Identifying cultural differences in metacognition

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All anonymized behavioral data and analysis scripts supporting the findings of this work are available on GitHub (github.com/elisavanderplas/CulturalMetacognition).

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ABSTRACT

Aspects of human metacognition such as the ability to consciously evaluate our beliefs and decisions are thought to be culturally acquired. However, direct evidence for this claim is lacking. As an initial step towards answering this question, here we examine differences in metacognitive performance between populations matched for occupation (students), income, demographics and general intelligence, but drawn from two distinct cultural milieus (Beijing, China and London, UK). We show that Chinese participants have heightened metacognitive evaluation of perceptual decision-making task performance in comparison with UK participants. These differences manifested in boosts to post-decisional processing following error trials, despite no differences in first-order performance. In a second experiment, we directly replicate these findings and show that a metacognitive advantage generalizes to a new task that replaces post-decision evidence with equivalent social advice. Together, our results are consistent with a proposal that metacognitive capacity is shaped via socio-cultural interactions.

INTRODUCTION

A canonical aspect of human cognition is the ability to reflect on our perceptions, memories and decisions to reach conclusions such as “I’m sure” or “I’m doubtful” (Flavell, 1979; Nelson, 1990; Shea et al., 2014). Such self-evaluations, known as explicit metacognition, are thought to facilitate adaptive behavior in two ways: first, by allowing more efficient intrapersonal control, such as prompting further revision when we realize we do not know enough to perform well in an upcoming exam; and second, by facilitating interpersonal communication and collaboration, such as when two football referees pool their confidence about what just happened on the pitch (Bahrami et al., 2010). In both of these cases, “better” metacognition, i.e., a tighter coupling between second-order self-evaluations and first-order cognitive or perceptual performance, tends to lead to greater individual and group performance (Bahrami et al., 2010; Bang et al., 2014, 2017; Fusaroli et al., 2012). By leveraging frameworks derived from psychophysics and signal detection theory, it has now become possible to isolate precisely metrics of metacognitive ability in laboratory tasks, for instance the extent to which subjects recognize their mistakes by adjusting their confidence accordingly (Galvin et al., 2003; Maniscalco & Lau, 2012). However, the origin of these high-level, reflective abilities remains poorly understood.

Developmentally, explicit metacognition is thought to crystallize between the ages of 3 and 4 (Hembacher & Ghetti, 2014), although implicit precursors have been identified earlier in infancy (Goupil & Kouider, 2016a, 2016b). Intriguingly, explicit metacognition emerges around the same time as the ability to think about the minds of others (Carruthers, 2009; Lockl & Schneider, 2007), suggesting that similar computations may underpin self- and other-evaluation (Fleming & Daw, 2017). A recent theoretical framework proposes that aspects of explicit metacognition are culturally acquired and determined by the extent to which cultures place emphasis on discussing and understanding the mental states of self and other (Cleeremans et al., 2020; Heyes et al., 2020; Heyes & Frith, 2014). In other words, just as children learn to understand the meaning of written words from teachers and parents, children who grow up in cultures where working together is the norm may develop a stronger awareness of their own and others' mental states.

A key implication of this "cultural origins hypothesis" is that metacognition should be subject to cultural variation to the extent that there are cultural differences in social collaboration and integration. Specifically, the supra-personal functions of metacognition—accurate communication and broadcast of private mental states to others—should have benefits not only to the owner of those skills, but also to other members of the social group with whom they make decisions and coordinate action. Consequently, it is in the interests of a person with enhanced metacognitive skills to teach those skills, deliberately or inadvertently, to others in the group. The requirement to do so is presumably stronger in more socially integrated groups, such as cultures where collaboration and shared goals are more common. The cultural origins hypothesis suggests that these slight differences in the importance of communication may have a downstream impact on objectively measured metacognitive abilities (the alignment between confidence and performance).

A rich source of potential cross-cultural differences in social integration has been documented in studies comparing China with the West. Chinese populations are more likely to pay attention to and conform to others' opinions than UK or US populations (Korn et al., 2014; Mesoudi et al., 2015; Oeberst & Wu, 2015); are thought to be more interdependent than independent in thinking styles (Singelis, 1994); and be more collectivist in emphasizing harmony with others than Western countries (Hofstede & Hofstede, 2010; Markus & Kitayama, 2010; Weber, 1905). However, whether cultural background similarly affects explicit metacognition remains unknown. Here, by applying recently developed psychophysical tools for isolating and quantifying the capacity for explicit metacognition about simple decisions, we seek to evaluate this hypothesis.

