# THE WHEN AND WHO OF SOCIAL LEARNING AND CONFORMIST TRANSMISSION

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## ABSTRACT

Formal evolutionary models predict when individuals' rely on social learning over individual learning and the relative strength of their conformist social learning biases. Here we use both treatment effects and individual variation to test predictions about the impact of (1) the number of traits in an environment, (2) the adaptive or payoff relevance of those traits, (3) the fidelity of transmission, and (4) the size of groups. We find that both social learning and the strength of conformist transmission increases with the number of traits, the adaptive value of those traits, and the fidelity of social information. The strength of conformist transmission increases with group size, but only with 2 traits. Using individual-level variation and recognizing that treatment effects predictably impact individuals differently, we show that IQ negatively predicts social learning, but has a U-shaped relationship to conformist transmission, suggesting strategic use of conformist-biased social learning among those with the highest IQ. Other plausible predictors, such as status, cultural background, and personality, were not predictive. Broadly, our results reveal that not only is the conformist transmission bias ubiquitous, but that past experiments, both human and non-human, have likely underestimated its prevalence and the prevalence of social learning by restricting designs to only 2 traits.

**Keywords:** cultural evolution, social learning, evolution, conformist transmission, culture

# 1. INTRODUCTION

Humans are a cultural species, heavily reliant on a rich repertoire of ideas, beliefs, values, and practices acquired from other members of their social groups. Evolutionary approaches to culture postulate that our species' social learning abilities – the psychological foundations that undergird these cultural repertoires – are genetically evolved cognitive adaptations for surviving in environments in which individually acquiring information is costly. Building on this, a large body of theoretical research has explored the conditions under which natural selection will favor various learning strategies (Boyd & Richerson, 1985, 1988, 1996; Henrich & Boyd, 1998, 2002; King & Cowlishaw, 2007; Nakahashi, Wakano, & Henrich, 2012; Perreault, Moya, & Boyd, 2012). This theoretical research provides clear predictions about when individuals should rely on their individual or asocial experience and when they should deploy one or more social learning strategies, such as conformist transmission (a tendency to disproportionately copy the majority or plurality). By contrast, relatively little empirical research has sought to directly test these models in the laboratory with human participants, though key exceptions include McElreath, et al. (2005), Efferson, et al.

(2008), and Morgan, et al. (2012). Here, we aim to advance this research program empirically by testing some novel predictions and implications derived from existing theoretical work, as well as to replicate some prior results in new and more diverse populations. We test predictions regarding how (a) the number of cultural traits, (b) payoffs associated with different decisions, (c) fidelity of social transmission, and (d) group size influence the use of social over asocial learning, and the application of conformist biases within social learning. In addition, we consider the implications of existing models for predicting who might tend to use which strategies, and use individual differences in cognitive abilities, social status, and cultural background to account for individual level variation in learning strategies. These efforts extend prior research, which revealed much individual variation, but did not attempt to account for it.

## 1.1. THEORETICAL RESEARCH

Several evolutionary models (Boyd & Richerson, 1985, 1988, 1996; Henrich & Boyd, 1998) predict that reliance on social learning (over asocial learning) should increase with the cost or difficulty of asocial learning, the size of the majority, and the stability of the environment. These predictions make intuitive sense – individuals will prefer cheap, reliable, and accurate information; the reliability of social information increases with larger majorities and accuracy decreases with changes to the environment to which it pertains. Other models (King & Cowlishaw, 2007) predict that reliance on social learning should increase with access to more demonstrators, which typically increases with group size. More demonstrators reduce sampling error.

Within the realm of social learning, evolutionary models reveal the social learning strategies (Laland, 2004; Rendell et al., 2011) and biases (Boyd & Richerson, 1985) favored by different situations or circumstances. One such bias is the conformist transmission bias. In a particular population, there may be many variants in behaviors, beliefs, or values, from herein referred to as *traits*. Conformist transmission represents a type of frequency dependent social learning strategy in which individuals are *disproportionately* inclined to copy the most common trait in their sample of the population (e.g. individuals are 90% likely to copy a trait that 60% of people possess) (Boyd & Richerson, 1985). Conformist transmission is particularly important, because it tends to homogenize behavior within groups, increasing between group variation relative to within group variation (Boyd & Richerson, 1985; Henrich & Boyd, 1998), strengthening the effect of intergroup competition on cultural variation (Chudek, Muthukrishna, & Henrich, in press; Henrich, 2012), and potentially hindering cumulative cultural evolution within a group (Eriksson, Enquist, & Ghirlanda, 2007). Conformist transmission contrasts with unbiased transmission, whereby individuals copy a trait at the frequency found in the population (e.g. individuals are 60% likely to copy a trait that 60% of people possess).

Several evolutionary models reveal the conditions when the conformist transmission bias is more adaptive than unbiased transmission. Typically, these models have analyzed only 2 traits. However, Nakahashi, Wakano, and Henrich (2012) have extended these models to $N$ traits. Their model predicts that the strength of the conformist bias will increase with the number of traits in the environment. To understand the logic, consider a world with only 2 traits—black and white shirts. The presence of black shirts at anything above 50% suggests that people are selecting black shirts above chance. However, in a world with four traits – black, white, green, and red shirts – black shirts need only be present above 25% to suggest selection above chance. Thus, if 51% of people were clothed in black shirts, you would be much more likely to also wear a black shirt if there were 4 shirt options than 2 and even more so if there were 10 options and so on. One important implication of this model is that all current models and experiments have been underestimating the strength of the conformist bias, because there are generally more than 2 traits in the real world. In addition to the number of traits, the model also predicts that the strength of the conformist bias will increase with error in transmission and the strength of selection (for weak selection), consistent with other 2 trait conformist bias models (Henrich & Boyd, 2002)[1]. Other models (Perreault et al., 2012) predict that a stronger conformist bias will be more adaptive in larger groups, as information reliability increases, with an asymptotic relationship between group size and the strength of the conformist bias. To understand why, consider a non-asymptotic monotonic relationship – copying the majority would be almost certain in a sufficiently large group, preventing rare adaptive traits from being selected, all else being equal.

## 1.2. EXPERIMENTAL RESEARCH

In contrast to a growing body of theory, there has been little experimental research investigating conformist biases. The first experimental test of these theories tested the effects of task difficulty and environmental variability (McElreath et al., 2005). The results revealed both unbiased and conformist transmission, with increased conformist transmission as the environment fluctuated. However, the results were inconsistent between experiments and were ultimately difficult to interpret. A later experiment by Efferson et al. (2008) separated participants into asocial and social learners and looked for evidence of a conformist bias among the social learners. On average, participants exhibited a conformist bias, but there was also considerable variation within participants, including some non-conformists. Most recently, Morgan et al. (2012) systematically tested nine theoretically derived hypotheses, including hypotheses related to group size, majority size, confidence, asocial learning cost and difficulty, number of iterations, participant performance, and demonstrator performance. In all cases, the results supported evolutionary predictions and

[1] We infer this last prediction based on migration less than 50% and weak selection (see Supplementary Materials).

found evidence of a conformist bias. All three sets of experiments described above revealed heavy reliance on social learning and the presence of a conformist bias, but they also documented, but did not explain, substantial individual variation. In the present research, we test several evolutionary theories and address this gap.

