is available but the outcome of a decision is delayed, such as for habitats, mating partners or (in humans) pension schemes and medical treatments. In these cases, the possibilities for outcome-based learning are restricted, and individual proclivities for social information use are likely to be particularly important.

In many problems, individuals do not only decide between alternatives but can also allocate resources, such as time and energy, between options. Our data indicate that choice confidence will be an important driver of investment across choices. For example, hunters who make new arrowheads are unlikely to immediately discard the old arrowheads. Instead, confidence in their new arrowhead is likely to guide how much they hunt with the old versus trying the new. The fact that choice confidence was often low when personal and social information conflicted suggests that social information could prompt abandonment of one option and exploration of new options [39]. The modulation of choice confidence based on perceived reliability of available information may reduce the risk of adoption of disadvantageous traits, acting as an important cognitive mechanism guiding adaptive flexibility in behaviour [16,40].

(b) Context-independent, consistent individual differences

Confirming previous studies [21,23], we detected considerable individual differences in the propensity to use social information. Here, we demonstrate that these individual differences are consistent across contexts. Although a considerable part of the variance in participants' choices was unaccounted for, our results show that variance between individuals is partly explained by consistent individual differences in how players value social information. For example, some participants repeatedly disregarded social information in the investment task even though their own individual actions did not yield any useful information. At this early stage of investigation, it is too early to say whether this individual consistency arises because of differences in ability, personality or previous experience, or is a by-product of another individual difference. Animal work suggests that social information use may be part of a syndrome of correlated traits and has evolved together with other cognitive abilities [41,42]. Studies in diverse species have linked individual behavioural or physical characteristics to the propensity to employ social information [5,43,44]. For example, zebra finches *Taeniopygia guttata* that sampled their environment less actively were more influenced by social information in both foraging and mate choice decisions [45]. Individual propensities may emerge from previous experience with social information, from experience with environmental cues that indicate the potential reliability of social information, from evolved differences, or, most likely, from a combination of these possibilities [21,25]. Individuals may 'specialize' in particular information-gathering strategies, becoming more skilled in particular personal or social information strategies with experience. However, our data can equally support the view that flexibility is constrained. The net costs or benefits of the observed individual differences and of switching between information-gathering strategies remain significant open questions.

(c) Implications for social information use and cultural evolution

Here, individual differences in self-reported collectivism were linked to social information use. Although our analysis of personality traits was exploratory and correlational, these results suggest that social information use may be linked to a personality trait—collectivism—that is known to be stable across individual lifetimes, to vary across cultures, and has been linked to population differences in social transmission and serotonin transporter alleles [30,32,46,47]. Our findings raise the possibility of population differences in social information use. Indeed, the local culture or temporal cultural changes will likely shape the potential benefits of a particular social learning strategy, as well as particular strategies being culturally transmitted: cultural evolution itself shapes cultural transmission [48].

Many classical theoretical models of social learning and social information use do not account for different decision-making strategies on the part of different individuals [1,49]. Producer–scrounger models [5,15,50] provide one route to investigate such individual differences. Our findings in combination with recent work in non-human animals [45] suggest that individual differences in social learning should be explicitly incorporated into theoretical models, and are an important subject of enquiry in their own right.

The procedures and questionnaires used comply with the ethical guidelines of the APA and the principles expressed in the declaration of Helsinki.

Acknowledgements. We thank Richard McElreath for providing the farming game software and analysis code, Lisa Jacquin, Magdalena Zdebik, Laura Chouinard-Thuly, Ioannis Leris, William Swaney, Maria Cabrera, Paul Sims, and two anonymous reviewers for helpful comments or discussion

Funding statement. We thank NSERC, the Einstein Foundation and the Netherlands Organisation for Scientific Research (NWO) 'Evolution and Behaviour' and 'Cognition' Programmes for financial support.