Previous cross-cultural studies of metacognition have focused on quantifying differences in confidence ratings. For example, a typical study might ask subjects general knowledge questions such as “Which one is further north: New York or London?” after which participants indicate their confidence that the decision was correct. Such studies have often found that Chinese populations report higher confidence than US or UK populations (Moore et al., 2018; Yates et al., 1989, 1998). It is important to note, however, that average confidence is only one facet of metacognition, known as metacognitive bias, and can vary independently of metacognitive sensitivity, the ability to discriminate between correct and error trials using confidence ratings (Fleming & Lau, 2014; Maniscalco & Lau, 2012). In other words, a highly confident person may still realize when they are wrong, and rate lower confidence accordingly—thus demonstrating good metacognitive sensitivity. This capacity for metacognitive sensitivity, rather than idiosyncrasies in metacognitive bias, is also likely to be a key variable for effective collaboration with others (Bahrami et al., 2010; Fusaroli et al., 2012; Bang et al., 2014).

Two previous studies have quantified cross-cultural differences in both metacognitive bias and sensitivity. Yates and colleagues found that, despite a heightened (overconfident) metacognitive bias, metacognitive sensitivity was also higher in Chinese than US populations, as measured by probability judgment discrimination scores (Yates et al., 1989). Another study found heightened metacognitive bias in Chinese people living in Taiwan in comparison to Japanese and American populations, but inconsistent effects on metacognitive sensitivity (Yates et al., 1998). However, in both of these studies, first-order performance (judgment accuracy) was left free to vary across a wide range, and differences in metacognitive sensitivity are known to be potentially confounded by group differences in accuracy (Fleming & Lau, 2014)—people tend to better discriminate between their incorrect and correct decisions when the task at hand is easier. Moreover, both of these studies looked at associations between average confidence and average accuracy collapsed over groups of trials. Much less is known about cultural differences in the computational processes that give rise to fluctuations in confidence. For instance, recent work suggests that confidence is informed by evidence that becomes available after an initial decision has been made ("post-decision evidence") (Navajas et al., 2016; van den Berg et al., 2016). When post-decision evidence contradicts a past decision, people tend to rate lower confidence, whereas post-decision evidence that confirms a past decision results in higher confidence (Fleming et al., 2018). Given the central role that post-decisional processing plays in promoting openness to others' (conflicting) viewpoints (Rollwage et al., 2018; Schulz et al., 2020), it could be that cultural norms of harmony and collaboration selectively impact metacognition through shaping the processing of post-decision evidence.

Here we sought to provide an initial assessment of whether metacognitive capacity, as measured using performance-controlled laboratory tasks, differs between individuals drawn from distinct Northern European and Chinese cultural milieus. To ensure well matched samples, we compare the profiles of confidence judgments in Chinese and British samples matched for occupation (full-time students at Peking University, PKU, and University College London in the UK), age, gender, income and IQ. We only recruited Chinese/British citizens that had at least one parent who was born and raised in mainland China/Britain and had not lived more than one year abroad. We then leveraged recent methodological advances in metacognition research (Fleming et al., 2012; Fleming & Lau, 2014; Frith, 2012; Yeung & Summerfield, 2012) to disentangle potential effects of cultural background on both first-order and metacognitive processes engaged during the task to examine confidence formation independently of other aspects of task performance. We also asked whether post-decision evidence might differentially modulate confidence across cultural backgrounds. After an initial perceptual decision about the direction of a patch of randomly moving dots (left versus right), participants were shown additional (post-decision) evidence and asked to rate their confidence that the initial decision was correct. Using a calibration procedure, we selected stimuli of similar perceptual strength across individuals and sites to match first-order task difficulty, such that any difference in metacognition between cultures was unrelated to the first-order performance.

To pre-empt our results, in two independent behavioral experiments, we found that Chinese participants had heightened metacognitive sensitivity and post-decisional processing in the absence of differences in first-order perceptual performance, consistent with a hypothesis that cultural variation contributes to metacognition.

METHODS

Experiment 1.

Participants. We recruited N = 83 participants at both Peking University (PKU) in Beijing, China and University College London (UCL) in London, UK (**Supplementary Table 1**). For Experiment 1 we did not conduct statistical tests to predetermine the sample size, as the effect size for a potential cultural difference was unknown. Instead, we used a sample size similar to those used in previous publications using the same paradigm (Fleming et al., 2018). At both sites the experiment was advertised via an online platform and flyers on campus, from which we recruited participants that were: (1) full-time students at PKU/UCL; (2) Chinese/British citizens; (3) had at least one parent that was born and raised in mainland China/Britain; and (4) had not lived more than one year abroad. All participants had normal or corrected-to-normal vision and no history of neurological or psychiatric illness. Instructions, advertisements and questionnaires in English were translated to Mandarin Chinese and then back translated by an independent translator. The study was approved by the University College London Ethics Committee (1260/003) and by the Ethics Committee of School of Psychological and Cognitive Science at Peking University. All participants gave written informed consent before taking part in the experiment.