## 1.3. PRESENT RESEARCH

In two experiments, we measure reliance on social learning and the strength of the conformist bias, testing several untested theoretical predictions. Based on the models, we predict that reliance on social over asocial learning will increase with: (a) transmission fidelity (Boyd & Richerson, 1985, 1988, 1996; Henrich & Boyd, 1998) and (b) group size (King & Cowlishaw, 2007; Perreault et al., 2012). We predict that the strength of the conformist bias will increase with (a) the number of traits (Nakahashi et al., 2012), (b) payoffs of the traits being copied (effectively the strength of selection; Nakahashi et al., 2012), and (c) errors in transmission (Henrich & Boyd, 2002; Nakahashi et al., 2012). Note that as transmission fidelity increases, reliance on social learning is expected to increase, but the strength of the conformist bias is expected to decrease. In testing these predictions, we also tested the effect of majority or plurality size in a more diverse population.

We also tested for individual differences. No work has yet shown what accounts for these differences, nor applied theoretical insights to understand the variation. Applying existing theory to individual variation, we explored three individual difference measures:

a) **Cognitive abilities:** Individuals with better cognitive abilities ought to possess better private information, resulting in less individual uncertainty, which should result in reduced reliance on social learning and conformist transmission. Alternatively, those with better cognitive abilities may select the more adaptive strategy (i.e. copying when uncertain) – that is, cognitive abilities may in part be about selecting the best learning strategy overall.

b) **Status:** Individuals who perceive themselves as higher in prestige status may reduce their reliance on learning from others who they perceive as less prestigious. Dominance status will bear no relationship to learning strategies once we control for prestige status and cognitive abilities.

c) **Cultural Background:** Populations may differ in their tendency toward social learning and conformist transmission (Bond & Smith, 1996; Cialdini, Wosinska, Barrett, Butner, & Gornik-Durose, 1999). Cultural psychologists have argued that East Asians in particular are more likely to conform than Westerners. This may result in population-level differences in social learning and conformist transmission.

Besides these theoretically motivated variables, we also examined individual differences in (1) reflective thinking styles (intuitive vs reflective), (2) rule following, (3) personality, and (4) a variety of demographic variables.

# 2. METHODS

We ran both our experiments on the same participants, but randomized the order of measures and experiments between groups. We report our participant demographics, general design, and specific procedures for each experiment.

## 2.1. PARTICIPANTS

We recruited 101 participants from the University of British Columbia's Economics Participant Pool, which is open to the public, but primarily consists of undergraduate students. Of these, 27 participants failed at least one of our two vigilance check questions, leaving us with 74 usable participants (39 Female; Mean Age = 21.73, SD = 5.55). Including all 101 participants is arguably defensible for our contextual variable analyses, because participants were incentivized for performance. Their inclusion generally strengthens our overall findings. However, since these participants were not incentivized for completing the individual-difference measures and failed vigilance checks within them, we conservatively exclude them from the main analysis, but report all analyses with their inclusion in Supplementary Materials.

## 2.2. GENERAL DESIGN

We ran two experiments on all participants. In Experiment 1, we tested the effects of the number of traits. In Experiment 2, we tested the effects of payoffs and transmission fidelity. In both studies, we also tested group size (from 5 to 11 participants) and the proportion of people who selected each trait. In our experiment, *traits* are the lines of different length that participants selected between; we will refer to them as *options* from herein. We also measured several individual-level factors, detailed in Background Measures. Participants were paid a show-up fee of $10 and could win an additional $20 based on performance in the two experiments. Fig. 1 illustrates the general design of the experiment.

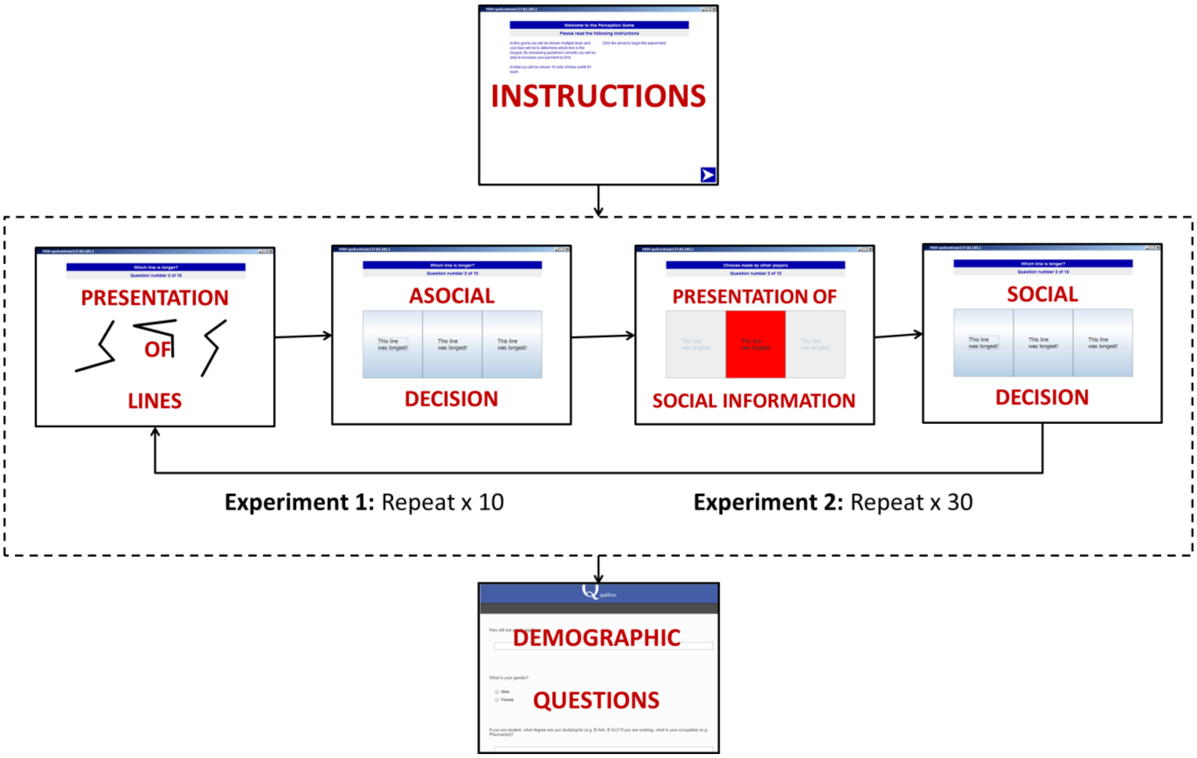



**Fig. 1. Flowchart of Experiment Design. The order of the experiments of was randomized. We always asked demographic questions at the end, but we asked background measures (not shown) before or after all experiments (also randomized).**

## 2.3. EXPERIMENT 1: NUMBER OF OPTIONS

In Experiment 1, participants had to compare between 2 and 6 lines to identify the longest line. This was repeated 10 times. The lines appeared for 3 seconds and then participants made their first 'asocial' decision. The software then displayed the decisions made by other participants using flashes corresponding to each option. After receiving this social information, participants answered the question again. Keep in mind there was no deception in this experiment, so this was real social information.