References

1. Boyd R, Richerson PJ. 1985 *Culture and the evolutionary process*. Chicago, IL: University of Chicago Press.
2. Boyd R, Richerson PJ, Henrich J. 2011 The cultural niche: why social learning is essential for human adaptation. *Proc. Natl Acad. Sci. USA* **108**, 10 918–10 925. (doi:10.1073/pnas.1100290108)
3. Dean LG, Kendal RL, Schapiro SJ, Thierry B, Laland KN. 2012 Identification of the social and cognitive processes underlying human cumulative culture. *Science* **335**, 1114–1118. (doi:10.1126/science.1213969)
4. Herrmann E, Call J, Hernàndez-Lloreda MV, Hare B, Tomasello M. 2007 Humans have evolved specialized skills of social cognition: the cultural intelligence hypothesis. *Science* **317**, 1360–1366. (doi:10.1126/science.1146282)
5. Giraldeau L, Dubois F. 2008 Social foraging and the study of exploitative behavior. *Adv. Stud. Behav.* **38**, 59–104. (doi:10.1016/S0065-3454(08)00002-8)
6. Reader SM, Biro D. 2010 Experimental identification of social learning in wild animals. *Learn. Behav.* **38**, 265–283. (doi:10.3758/LB.38.3.265)
7. Kendal RL, Coolen I, Laland KN. 2009 Adaptive trade-offs in the use of social and personal information. In *Cognitive ecology II* (eds R Dukas, JM Ratcliffe), pp. 249–271. Chicago, IL: University of Chicago Press.
8. Galef BG, Laland KN. 2005 Social learning in animals: empirical studies and theoretical models. *Bioscience* **55**, 489–499. (doi:10.1641/0006-3568(2005)055[0489:SLIAES]2.0.CO;2)
9. Valone TJ. 2007 From eavesdropping on performance to copying the behavior of others: a review of public information use. *Behav. Ecol. Sociobiol.* **62**, 1–14. (doi:10.1007/s00265-007-0439-6)
10. Laland KN, Atton N, Webster MM. 2011 From fish to fashion: experimental and theoretical insights into the evolution of culture. *Phil. Trans. R. Soc. B* **366**, 958–968. (doi:10.1098/rstb.2010.0328)
11. Henrich J, Boyd R. 1998 The evolution of conformist transmission and the emergence of between-group differences. *Evol. Hum. Behav.* **19**, 215–241. (doi:10.1016/S1090-5138(98)00018-X)
12. Wakano JY, Aoki K. 2007 Do social learning and conformist bias coevolve? Henrich and Boyd revisited. *Theor. Popul. Biol.* **72**, 504–512. (doi:10.1016/j.tpb.2007.04.003)
13. Laland KN, Richerson PJ, Boyd R. 1996 Developing a theory of animal social learning. In *Social learning in animals: the roots of culture* (eds CM Heyes, BG Galef), pp. 129–154. San Diego, CA, USA: Academic Press.
14. Rendell L *et al*. 2010 Why copy others? Insights from the social learning strategies tournament. *Science* **328**, 208–213. (doi:10.1126/science.1184719)
15. Kameda T, Nakanishi D. 2003 Does social/cultural learning increase human adaptability? Rogers's question revisited. *Evol. Hum. Behav.* **24**, 242–260. (doi:10.1016/S1090-5138(03)00015-1)
16. Boyd R, Richerson PJ. 1988 The evolution of reciprocity in sizable groups. *J. Theor. Biol.* **132**, 337–356. (doi:10.1016/S0022-5193(88)80219-4)
17. Rieucau G, Giraldeau L-A. 2011 Exploring the costs and benefits of social information use: an appraisal of current experimental evidence. *Phil. Trans. R. Soc. B* **366**, 949–957. (doi:10.1098/rstb.2010.0325)
18. Morgan TJH, Rendell LE, Ehn M, Hoppitt W, Laland KN. 2011 The evolutionary basis of human social learning. *Proc. R. Soc. B* **279**, 653–662. (doi:10.1098/rspb.2011.1172)
19. Galef BG. 2009 Strategies for social learning: testing predictions from formal theory. In *Advances in the Study of Behavior 39* (eds HJ Brockmann, C Snowdon, T Roper, M Naguib, K Wynne-Edwards), pp. 117–151. San Diego, CA: Academic.
20. Mesoudi A, Whiten A, Dunbar R. 2006 A bias for social information in human cultural transmission. *Br. J. Psychol.* **97**, 405–423. (doi:10.1348/000712605X85871)
21. Toelch U, van Delft MJ, Bruce MJ, Donders R, Meeus MTH, Reader SM. 2009 Decreased environmental variability induces a bias for social information use in humans. *Evol. Hum. Behav.* **30**, 32–40. (doi:10.1016/j.evolhumbehav.2008.07.003)
22. McElreath R, Lubell M, Richerson PJ, Waring T, Baum W, Edsten E, Efferson C, Paciotti B. 2005 Applying evolutionary models to the laboratory study of social learning. *Evol. Hum. Behav.* **26**, 483–508. (doi:10.1016/j.evolhumbehav.2005.04.003)
23. Efferson C, Lalive R, Richerson PJ, McElreath R, Lubell M. 2008 Conformists and mavericks: the empirics of frequency-dependent cultural transmission. *Evol. Hum. Behav.* **29**, 56–64. (doi:10.1016/j.evolhumbehav.2007.08.003)
24. Melo AI, Lovic V, Gonzalez A, Madden M, Sinopoli K, Fleming AS. 2006 Maternal and littermate deprivation disrupts maternal behavior and

social-learning of food preference in adulthood: tactile stimulation, nest odor, and social rearing prevent these effects. *Dev. Psychobiol.* **48**, 209–219. (doi:10.1002/dev.20130)