Exclusion criteria were defined a priori and are the same as the exclusion criteria employed by several previous papers using the same or similar tasks (Rollwage et al., 2018; Fleming et al., 2018). Two participants were excluded from the PKU dataset: one participant did not follow task instructions and one participant performed below our *a priori* accuracy cut-off threshold (i.e., less than 60% accuracy). Three participants were excluded from the UCL dataset: one participant was found not to have met the recruitment criteria after data collection (not a full-time student), one participant lacked variability in their confidence ratings (881/900 trials were rated as 100% confident) and one participant performed below the accuracy cut-off threshold of 60%. This resulted in the analysis of thirty-nine participants per site (N = 78 participants in total of which 39 female, mean age: 22.63 ± 0.33 years). All key site differences reported in the Results section remained significant after we re-introduced these participants.

To establish that patterns of task performance were consistent with previous literature, we re-analyzed a previous dataset using the same task (Fleming et al., 2018) which was collected at New York University (NYU). This dataset consisted of N = 25 participants (14 female, mean age: 24.0 ± 0.72 years), although information on the cultural background of the sample was not collected. The NYU recruitment was approved by NYU’s University Committee on Activities Involving Human Subjects and all participants provided written consent before taking part in the experiment.

Experimental paradigm. The experiment was programmed in Matlab 2014b (MathWorks) using Psychtoolbox (version 3.0.12) and presented on a desktop monitor at approximately 45 centimeters viewing distance. Stimuli were random dot kinematograms (RDKs): 30 moving dots (0.12° diameter) that appeared in a 7° circular white aperture for 300 milliseconds. The movement of the dots was generated by replotting the dots every three video frames, with a subset moving horizontally to either the left or the right and the remainder moving in a random direction. The subset that moved in the coherent direction was manipulated across conditions as giving rise to weak, medium or strong evidence strength. To ensure that these conditions were perceptually equivalent across participants, we performed a calibration procedure in which we estimated each participants’ psychometric function for a broad range of evidence strength levels and then selected the three evidence strength levels that were associated with three pre-specified levels of accuracy (weak = 60%, medium = 75% and strong = 90%; **Supplementary Material 1.2**).

On the psychophysical task, participants were shown 900 samples of evidence (RDK stimuli, pre-decision evidence) with variable evidence strength and were asked to judge the direction of dot movement (left or right). Participants indicated their choice by pressing a keyboard button [left: 1; right: 2] within 1,500 ms. After the choice, participants were shown “bonus” post-decision evidence where the dots moved in the same direction but with variable evidence strength (weak, medium, strong). In total, there were thus nine experimental conditions in a 3 (three pre-decision evidence strength levels) x 3 (three post-evidence strength levels) factorial design (**Figure 1a**). At the end of every trial, participants were asked to rate their confidence that the initial judgment was correct on a scale ranging from 0 to 100%. Participants indicated their response by selecting a point on the scale with the mouse cursor within 3,000 ms. We implemented a Quadratic Scoring Rule (QSR) to motivate participants to report their confidence as accurately as possible. In particular, participants earned maximum points on a trial if they rated the lowest possible confidence about an incorrect judgment, or if they rated the highest possible confidence about a correct judgment.

Additional measures. After the psychophysical task, we administered three additional surveys: Self-Construal scale (Singelis, 1994), Analysis-Holism scale (Choi et al., 2003), and Culture-Free Intelligence test (Cattell, 1940). One of the authors translated the Analysis-Holism scale and the Culture-Free Intelligence Task to Mandarin Chinese and we used a published Mandarin Chinese translation of the Self-Construal scale (Singelis, 1994). All Mandarin Chinese translations of the questionnaires were back translated by an independent translator to ensure translation quality before the questionnaires were used at PKU. In **Supplementary Material 1.1** we report the details of these questionnaires and compare their scores across sites.

Statistics. Group differences were tested with two-tailed independent samples t-tests (assuming equal variances). We confirm basic demographical differences with two-sided

Bayesian independent samples student t-test (using JASP 0.14.1). To assess the effects of our factorial design on accuracy and confidence, we conducted hierarchical mixed-effect regression models using the ‘lme4’ package in R (version 3.3.3) and plotted the behavioral data and the output of the model fits in MATLAB (version R2018a). We obtained the *P*-values of the regression coefficients using the *car* package. All models include a random effect at the participant level and all statistics are computed at the group level. Given that we expected individual differences in the association between confidence and task variables between individuals even within each cultural group, we specified a random effect at the subject level corresponding to each fixed effect of interest. We reported type III Wald chi-square tests (χ^2), degrees of freedom (*df*) for fixed effects, and estimated beta-coefficients (β) together with their standard errors of the mean (± SEM) and *P*-values of the associated contrasts.