Each trial was worth up to $1. The payoff associated with each line was proportional to the length of the selected line relative to all other lines, with the longest line worth $1 and the shortest line worth nothing (see Supplementary Materials for details). With 10 trials each worth a maximum of $1, participants could earn $10 in this phase of the session. We informed participants at the beginning of the experiment that their payment depended only on their second response to each set of lines.

## 2.4. EXPERIMENT 2: TRANSMISSION FIDELITY AND PAYOFFS

In Experiment 2, we restricted the number of lines to 2 and varied the transmission fidelity and payoffs. The task involved comparing 30 pairs of lines to identify the longest line, with participants first giving an asocial response and then receiving social information and information about transmission fidelity before getting a chance to answer again. In other respects, participants went through the same process as in Experiment 1.

To explore the impact of transmission fidelity, we varied errors in transmission by replacing some of the social information with random computer generated answers. We informed participants of the probability of replacing real social information, which ranged from 0% (only true social information) to 40% (i.e. 60% social information, 40% random). See the Supplementary Materials for a screenshot and details. After receiving this noisy social information, participants made their final decision.

To explore the impact of payoffs, we made the value of each trial between $0 and $2, with the ability to earn up to $10 over 30 trials. The software clearly indicated the amount of money each question was worth before and throughout each trial.

We administered background measures either before or after the two experiments (randomly assigned with no significant difference between behavior or measures), but demographic questions (age, sex, time spent in Canada, strategies used while playing the game, etc.) were always asked at the end.

## 2.5. BACKGROUND MEASURES

Our three key individual-difference predictors were:

- **IQ:** We measured IQ using Raven's Advanced Progressive Matrices (Raven & Court, 1998).
- **Prestige and Dominance:** We measured self-reported prestige using the Prestige and Dominance scale (Cheng, Tracy, & Henrich, 2010).
- **Cultural Background:** We asked for participant ethnicity, if they had lived their entire lives in Canada, how well they speak their native language, how much they identify with Canada (Inclusion of Other in the Self Scale; Aron, Aron, & Smollan, 1992), and their degree of acculturation (Vancouver Index of Acculturation; Ryder, Alden, & Paulhus, 2000).

To pre-emptively counter other potential explanations for variation in social learning and conformist transmission, we also measured:

- **Reflective vs Intuitive Thinking Styles:** We measured reflective vs intuitive thinking styles using the Cognitive Reflection Test (CRT; Frederick, 2005). We included the CRT since it is plausible that copying or not copying others may be an intuitive decision. In this case, intuitive or reflective thinking styles will predict social learning and conformist transmission.
- **Rule Following:** We measured the tendency to follow rules using the Rule Following Task (RFT; Kimbrough & Vostroknutov, 2013). We included the RFT since it is plausible that

copying or not copying simply represents the rule in our experimental setting, in which case the tendency to follow rules will predict social learning and conformist transmission.

Finally, we included age, sex, and the Big 5 Personality Inventory, which are often a source of individual-differences. Further details can be found in Supplementary Materials.

# 3. ANALYSIS

Our first theoretical question concerns how our contextual variables influenced social learning and conformist transmission. In our analysis of social learning, we looked at the proportion of times participants changed their decision after viewing social information for each level of our predictor variables. We graphed these relationships and described them with a best-fitting function, and then predicted this binary decision (changed vs did not change) with each predictor. This analysis allowed us to look at how our manipulated predictors affected the use of social information, but we could not use the proportion of participants as a predictor, since those in the majority or plurality would themselves be less likely to change their decision.

To address the question of how majority size affected social learning with 2 traits, we followed Morgan et al. (2012): Participants are considered to have used social information if (a) their decision after viewing social information differed from their asocial decision *and* (b) the majority of other participants disagreed with the participant's original decision. In Experiment 1, there were pluralities rather than majorities (multiple options), and there was more information (e.g. relative proportions), which participants may have incorporated in addition to just the overall plurality. Here, we analyzed the data with all responses (not just where the plurality disagreed with the participant), but focused on the cases where participants changed their decision, using the frequency of options to which participants did and did not change their decision.

Finally, to determine the strength of any conformist bias, we ran an analysis where we calculated a single best-fit conformist transmission parameter ($\alpha$) by aggregating the data across all individuals for each level of our key predictors – number of options, transmission fidelity, and payoff value – except group size, where we did not have enough participants in each level. To accomplish this, we used a Signal Detection Theory (SDT) perspective, considering the four possible decision scenarios for a particular option and frequency:

SDT 1. Choosing the option both asocially (before seeing social information) and socially (after seeing social information).

SDT 2. Choosing the option asocially, but choosing a different option socially.

SDT 3. Choosing a different option asocially, but choosing the option socially.

SDT 4. Choosing a different option asocially and socially.

In SDT 1, we have no way of assessing if a decision was based on the social information or asocial prior. In contrast, in the other three cases, we know that the proportion was insufficient to retain the decision (SDT 2), the proportion was sufficient to make them choose the option (SDT 3), or the proportion was insufficient to make them choose the option (SDT 4).

We used a logistic function to fit a sigmoid to these latter three cases (SDT 2-4), similar to earlier theoretical work in social learning (McElreath et al., 2008; Szabó & Tőke, 1998; Traulsen, Pacheco, & Nowak, 2007):

$$p_i = \frac{1}{1 + e^{-\alpha(p_t - c)}}$$

Where $p_i$ is the probability of choosing option $t$ and $p_t$ is the frequency of option $t$. The $\alpha$ parameter of the sigmoid is a measure of the strength of the conformist bias. If $\alpha < 0$, this indicates anti-conformity and if $\alpha \approx 0$, we assume decisions are being made independent of social decisions, i.e. no social learning. In contrast, $\alpha < 5$ suggest some social learning, but not conformist transmission. Finally, $\alpha \geq 5$ is evidence of conformist transmission, with higher values indicating a stronger conformist transmission bias. The $c$ parameter tells us the inflection point, i.e. when individuals are 50% likely to choose the option and suggests a conformist bias when $c < 0.5$. These four categories match four types of formally defined frequency-dependent social learning strategies, which we discuss in Supplementary Materials.

Nakahashi, et al. (Nakahashi et al., 2012) predict that $c$ should be reciprocally related to the number of options ($N$), i.e. $c = 1/N$ – this is the frequency at which the trait would be present at chance levels. We used a nonlinear least-squares (NLS) estimate to fit $\alpha$ and $c$ in Experiment 1 with multiple options, measuring the strength of the conformist bias and testing Nakahashi et al.'s (Nakahashi et al., 2012) theoretical predictions. In Experiment 2, with only 2 options, we set $c = 0.5$, the expected inflection point $(c = 1/2)$ to fit the strength of the conformist bias ($\alpha$). In Fig. 2, we plot the sigmoid based on this function for different values of $\alpha$ and $c$.