25. Lindeyer CM, Meaney MJ, Reader SM. 2013 Early maternal care predicts reliance on social learning about food in adult rats. *Dev. Psychobiol.* **55**, 168–175. (doi:10.1002/dev.21009)
26. Réale D, Reader SM, Sol D, McDougall PT, Dingemanse NJ. 2007 Integrating animal temperament within ecology and evolution. *Biol. Rev.* **82**, 291–318. (doi:10.1111/j.1469-185X.2007.00010.x)
27. McElreath R, Bell AV, Efferson C, Lubell M, Richerson PJ, Waring T. 2008 Beyond existence and aiming outside the laboratory: estimating frequency-dependent and pay-off-biased social learning strategies. *Phil. Trans. R. Soc. B* **363**, 3515–3528. (doi:10.1098/rstb.2008.0131)
28. Oyserman D, Coon HM, Kemmelmeier M. 2002 Rethinking individualism and collectivism: evaluation of theoretical assumptions and meta-analyses. *Psychol. Bull.* **128**, 3–72. (doi:10.1037/0033-2909.128.1.3)
29. Raskin R, Terry H. 1988 A principal-components analysis of the narcissistic personality inventory and further evidence of its construct validity. *J. Pers. Soc. Psychol.* **54**, 890–902. (doi:10.1037/0022-3514.54.5.890)
30. Yaveroglu IS, Donthu N. 2002 Cultural influences on the diffusion of new products. *J. Int. Consum. Mark.* **14**, 49–63. (doi:10.1300/J046v14n04_04)
31. Van den Bulte C, Stremersch S. 2004 Social contagion and income heterogeneity in new product diffusion: a meta-analytic test. *Mark. Sci* **23**, 530–544. (doi:10.1287/mksc.1040.0054)
32. Chiao JY, Blizinsky KD. 2010 Culture–gene coevolution of individualism–collectivism and the serotonin transporter gene. *Proc. R. Soc. B* **277**, 529–537. (doi:10.1098/rspb.2009.1650)
33. Eisenberg DTA, Hayes MG. 2010 Testing the null hypothesis: comments on 'Culture–gene coevolution of individualism–collectivism and the serotonin transporter gene'. *Proc. R. Soc. B* **278**, 329–332. (doi:10.1098/rspb.2010.0714)
34. Foster JD, Keith Campbell W, Twenge JM. 2003 Individual differences in narcissism: inflated self-views across the lifespan and around the world. *J. Res. Pers.* **37**, 469–486. (doi:10.1016/S0092-6566(03)00026-6)
35. Gelman A, Hill J. 2006 *Data analysis using regression and multilevel/hierarchical models*, 1st edn. Cambridge, UK: Cambridge University Press.
36. R Core Team. 2012 *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
37. Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, White J-SS. 2009 Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol. Evol.* **24**, 127–135. (doi:10.1016/j.tree.2008.10.008)
38. Heyes C. 2012 What's social about social learning? *J. Comp. Psychol.* **126**, 193–202. (doi:10.1037/a0025180)
39. Toelch U, Bruce MJ, Meeus MTH, Reader SM. 2011 Social performance cues induce behavioral flexibility in humans. *Front. Psychol.* **2**, 160. (doi:10.3389/fpsyg.2011.00160)
40. Toelch U, Bach D, Dolan R. 2013 The neural underpinnings of an optimal exploitation of social information under uncertainty. *Soc. Cogn. Affect. Neurosci*. (doi:10.1093/scan/nst173)
41. Marchetti C, Drent PJ. 2000 Individual differences in the use of social information in foraging by captive great tits. *Anim. Behav.* **60**, 131–140. (doi:10.1006/anbe.2000.1443)
42. Reader SM, Hager Y, Laland KN. 2011 The evolution of primate general and cultural intelligence. *Phil. Trans. R. Soc. B* **366**, 1017–1027. (doi:10.1098/rstb.2010.0342)
43. Jolles JW, Ostojić L, Clayton NS. 2013 Dominance, pair bonds and boldness determine social-foraging tactics in rooks, *Corvus frugilegus*. *Anim. Behav.* **85**, 1261–1269. (doi:10.1016/j.anbehav.2013.03.013)
44. Mathot KJ, Giraldeau L-A. 2010 Family-related differences in social foraging tactic use in the zebra finch (*Taeniopygia guttata*). *Behav. Ecol. Sociobiol.* **64**, 1805–1811. (doi:10.1007/s00265-010-0992-2)
45. Rosa P, Nguyen V, Dubois F. 2012 Individual differences in sampling behaviour predict social information use in zebra finches. *Behav. Ecol. Sociobiol.* **66**, 1259–1265. (doi:10.1007/s00265-012-1379-3)
46. Hofstede GH. 2001 *Culture's consequences: comparing values, behaviors, institutions, and organizations across nations*. Thousand Oaks, CA: Sage Publications.
47. Way BM, Lieberman MD. 2010 Is there a genetic contribution to cultural differences? Collectivism, individualism and genetic markers of social sensitivity. *Soc. Cogn. Affect. Neurosci.* **5**, 203–211. (doi:10.1093/scan/nsq059)
48. Heyes C. 2012 Grist and mills: on the cultural origins of cultural learning. *Phil. Trans. R. Soc. B* **367**, 2181–2191. (doi:10.1098/rstb.2012.0120)
49. Cavalli-Sforza LL, Feldman MW. 1981 *Cultural transmission and evolution: a quantitative approach*. Princeton, NJ: Princeton University Press.
50. Rogers AR. 1988 Does biology constrain culture? *Am. Anthropol.* **90**, 819–831. (doi:10.1525/aa.1988.90.4.02a00030)