We investigated the effect of the pre-decision evidence strength (pre) [weak: -0.5, medium: 0, strong: 0.5] across sites [1: PKU, 2: UCL] on trial-by-trial accuracy [0: error, 1: correct] with the following hierarchical mixed-effect logistic regression model:

$$\text{(1) } accuracy \ \sim site * pre + (\ 1 + pre \mid subj)$$

To predict confidence, we used a hierarchical mixed-effect regression model with trial-by-trial confidence (conf) as the dependent variable, and accuracy (acc) [-1: error, 1: correct], z-score of the log response time (RT), pre-decision evidence strength (pre) [weak: -0.5, medium: 0, strong: 0.5], post-evidence strength (post) [weak: -0.5, medium: 0, strong: 0.5], site [PKU:1 , UCL: 2] and their interactions as predictors:

$$\text{(2) } conf \sim site * (acc + pre + post + pre * post + pre * acc + post * acc + pre * post * acc + RT) + (1 + acc + pre + post + pre * post + pre * acc + post * acc + pre * post * acc + RT \mid subj)$$

After demonstrating that we replicate the results of Fleming et al (2018) in each site separately, we combined the two datasets and included a site interaction term to investigate whether the effects are consistent between PKU and UCL (see **Supplementary Material 1.3** for a comparison of all three sites including NYU). To investigate whether the model's prediction of confidence improved when cross-cultural terms were included, we conducted a Likelihood Ratio Test that assesses the benefit of including interactions with site, here expressed in terms of the *Akaike Information Criterion* (*AIC*): $\Delta AIC = AIC_{without\ site} - AIC_{with\ site}$, and the *Log Likelihood* (*LL*): $\Delta LL = LL_{with\ site} - LL_{without\ site}$ with associated *P* value extracted from a type III Wald chi-square tests (χ^2). In addition, we confirmed that simulating data from the summary statistics of the hierarchical regression model in Equation 2 successfully recaptured key features of the actual dataset (**Supplementary Material 1.4**).

To visualize the direction of the effects in Equation 2, we obtained the beta-coefficients of the pre-decision evidence conditions (pre) [weak: -0.5, medium: 0, strong: 0.5] and the post-evidence conditions (post) [weak: -0.5, medium: 0, strong: 0.5] and their interactions on confidence for each site separately [1: PKU, 2: UCL] and on error and correct trials separately:

$$(3)\quad conf_{err/corr} \sim pre + post + pre * post + RT \ + (1 + pre + post + \ pre * post + RT \mid subj)$$

Experiment 2

Participants. We recruited two new samples of participants at UCL and PKU, using the same procedure as in Experiment 1. A minimum sample size of N = 53 at each site was defined by an *a priori* power calculation of the t-test between the impact of post-decision evidence on confidence in PKU and UCL in Experiment 1 (power = 80%, *P* = 0.05, Cohen's d = 0.54). This power calculation provides a simple, relatively assumption-free estimate of effect size for our key contrast of interest. Four participants were excluded from the PKU dataset: one participant performed below our *a priori* accuracy cut-off of 60%; two participants' calibration data was unusable, and one participant violated transitivity in performance (i.e., average performance was lower in the medium evidence condition than in the weak evidence condition). Two participants were excluded from the UCL dataset: one participant did not believe the social manipulation and never followed the advice (see '**Experimental paradigm'**), the other participant violated transitivity. We note that all reported site differences of post-decision evidence on confidence remained significant after we re-introduced these excluded participants. All participants had normal or corrected-to-normal vision and no history of neurological or psychiatric illness. The study was approved by the University College London Ethics Committee (1260/003) and by the Ethics Committee of School of Psychological and Cognitive Science at Peking University. All participants gave written informed consent before taking part in the experiment.

Experimental paradigm. We adapted the task used in Experiment 1. As in the original task, participants were asked to judge the direction of moving dots (pre-decision evidence) with varying evidence strength (weak, medium or strong). In addition, we made a number of changes to the original paradigm. Confidence ratings were made on a confidence scale that ranged from 100% confidence in the left direction to 100% confidence in the right direction (100%, 80%, 60% left and 60%, 80%, 100% right). Participants were asked to rate their confidence on this scale because, on a randomly selected half of the trials, the same scale was used to display the confidence estimation of a previous participant ('adviser') as social post-decision evidence. On the other half of the trials, post-decision evidence was a second RDK stimulus with dots moving in the same direction as pre-decision evidence but with variable evidence strength (weak, medium, strong). Social post-decision evidence was presented below a silhouette with a unique, uninformative background color. Participants were told that, because of the calibration procedure, the performance of the advisers was similar to theirs. In reality, the social advice was obtained from a computational model that made confidence and direction decisions with the same perceptual sensitivity level as the participant. This manipulation allowed us to keep the informativeness of post-decision evidence equal across conditions (social, perceptual) and manipulate the confidence levels of the adviser as a function of three evidence strength levels (with more confident advisers following stronger evidence; **Supplementary Material 2.1**). Together, this full-factorial design crossed three (pre-decision evidence strength) x three (post-decision evidence strength) x two (social, perceptual post-decision evidence type) within-subject conditions. All but one of our 106 participants across both sites indicated to have believed the social manipulation during our extensive debriefing.