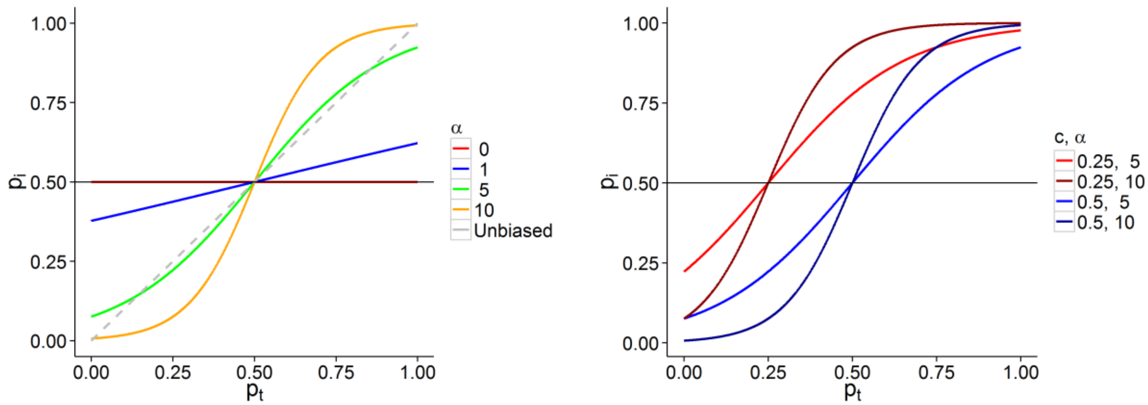



**Fig. 2. Logistic function sigmoid for different values of $\alpha$ (with $c = 0.5$ on left) and different values of $c$ (right). The $\alpha$ parameter determines the curvature of the sigmoid and therefore the strength of the conformist transmission bias. The $c$ parameter determines the inflection point.**

Our second theoretical question was what individual factors predicted the strength of conformist transmission. To answer this second question, we fit the strength of conformist transmission to all responses for each individual separately. We then regressed these individual-level $\alpha$ values on our individual-level predictors.

# 4. RESULTS

We report the results for contextual predictors and then individual predictors, analyzing Experiment 1 and 2 separately. We analyze the effect of each predictor on social learning and then the strength of the conformist bias.

## 4.1. NUMBER OF OPTIONS (EXPERIMENT 1)

Recall that in Experiment 1 participants had to select the longest line from between two and six options. We begin by analyzing the effect of the number of options on people's reliance on social learning over asocial learning.

### 4.1.1. SOCIAL LEARNING

Fig. 3 shows a non-linear relationship between the number of options and the percentage of decisions that changed after seeing social information. With only 2 options, a little over 10% of people changed their decision after viewing social information, but this number rises to over 25% with 4 options and almost 30% with 6.

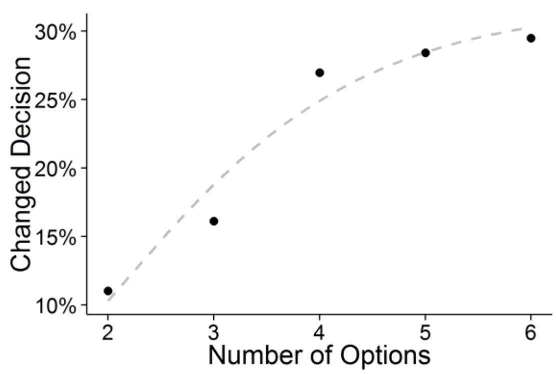



**Fig. 3. Percentage of decisions that were changed after seeing social information for different number of options. Although there are too few points to be certain about the function that best fits these data, we used a non-linear least squares method to fit to the reciprocal of traits $\left(y = -0.60\,{}^{1}/_{x} + 0.40\right)$, plotted with a grey dashed line.**

Next, we look at how the frequency of each option in the social information predicted changing to that option. To do this, we use a binary logistic model to regress participant's decisions on the proportion of participants who selected an option (*Proportion*), the number of options (*Options*), and number of participants in the group (*Participants*), thereby testing several theoretical predictions (Boyd & Richerson, 1985, 1988, 1996; Henrich & Boyd, 1998; King & Cowlishaw, 2007). Each participant made multiple decisions. We control for common variance created by multiple observations from the same person with random effects for each individual. We remove age and gender from the analysis; neither was significantly predictive and made very little difference to the results (see Supplementary Materials for full models). Nakahashi et al. (2012) made no specific predictions about the functional form of the relationship between the rate of social learning and number of traits. But, guided by their predictions for the conformist bias and predictions made by other models for the effect of the cost of asocial learning (which should increase with more traits), we test a model with the number of options (Model 1) and a model with the reciprocal of the number of options ($1/(N-1)$; Model 2). We report these in Table 1.

| | **Model 1**<br>**Number of Options** | **Model 2**<br>**Reciprocal of Options** |
|---|---|---|
| (Intercept) | <0.01*** [0.00,0.01] | 0.05** [0.01,0.42] |
| Proportion 10% | 3.62*** [2.82,4.87] | 3.56*** [2.79,4.78] |
| Options | 1.68** [1.23,2.35] | 0.04** [0.01,0.32] |
| Participants | 0.96 [0.76,1.21] | 0.92 [0.73,1.16] |
| **AIC** | 171.67 | 173.13 |
| **Obs.** | 332 | 332 |
| **Groups** | 64 | 64 |

***: $p < .001$, **: $p < .01$, *: $p < .05$

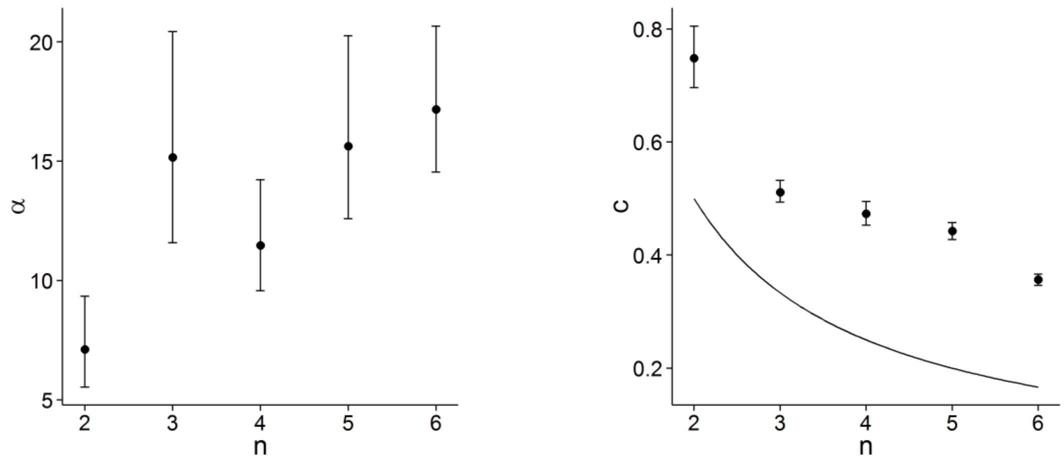
**Table 1. Binary logistic multilevel model of decision to switch regressed on the proportion of participants in the option (in 10% increments for easier interpretation), the reciprocal and number of options (separate models), and the number of participants in the group. All coefficients are odds ratios. We control for common variance created by multiple observations from the same person with random effects for each individual.**

Table 1 reveals that participants are much more likely to change their decision overall if there are more options – 1.68 times as likely for every additional option. Participants are also more likely to change their decision as the proportion of others who select the option increases – 3.6 times as likely for every additional 10% of participants. Our results indicate that the number of participants in the group (5-11) did not affect the likelihood of changing the decision. The fit of number of options and reciprocal of options models were almost identical.