Additional measures. In addition to the three questionnaires administered in Experiment 1: the Self-Construal Scale (Singelis, 1994), Cattell Culture Free Intelligence Quotient (Cattell, 1940) and the Analysis Holism Scale (Choi et al., 2003) we also obtained participant's responses on the Beck Cognitive Insight Scale (BCIS; Beck et al., 2004). This scale was originally developed to measure insight into symptoms within clinical populations but has also been used in non-clinical settings (Fleming et al., 2012). On the BCIS, participants indicated their agreement with statements about the recognition that experienced reality may be different from the objective truth. We were interested in knowing how insight would relate to differences in post-decision evidence processing on the main task and whether, in light of the cultural variation hypothesis, we would find cross-cultural differences on the BCIS (**Supplementary Material 2.6, Supplementary Table 1**).

Statistics. Statistical inference was conducted similarly to analysis of Experiment 1. As confidence estimates were given on a different scale in Experiment 2, we first converted confidence in the dots moving left or right (conf_{dir}) to confidence in the chosen direction [certainly wrong: 0, certainly correct: 1], by subtracting $conf_{dir}$ from 1 when the chosen direction was left (a = -1), as follows:

$$(4)\ if(a = -1)$$
$$confidence = 1 - conf_{dir}$$

To index the strength of social post-decision evidence while ignoring the direction of the advice, we transformed adviser confidence ($conf_{adv}$) on a scale from 100% left to 100% right. We recoded this variable as ranging from 0-1, such that values < 0.5 indicated greater adviser confidence in leftward motion and values > 0.5 indicated greater adviser confidence in rightward motion. We then transformed this signed confidence variable to an unsigned confidence variable ranging from 0.5 to 1, as follows:

$$(5)\quad if\ (conf_{adv} < 0.5)$$
$$conf_{adv} = 1 - \ conf_{adv}$$

We then binned adviser confidence into three equal quantiles representing the lowest, middle and highest 33% confidence ratings ($conf_{adv}$) to create 3 levels of social post-decision evidence [weak: -0.5, medium: 0, strong: 0.5], which we used instead of ‘post’ in Equation 2. Each individual’s beta coefficient for the main effect of perceptual and social post-decision evidence (derived from Equation 3) were entered into a robust correlation using the MATLAB robust correlation toolbox (Pernet et al., 2013).

RESULTS

In Experiment 1, we analyzed the data of N = 78 participants (N = 39 at each site) who were matched in terms of age (M_{PKU} = 22.33 (SE = 0.38), M_{UCL} = 22.92 (SE = 0.54), independent samples t-test, t_{76} = -0.89, 95% Confidence Interval (CI) = [-1.91, 0.73], *P* = 0.38), gender (M_{PKU} = 49%, UCL = 51%, t_{76} = -0.22, 95% CI = [-0.25, 0.20], *P* = 0.82) and annual family income (their parents' combined gross income before tax, converted from Chinese renminbi (¥) to pounds (£) at 2017 purchasing power parity) relative to the *per capita* purchasing power parity at the time of recruitment (M_{PKU} = £37,615.38 (SE = 4,535.01) and UCL (M_{UCL} = £39,381.35 (SE = 3,962.23), t_{75} = -0.29, 95% CI = [-13852, 10320], *P* = 0.77). To further support the absence of demographic differences between sites, we applied Bayesian analyses (two-sided Bayesian independent samples student t-tests) as implement in JASP 0.14.1 (https://jasp-stats.org/). Bayes factors indicated anecdotal evidence for an absence of difference in income (BF_{01} = 1.86, error: 0.01) between sites; and substantial evidence for an absence of difference in gender (BF_{01} = 4.17, error: 0.02), age (BF_{01} = 3.03, error: 0.02) and IQ (BF_{01} = 3.75, error: 0.02) between sites. In addition, we administered a non-verbal measure of fluid intelligence which minimizes the influence of verbal fluency, culture and education (Cattell Culture-Free Intelligence test; Cattell, 1940), which showed no differences in intelligence between both sites (M_{PKU} = 102.36 (SE = 1.79), M_{UCL} = 101.15 (SE = 1.52), t_{73} = 0.51, 95% CI = [-3.55, 5.96], *P* = 0.61; see **Supplementary Table 1** for additional measures).

We next turn to the psychophysical task used in Experiment 1 (**Figure 1a**). Participants were asked to detect the direction of dot motion in a brief random-dot motion stimulus. The coherence level of random-dot motion was selected from a calibration phase to ensure that accuracy was equal across participants. As a result of the calibration procedure, the accuracy of participants' initial decisions (first-order performance) was not statistically different between sites (M_{PKU} = 83% (SE = 0.01), M_{UCL} = 83% (SE = 0.01), independent samples t-test, t_{76} = -0.20, 95% CI = [-0.03, 0.02], *P* = 0.85). The effect of pre-decision evidence (coherence) level on accuracy, i.e., the slope of the psychometric function, was also similar across sites (**Supplementary Material 1.2**). Average response times were not statistically different between sites (logRT; M_{PKU} = -1.01 (SE = 0.06), M_{UCL} = -1.13 (SE = 0.10), independent samples t-test, t_{76} = 1.14, 95% CI = [-0.10, 0.35], *P* = 0.26).

Using a hierarchical logistic regression to predict trial-by-trial accuracy, we found that first-order performance was indeed more accurate with stronger evidence (hierarchical linear regression, main effect of pre-decision evidence: $\chi^2(1) = 363.02$, $P < 2e^{-16}$, $\beta = 2.92$ (SE = 0.15), $z = 19.05$, $P < 2e^{-16}$). As expected, this effect did not interact with site (interaction between site and pre-decision evidence: $\chi^2(1) = 0.94$, $P = 0.33$, $\beta = -0.21$ (SE = 0.21), $z = -0.97$, $P = 0.33$; **Figure 1b**).

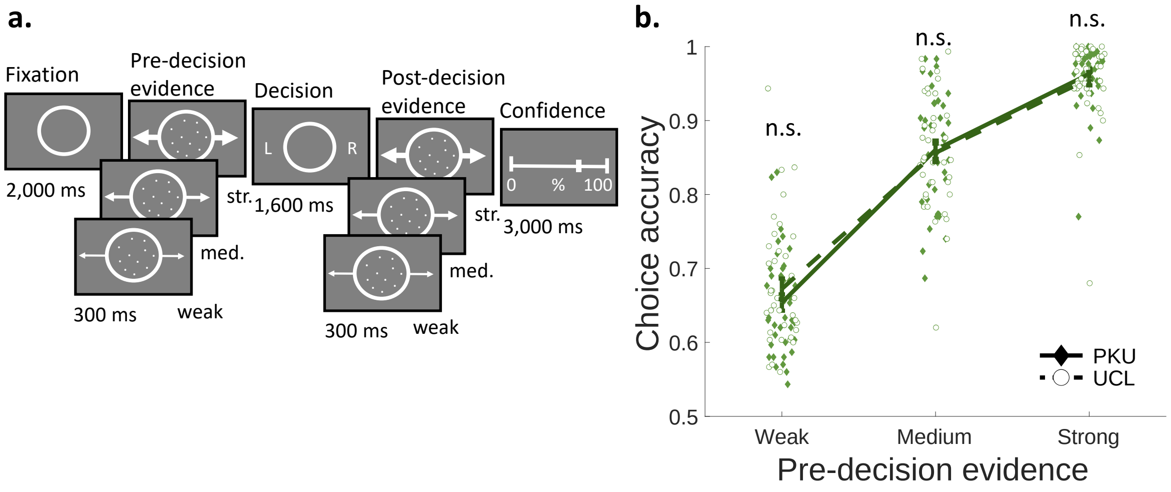

Figure 1. Experiment 1. Task design and matched first-order performance. a, *Participants made judgments about the direction (left versus right) of random dot motion. After seeing this pre-decision evidence, participants were shown additional post-decision evidence in the same direction as the pre-decision evidence but of potentially differing strength. Finally, they were asked to rate their confidence of their initial decision being correct on a scale from 0% to 100%, with percentages indicating probability of being correct.* ***b,*** *Choice accuracy was matched between sites (n.s.) and higher following*

stronger pre-decision evidence levels (P < 0.001, N = 39 participants at each site). Error bars represent group mean ± SEM.

Having shown that we matched choice accuracy (first-order performance) across sites, our next question was whether confidence ratings varied as a function of the strength of confirming or disconfirming post-decision evidence (weak, medium or strong) that each participant received (**Figure 2a**). Participants were instructed that the new evidence would always move in the same direction as the initial evidence and that they could use both pieces of evidence to rate their confidence about their initial response on a scale from 0 to 100%. We crossed three levels of pre-decision evidence strength with three levels of post-decision evidence strength to create a fully factorial 3 (pre-decision evidence strength) x 3 (post-decision evidence strength) factorial design (**Figure 1a**).

Across both sites, we replicated key patterns of confidence modulation reported previously using this task (Fleming et al., 2018): stronger post-decision evidence after an incorrect choice led to lower confidence (as participants could use the new evidence to realize that they were wrong), whereas stronger post-decision evidence after a correct choice led to higher confidence (as participants could use the new evidence to confirm that they were correct; **Figure 2a** and **Supplementary Material 1.3**). As expected, we also find a clear impact of post-decision evidence strength on metacognitive efficiency (**Supplementary Material 1.5**).

We next tested whether a hierarchical regression model better predicted trial-by-trial confidence when the predictor variables (pre- and post-decision evidence levels, accuracy, standardized log response time (RT) and their interactions) were allowed to vary across sites. A Likelihood Ratio Test indicated that this was indeed the case (log likelihood (LL): ΔLL = 11 and Akaike Information criteria (AIC): ΔAIC = 5, $\chi^2(9) = 23.38$, $P = 0.005$; **Supplementary Material 1.4**), suggesting a significant role for cultural differences in affecting the construction of confidence. In addition, we replicated previous findings of higher average confidence ratings in Chinese participants (M_{PKU} = 85% (SE = 0.01), M_{UCL} = 80% (SE = 0.01), independent samples t-test, $t_{76} = 2.32$, 95% CI = [0.01, 0.08], $P = 0.02$), driven by PKU subjects tending to use higher confidence ratings on correct trials (**Figure 2a**). The variance of confidence ratings was not different between sites (M_{PKU} = 85% (SE = 0.01), M_{UCL} = 80% (SE = 0.01), independent samples t-test, $t_{76} = 1.35$, 95% CI = [0.004, 0.02], P = 0.18).