#### 4.1.2. CONFORMIST BIAS

To examine the influence of multiple options on the strength of the conformist bias in social learning, we fit the logistic function described in the Analysis section to the frequencies participants saw and their decisions for each number of options. We did this combining all participants for each level of options – 2, 3, 4, 5, and 6. Thus, for each number of options, we calculate the strength of conformist bias ($\alpha$) and the inflection point ($c$), i.e. what percentage of demonstrators need to have selected an option for the participant to copy that option with a 50% likelihood.

Fig. 4a reveals that with each additional option, the strength of the conformist bias increases, but consistent with Nakahashi et al. (2012), the size of each increase decreases. Fig. 4b reveals that the inflection point decreases reciprocally with increasing options, as predicted by Nakahashi, et al.'s (2012) model, though the actual value is higher than theoretical predictions (shown as a solid line to distinguish it from dashed lines fitted to the data). The difference between the experimental measurements and theoretical prediction may be an indication of the size of participants' asocial prior, which Nakahashi, et al.'s model does not address. Nakahashi et al. model a situation where individuals only have access to social information. The pattern in Fig. 4b is what one would expect if individual's can combine asocial and social learning, as is the case in our experiments.




**(a)** **(b)**

**Fig. 4. (a) Strength of conformist transmission parameter ($\alpha$) as a function of number of options. The strength of the conformist transmission bias increases with more options. (b) Inflection point of logistic function as a function of number of options. The predicted value is shown as a solid line to distinguish it from the data (points) and model fitted values. The inflection point decreases, but remains higher than the predicted value, indicating an asocial prior.**

Fig. 4b reveals the point at which individuals will select an option 50% of the time ($c$). With only 2 options, individuals will select an option 50% of the time if 75% of others select it. With 4 options, individuals will select an option 50% of the time if 50% of others select it. And with 6 options, individuals will select an option 50% of the time if just 35% of others select it. Fig. 4a reveals a measure of the gradient of the sigmoid ($\alpha$). To get a sense for what these two parameters are telling us, consider what happens when someone sees 80% of other people select an option. If there are 2 options ($\alpha = 7$ and $c = .75$), the person is 59% likely to change their decision, but if there are 6 options ($\alpha = 17$ and $c = 0.35$), the person is 99.95% likely to change their decision. These results strongly support the theoretical predictions. Together, these results reveal that as the number of traits in an environment increases, both social learning and the strength of the conformist bias increase, but at a diminishing rate.

### 4.2. TRANSMISSION FIDELITY AND PAYOFFS (EXPERIMENT 2)

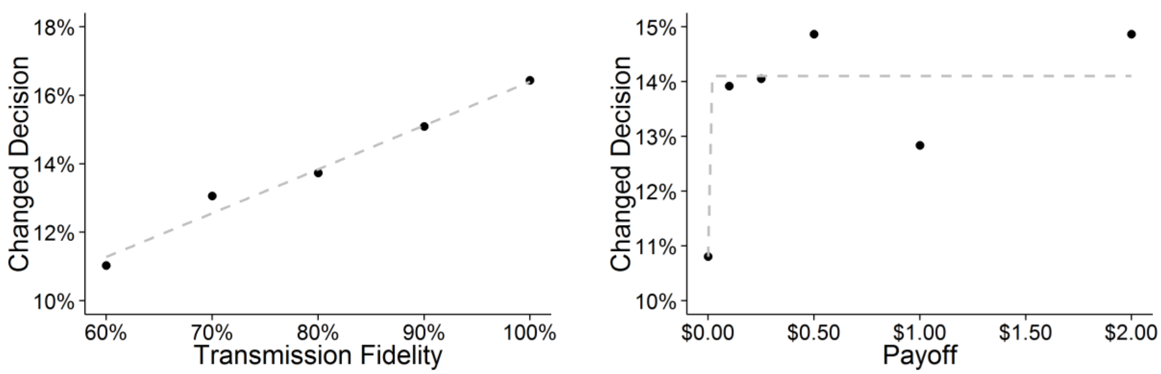
Experiment 2 varied errors in the transmission channel and payoffs. To remain consistent with most existing theoretical models and with prior experimental research, we restricted choices to 2 options (instead of the 2 to 6 options in Experiment 1). As for Experiment 1, we first examine how these 2 factors influence social learning, and then look at their effect on the strength of the conformist bias.

#### 4.2.1. SOCIAL LEARNING

Reliance on social information increased with higher fidelity transmission. Fig. 5a suggests a linear relationship between transmission fidelity and the percentage of decisions that changed after seeing social information. At 100% transmission fidelity, about 16% of people changed their decision after viewing social information, but this number drops to 11% at 60% fidelity. Though this increase with fidelity is consistent with theoretical expectations, the differences in social learning were small; participants were not particularly responsive to our rather explicit manipulation of transmission fidelity.

Reliance on social information increased between having no payoff and some payoff, but did not increase with higher payoffs. Fig. 5b shows that the percentage of decisions that changed after seeing social information increased by about 3% in moving from a zero payoff to 10 cents, but then remained consistent between 13% and 15% up to payoffs of $2. The difference between zero and even a small payoff is consistent with prior experimental work on the Zero Price Effect (Shampanier, Mazar, & Ariely, 2007). One possible explanation for the lack of effect of increasing payoffs is that our experiment did not have the range or sensitivity to capture the effect of payoffs. For the transmission rates used in our experiment, Nakahashi et al. (2012) predict small and diminishing returns for low payoffs (weak selection in the model).

As in Experiment 1, we use a binary logistic multilevel model to regress participant decision on the size of the majority, transmission fidelity, question payoff, and number of participants in the group. We control for common variance created by multiple observations from the same person with random effects for each individual. We removed age and gender from the analysis; neither was significantly predictive and made very little difference to the results (see Supplementary Materials for full models). We consider majority percentage and transmission rate in 10% intervals and payoffs in 10-cent intervals for more intuitively interpretable coefficients (Model 1). We also ran a second model with payoffs as a binary variable with no payoffs vs non-zero payoffs (Model 2).