We next asked how cultural background modulated the impact of new evidence on confidence by testing which predictor variables interacted with site. We found that post-decision evidence had a higher impact on confidence in the PKU dataset than in the UCL dataset (hierarchical linear regression, interaction of post-decision evidence x site: $\chi^2(1)$ = 6.89, $P = 0.009$, $\beta = 0.05$ (SE = 0.02). This effect was most evident on error trials, as shown by the steeper slope in the PKU dataset (**Figure 2a**). Indeed, when we fitted a hierarchical regression model on error trials only, the impact of post-decision evidence on confidence was significantly higher in the PKU dataset than in the UCL dataset (interaction between site x post-decision evidence on error trials: $\chi^2(1) = 4.85$, $P = 0.03$, $\beta = 0.08$ (SE = 0.04) but not on correct trials: $\chi^2(1) = 2.40$, $P = 0.12$, $\beta = 0.02$ (SE = 0.02); **Figure 2b**). This result remained unchanged when we excluded response times from the regression model. However, the three-way interaction between post-decision evidence, accuracy and site did not reach statistical significance when tested within a single hierarchical regression model ($\chi^2(1) = 2.23$, P = 0.14, $\beta = -0.03$ (SE = 0.02), $t_{74.04} = -1.49$, $P = 0.13$), suggesting an enhanced susceptibility to new evidence in the PKU sample that was not necessarily restricted to error trials.

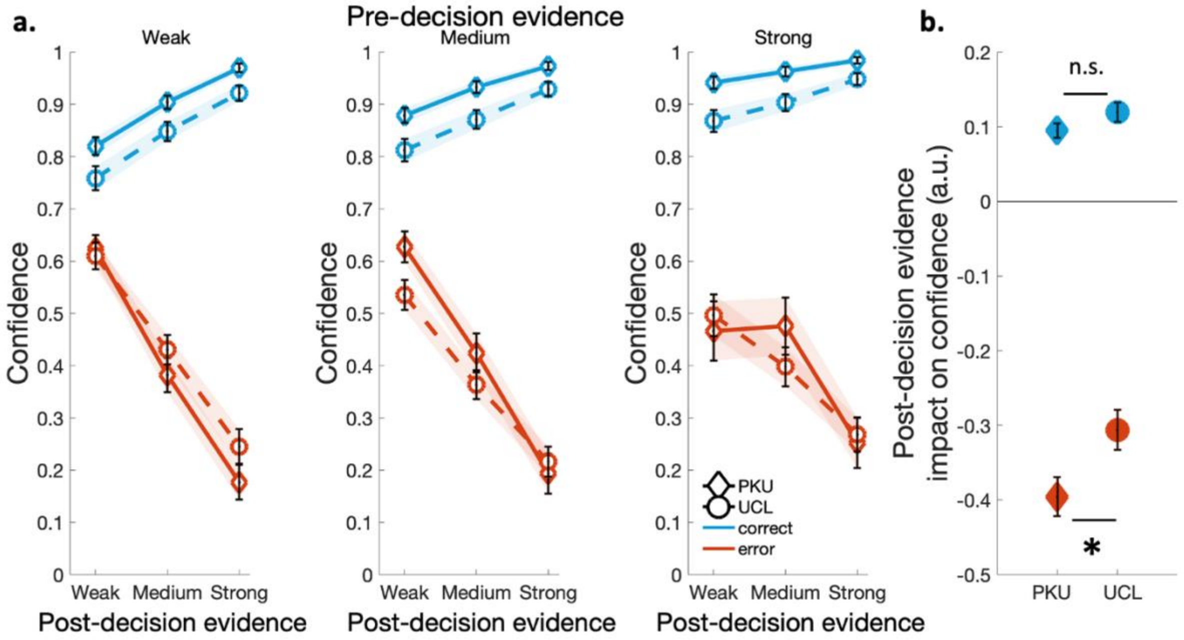

Figure 2. Behavioral results for Experiment 1. a, *Confidence as a function of post-decision evidence strength on error trials (red) and correct trials (blue) for each pre-decision evidence level. Shaded error bars represent group mean ± SEM. N = 39 at each site.* ***b,*** *Impact of post-decision evidence on confidence indicated as standardized beta-coefficients from a hierarchical mixed-effect regression model on error trials (red) and correct trials (blue) at each site. Error bars represent group mean ± SEM, * P < 0.05.*

In summary, in Experiment 1 we found enhanced susceptibility to post-decision evidence in PKU participants compared with UCL participants. Importantly, since first-order performance was matched between sites, these results suggest that metacognitive processes are liable to cultural influence.