**(a)** **(b)**

**Fig. 5. Percentage of decisions that were changed after seeing social information for (a) different levels of transmission fidelity, and (b) different question payoff values. Although there are too few points to be certain about the function that best fits these data, we used a non-linear least squares method to fit (a) to a linear model ($\boldsymbol{y = 0.13x + 0.04}$), and (b) to a step-function ($\boldsymbol{y = 0.14 \text{ if } x > 0 \,;\, y = 0.11 \text{ if } x = 0}$). Fit functions are plotted with a grey dashed line.**

Table 2 reveals a large effect of majority percentage, such that every 10% increase is associated with participants being 3.5 times more likely to change to the majority. We also find a large positive effect of transmission fidelity, with every additional 10% increase in fidelity associated with participants 1.3 times as likely to change to the majority. Consistent with Fig. 5b, we see no linear effect of payoff, but a significant difference between zero payoff and non-zero payoffs (participants are 2.6 times as likely to switch to the majority with some payoff). Finally, every additional participant in the group results in participants 1.28 times as likely to switch to the majority. Except for payoffs, these results are consistent with our theoretical predictions (Boyd & Richerson, 1985, 1988, 1996; Henrich & Boyd, 1998; King & Cowlishaw, 2007).

| | **Model 1**<br>**Linear Payoff 10c** | **Model 2**<br>**Binary Payoff** |
|---|---|---|
| (Intercept) | 1.22 [0.81,1.84] | 0.49 [0.16,1.21] |
| Majority 10% | 3.50*** [2.84,4.32] | 3.60*** [3.06,5.01] |
| Transmission 10% | 1.29*** [1.12,1.49] | 1.31*** [1.13,1.55] |
| Payoff | 1.01 [0.97,1.06] | 2.62* [1.16,7.79] |
| Participants | 1.28** [1.07,1.53] | 1.28* [1.09,1.59] |
| **AIC** | 761.47 | 750.10 |
| **Obs.** | 818 | 818 |
| **Groups** | 74 | 74 |

***: $p < .001$, **: $p < .01$, *: $p < .05$

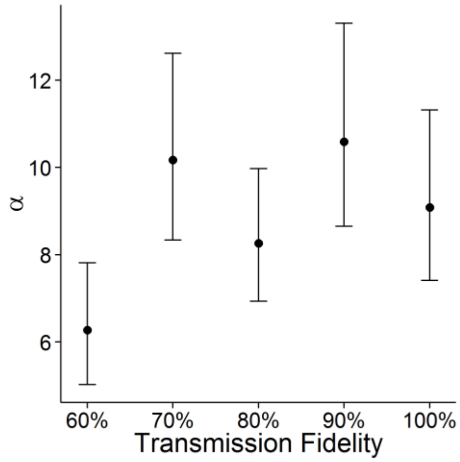
**Table 2. Binary logistic multilevel model of decision to switch to majority on majority size, transmission fidelity, payoff, and number of participants in the group. All coefficients are odds ratios. We control for common variance created by multiple observations from the same person with random effects for each individual.**

### 4.2.2. CONFORMIST BIAS

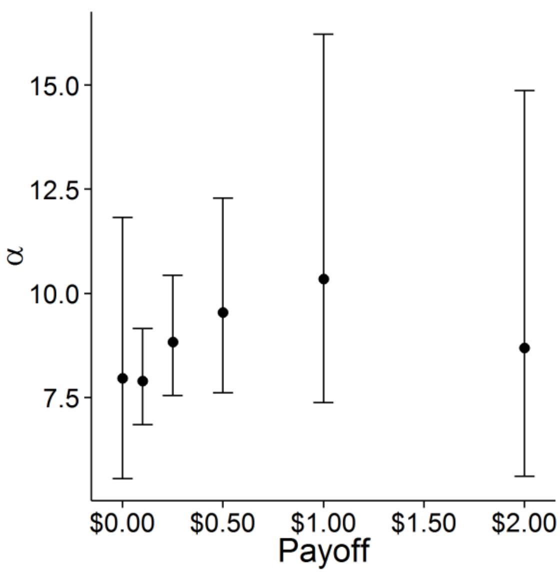
To analyze the effect of the number of options on the strength of the conformist bias, we fit the logistic function described in the Analysis section for 2 options, 3 options, and so on. Here we perform the same analysis for each level of transmission fidelity (60%, 70%, 80%, etc.) and then each level of payoffs (0c, 10c, 25c, etc.).

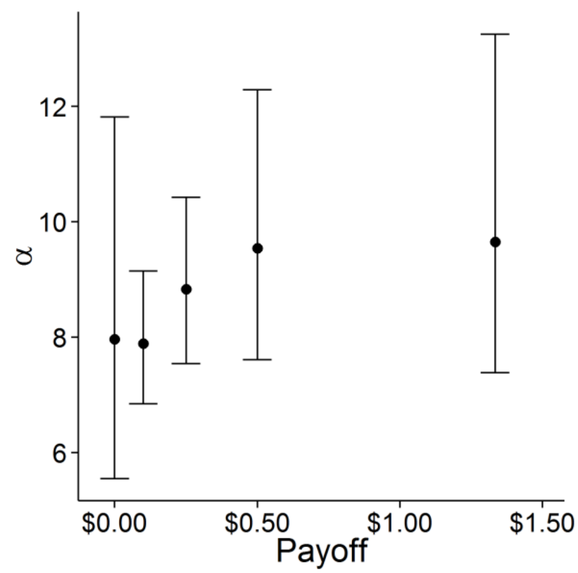
Transmission fidelity significantly increases the strength of the conformist bias between 60% and 70% fidelity, but there is no clear difference above 70% (see Fig. 6a). Recall that in contrast, social learning increases linearly with transmission fidelity. The difference in the strength of the conformist bias between 60% and 70% fidelity is large. An individual who sees 80% of others select an option will be 85% likely to copy that option if transmission fidelity is 60%, but will be 95% likely to copy the option if transmission fidelity is 70%.

Higher payoffs predict a stronger conformist bias (although the large confidence intervals make it difficult to determine if this trend is more than chance; see Fig. 6b). The very large confidence interval on $1 and $2 may be due to fewer cases for these values. To compensate for this, we averaged the $1 and $2 cases in Fig. 6c. These results suggest that higher payoffs lead to a stronger conformist transmission bias, with diminishing returns. Recall that we saw no trend in social learning, except between no payoff and some payoff. Thus payoffs have little effect on social learning, but do have an effect on the conformist social learning bias. Overall, these results only partially support the theoretical predictions. We will return to this in the Discussion.




**(a)**




**(b)** **(c)**

**Fig. 6. (a) Strength of conformist transmission parameter ($\alpha$) as a function of transmission fidelity. Conformist transmission is strong when fidelity is higher than 60%, but at 60% it's only slightly above unbiased transmission. Strength of conformist transmission parameter ($\alpha$) as a function of question payoff with (b) all payoff values and (c) $1 and $2 averaged to increase sample size for the highest value. The strength of the conformist transmission bias increases with diminishing returns as the payoffs increase.**

## 4.3. INDIVIDUAL VARIATION IN SOCIAL LEARNING STRATEGIES

Consistent with past empirical research (Efferson et al., 2008; McElreath et al., 2005; Morgan et al., 2012), we found evidence of substantial individual variation in social learning and social learning strategies. We used the same analytic approach as in the previous sections analyzing social learning and then conformist transmission. To measure reliance on social information, we calculated the percentage of decisions that each participant changed after seeing social information. To measure the strength of the conformist bias ($\alpha_i$), we fit a logistic curve based on the frequency of options they saw. We then regressed the social learning measure and the conformist bias measure on our theoretically motivated predictors (IQ, prestige, and culture), as well as several other measures that have been used in the literature, including reflective thinking styles, rule following, personality, and a variety of demographic variables.

### 4.3.1. SOCIAL LEARNING

In both experiments, IQ was significantly predictive of lower reliance on social information (see Table 3). Every standard deviation increase in IQ resulted in a 4% reduction in social learning in Experiment 1 and a 2% reduction in social learning in Experiment 2. This effect is small, but reliable.

| | **Experiment 1** | **Experiment 2** |
|---|---|---|
| (Intercept) | 0.22 (0.15,0.30)*** | 0.20 (0.02,0.39)* |
| zIQ | −0.04 (−0.08,−0.00)* | −0.02 (−0.05,−0.00)* |
| zPrestige | −0.01 (−0.05,0.02) | −0.01 (−0.05,0.02) |
| East Asian | 0.00 (−0.09,0.09) | −0.01 (−0.06,0.04) |
| Other Ethnicity | −0.02 (−0.12,0.08) | 0.03 (−0.03,0.10) |
| zAge | −0.00 (−0.04,0.04) | −0.00 (−0.03,0.02) |
| Male | 0.01 (−0.06,0.09) | −0.00 (−0.05,0.04) |
| $R^2$ | 0.09 | 0.09 |
| **N** | 74 | 74 |

***: $p < .001$, **: $p < .01$, *: $p < .05$, $^{+}$: $p < .1$

**Table 3. OLS regression model percentage of decisions that were changed after viewing social information regressed on theoretical predictors as well as age and gender. All predictors with a "z" prefix are standardized scores. Ethnicity was dummy coded, with Euro Canadians as the reference group. These results show a negative relationship between IQ and social learning with higher IQ resulting in less social learning. The regression models reported show all theoretically inspired predictors; the regression model is significant when the non-significant predictors are removed (see Supplementary Materials).**

Neither prestige nor culture were sizably or significantly predictive, nor were reflective thinking styles, rule following tendencies, personality, dominance, and a variety of other demographic variables, including acculturation and cultural identification measures, interacted with cultural background. With the exception of IQ, no other predictors were reliably predictive. However, all of our predictors together account for only about 9% of the variance in social learning. We briefly return to our null results with regard to cultural differences and prestige in the Discussion.

### 4.3.2. CONFORMIST BIAS

To assess the variation in the strength of conformist biases in social learning, we fit a logistic curve to all participant responses in Experiment 1 and 2 separately, assuming an inflection point of $1/N$, in order to fit the model. For all models, we again used a SDT approach, focusing on the 3 cases of interest and used the NLS method to estimate parameters.

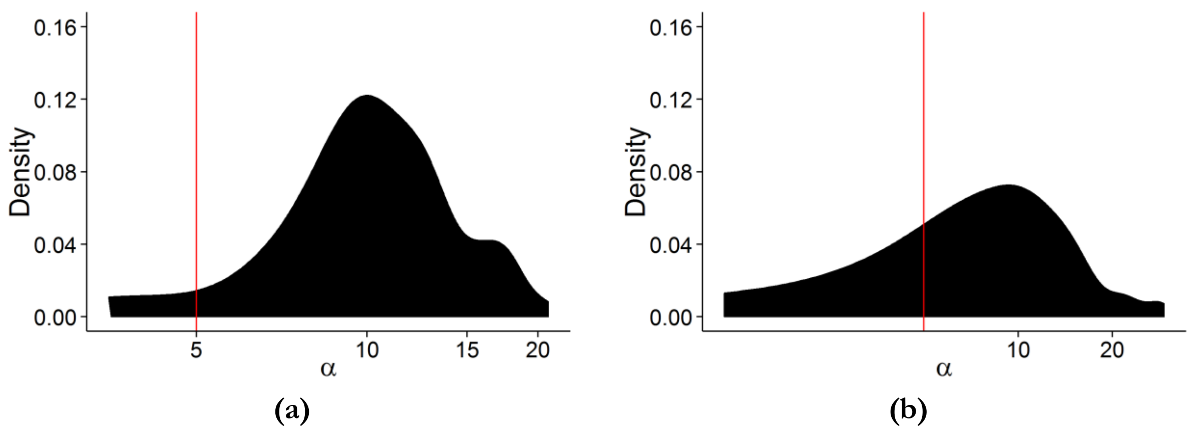



**Fig. 7. Density distribution of $\alpha$ conformist transmission values in (a) Experiment 1 and (b) Experiment 2, with $\alpha$ calculated after scaling frequency of options by transmission fidelity. The red line indicates the cut off for conformist transmission with values to the left of this line indicating unbiased social learning. The x-axis is log-scaled. For visual purposes, we remove some outliers – see Supplementary Materials for figure including these.**

Fig. 7 shows the distribution of $\alpha_i$ values in both experiments, with the vertical line marking unbiased, as opposed to conformist, transmission. In Experiment 1, only 3% of people showed unbiased social learning (or weaker). The remaining 97% of participants showed a conformist transmission bias to varying degrees, with the modal value a bit above 10. We found no evidence of anti-conformity. In Experiment 2, 15% of participants showed unbiased social learning (or weaker) when data was fitted to the raw majority percentage. However, this value may inflate the tendency toward unbiased social learning because it combines individuals relying on social information with very different transmission fidelities. To address this, we scaled the majority size by the transmission fidelity and re-estimated $\alpha_i$. With this adjustment, the percentage of unbiased social learners dropped to 9%. The remaining 91% of participants, or 85% for the unscaled calculation, showed some conformist transmission bias, with a modal strength close to 10. These results further support the argument that fewer options underestimate the strength of the conformist transmission bias. In neither experiment did we find any evidence of anti-conformity (Morgan, Laland, & Harris, 2014)—negative $\alpha_i$ values.

In Table 4, we regress the strength of the conformist transmission bias on our theoretically inspired individual predictors. Because the distribution of the $\alpha$ parameter was highly positively skewed, we took the logarithm of this value before standardizing it (see Fig. 7). For Experiment 2, we used the scaled $\alpha_i$ values, in part because it resulted in a better fitting model. However, no substantive differences were found using the unscaled fitted values, reported in Supplementary Materials.

Unlike our analysis of social learning above, the regression models in Table 4 reveal that the conformist bias is higher among those with low IQs *and* those with high IQs, compared to more average individuals. We found these results in both Experiments 1 and 2. We also found that the conformist bias was stronger in females and increased with age. Females had $\alpha_i$ values half a standard deviation higher than males, which translates to $\alpha_i = 1.6$ higher. For age, every 5.6 years translated to a $\alpha_i = 1.5$ increase. However, we had a limited age range with a mean age of 22. These differences were only found in Experiment 1, which is arguably more sensitive than Experiment 2, because there are often more than 2 options.

As with social learning, other analyses revealed no effect of the other plausible predictors and no effect of increased acculturation or identification. Note that, unlike with social learning, we had no specific predictions about the effect of social status (prestige or dominance) on conformist transmission.

| | **Experiment 1** | **Experiment 2** |
|---|---|---|
| (Intercept) | −0.31 (−0.76,0.14) | 0.33 (−1.64,2.29) |
| zIQ | 0.09 (−0.16,0.33) | 0.09 (−0.18,0.37) |
| $zIQ^2$ | 0.26 (0.11,0.41)*** | 0.25 (0.09,0.42)** |
| zPrestige | 0.04 (−0.18,0.26) | −0.10 (−0.45,0.26) |
| East Asian | 0.36 (−0.15,0.87) | −0.20 (−0.77,0.36) |
| Other Ethnicity | 0.49 (−0.11,1.10) | 0.07 (−0.60,0.75) |
| zAge | 0.39 (0.17,0.60)*** | −0.05 (−0.29,0.20) |
| Male | −0.51 (−0.93,0.09)* | 0.04 (−0.43,0.51) |
| $R^2$ | 0.33*** | $0.17^{+}$ |
| **N** | 74 | 74 |

***: $p < .001$, **: $p < .01$, *: $p < .05$, $^{+}$: $p < .1$

**Table 4. OLS regression model of standardized log measures of strength of conformist transmission ($\alpha$) regressed on our theoretical predictors as well as age and gender. All predictors with a "z" prefix are standardized scores. Ethnicity was dummy coded, with Euro Canadians as the reference group. These results suggest a consistent quadratic (U shaped) relationship between IQ and the strength of the conformist transmission bias. Both those who score high or very low on the IQ test are more likely to have stronger conformist transmission biases than those who score in the middle. In Experiment 1,**

**which is arguably more sensitive than Experiment 2 because there are often more than 2 options, conformist biases strengthen among older individuals and weakens among males.**

Given the effect of IQ on the amount of social learning and the strength of the conformist transmission bias, a reasonable question is whether these individual differences result in differences in performance and therefore payoffs. A regression analysis of performance on individual predictors revealed a consistent, but weak and non-significant positive effect of IQ on performance (both before and after seeing social information), suggesting that if IQ is helpful in this task, the effect is very weak (see Supplementary Materials for details).

# 5. DISCUSSION

Across two experiments and an ethnically diverse sample, we tested the effect of number of options, transmission fidelity, and payoff size on the degree of social learning and the strength of the conformist bias. Our major findings can be summarized as follows:

**Substantial conformist transmission.** In both experiments, we found substantial reliance on conformist biased social learning, with only 3% and 9% (or 15%) showing no conformist biases in Experiments 1 and 2, respectively. We suspect the stronger biases in Experiment 1 resulted from having multiple options at play.

**Increased social learning and stronger conformist bias as the number of options increases.** Both the amount of social learning and the strength of conformist biases increased as the number of options increased. This means that all prior experiments have merely established a lower bound on the amount of social learning and strength of conformist transmission, since all use only 2 options.

**Changing inflection point with more options.** The inflection point for conformist transmission behaves in a pattern consistent with the theory developed in Nakahashi et al. (2012), except that it is substantially and consistently upward biased. We suspect that this is due to a lack of any account of people's asocial priors in the Nakahashi et al. model. Future models should include asocial priors.

**More reliance on social learning, but stable conformist bias across different transmission fidelities.** Unexpectedly, except at very low transmission fidelities (40% error), the strength of conformist transmission was relatively stable and flat across a wide range of transmission fidelities. Though not formally modelled, this pattern seems inconsistent with what we inferred by considering Henrich and Boyd (2002) together with Nakahashi et al. (2012). Three different factors may be relevant. First, the spatial variation typically modelled may be different from transmission errors in some fundamental way, leading us to make an inferential mistake. A proper model of transmission error is required. Another possible issue is that these results are constrained by the limited degrees of freedom in our experiment. That is, in theoretical models (and the real world) where many different types of errors can be made, conformist transmission is adaptive when transmission fidelity is low as these mistakes may result in small improvements. However, by constraining our experiment to two options, of which only one is correct, mistakes are always fatal (win-lose). New experimental designs and more data are needed to address this discrepancy. Finally, it could simply be that human psychological mechanisms are not designed to intuitively evaluate the format in which we provided the transmission fidelities – probabilities of accurate social information – a wealth of research suggests that people are bad at using probabilities (Tversky & Kahneman, 1981). But, since we do observe some effects on social learning, this can't be the complete explanation.

**Higher payoffs have little or no effect on learning strategies.** The amount of social learning differs between no payoff and some payoff, but does not continue to increase with higher payoffs

(Table 2). In contrast, paying people usually reduces conformist transmission, but here, the strength of conformist transmission increases as the payoffs for correct answers increase. This result is not significant (Fig. 6b and 6c), however, Nakahashi et al. (2012) predict a very small effect, so it may be that our transmission error and payoff range were too small to detect the pattern (see Supplementary Materials Mathematica file).

**Group size affects social learning with 2 options.** Consistent with King and Cowlishaw (2007) and Perreault, Moya, and Boyd's (2012) theories, we find that increased group size predicts increased social learning independent of the frequencies of options. However, we did not find this relationship for more than two options. One possibility is that with increased traits, larger groups are required for group size to have a discernible effect (our range of group sizes was 5 to 11).

**Cognitive ability differences are associated with both social learning and the strength of the conformist bias.** Extrapolating from the existing modelling work, we suspected that IQ would be negatively related to social learning and the strength of the conformist bias. This is the case for social learning, but only the case for the conformist bias in the lower range of IQs. At the upper end, higher IQs, like very low IQs, are associated with stronger conformist biases. These results together suggest that higher IQ individuals are strategically using social learning (using it less, but with a stronger conformist bias when they choose to use other information). However, IQ is only weakly related to overall performance, suggesting that, even if this is the case, these strategies are not particularly effective. Differences in cognitive ability may also help explain individual variation in social learning and conformist transmission in non-human species (Laland, Atton, & Webster, 2011; Pike & Laland, 2010).

**No detectable 'cultural' differences.** Neither our East Asian ethnicity variables nor our cultural identification or acculturation index pointed to any variation in social learning or conformist transmission across these populations. Nevertheless, although 53% of our sample was East Asian and 85% of them were born outside of Canada, we should take this as only preliminary evidence since it would be preferable to measure East Asians living in East Asia rather than rely on acculturation or cultural identification measures to compensate for the partial acculturation of our Canadian sample.

**No detectable relationship between prestige and social learning.** We predicted that individuals who view themselves as prestigious compared to others may be disinclined to copy others, because they don't see others as superior sources of information. However, we found no relationship between our measure of self-reported prestige and social learning. One reason for this might be that this general sense of prestige is psychologically very distant from the skill domain of line-length judgments, since line-length judging is not a valued skill in Vancouver. Thus, broadly prestigious individuals may not have mapped this over to the experimental task. Further research on this requires using tasks involving locally esteemed skills.

**No detectable relationships between other individual variables and social learning or the strength of the conformist bias.** Our measures of dominance, rule-following, reflective thinking, or any of the Big 5 personality dimensions did not reliably predict social learning nor the strength of the conformist bias. Thus, conformist biases are not a feature of personality, or other dispositional or normative tendencies like rule-following. Finally, though we were able to account for between 9% and 33% of the variance in individual's reliance on social learning and strength of conformist biases, there remains an immense amount of individual variation in these strategies that we could not explain.

Overall, our findings support the value of formal evolutionary modelling in developing and testing psychological theories about human psychology and about social learning in particular. Broadly, they indicate that at least in this domain conformist transmission is a central component of human social learning, which varies predictably across contexts and individuals.

## 6. ACKNOWLEDGMENTS

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