In order to replicate and extend our results we conducted Experiment 2. Two new samples of N = 53 PKU participants (25 females, M_{age} = 21.91 (SE = 0.46) and N = 53 UCL participants (29 females, M_{age} = 22.49 (SE = 0.41), again with similar age (t_{104} = -0.95, 95% CI = [-1.81, 0.64], *P* = 0.34), gender (M_{PKU} = 47%, M_{UCL} = 55%, t_{104} = -0.77, 95% CI = [-0.27, 0.12], *P* = 0.44), Culture Free Intelligence Quotient (M_{PKU} = 99.21 (SE = 1.41), M_{UCL} =

102.00 (SE = 1.46), $t_{102} = -1.37$, 95% CI = [-6.82, 1.24], $P = 0.17$) and annual family income (M_{PKU} = £41,373.58 (SE = 5,454.69) and UCL (M_{UCL} = £56,988.89 (SE = 13,766.63), $t_{102} = -1.05$, 95% CI = [-45060, 13830], $P = 0.30$) were recruited. Again, using Bayesian analyses, Bayes factors indicated anecdotal evidence for an absence of difference in age ($BF_{01} = 0.31$, error: 0.03) between sites, gender ($BF_{01} = 0.27$, error: 0.03), income ($BF_{01} = 2.20$, error: 1.07e-05) and IQ ($BF_{01} = 0.48$, error: 2.29e-05) between sites. In Experiment 2 (but not in Experiment 1) we also included a measure of cognitive insight as quantified using the Beck Cognitive Insight Scale (BCIS; Beck et al., 2004). The BCIS includes questions about a person's ability to recognize that objective reality may be different from what one subjectively feels to be true. In light of the findings of enhanced metacognition in PKU participants in Experiment 1, we hypothesized that PKU participants would report having greater insight than UCL participants. This hypothesis was confirmed by the questionnaire data, with PKU participants having higher average BCIS scores than UCL participants (M_{PKU} = 40.26 (SE = 0.49); M_{UCL} = 20.96 (SE = 0.82), independent samples t-test, $t_{104} = 20.08$, 95% CI = [17.40, 21.21], $P < 2.2e^{-16}$; see **Supplementary Material 1.1.** for other questionnaire measures and a comparison with Experiment 1).

In Experiment 2, participants again made a binary perceptual discrimination (left versus right random dot motion) based on pre-decision evidence of varying strength (weak, medium or strong). Half of the trials were similar to those in Experiment 1. In the other half of trials, the perceptual post-decision evidence was replaced by the confidence and direction judgment provided by an anonymous previous participant ('adviser'). This manipulation allowed us to assess whether cultural differences in post-decision processing would generalize across different domains (perceptual, social). In practice, we generated adviser choices from a model that mimicked the perceptual sensitivity of the participant. The stimulus that we presented to the simulated adviser was that trial's perceptual post-decision evidence level, i.e., the evidence strength that would have been presented to the participant in the equivalent perceptual condition (with the same dot direction as the participant's pre-decision evidence yet with potentially variable strength). As a result of this, adviser accuracy and confidence levels were contingent on the perceptual post-decision evidence strength on any particular trial, which was counterbalanced with respect to the pre-decision evidence strength just as for the perceptual condition. Participants were paired with a new adviser on every trial and were told that all advisers had the same accuracy in detecting the motion direction as themselves due to completion of an identical calibration procedure. One participant reported not to believe the social manipulation and was excluded from further analyses (see Methods).

We defined social post-decision evidence strength as the adviser's confidence rating binned into three levels (low, medium, high), creating a fully factorial 3 (pre-decision evidence strength) x 3 (post-decision evidence strength) x 2 (post-decision evidence type) design (**Figure 3a** and **Supplementary Material 2.1**). We again ensured that first-order performance was matched across participants and across both post-decision evidence types (**Figure 3b** and **Supplementary Material 2.2**). In addition, the effect of evidence type (social or perceptual) on accuracy did not differ across sites (hierarchical regression model, site x evidence type: $\chi^2(1) = 0.51$, $P = 0.48$, $\beta = -0.007$ (SE = 0.01). We also did not find a difference in average confidence across sites ($M_{PKU} = 82\%$ (SE = 0.01), $M_{UCL} = 79\%$ (SE = 0.01), independent samples t-test, $t_{104} = 1.64$, 95% CI = [-0.01, 0.06], $P = 0.10$). Finally, response times to the initial decision were not significantly differently between sites when collapsed over both post-decision evidence conditions (log(RT); $M_{PKU} = -0.97$ (SE = 0.05), $M_{UCL} = -1.06$ (SE = 0.05), independent samples t-test, $t_{104} = 1.29$, 95% CI = [-0.05, 0.24], $P = 0.20$).

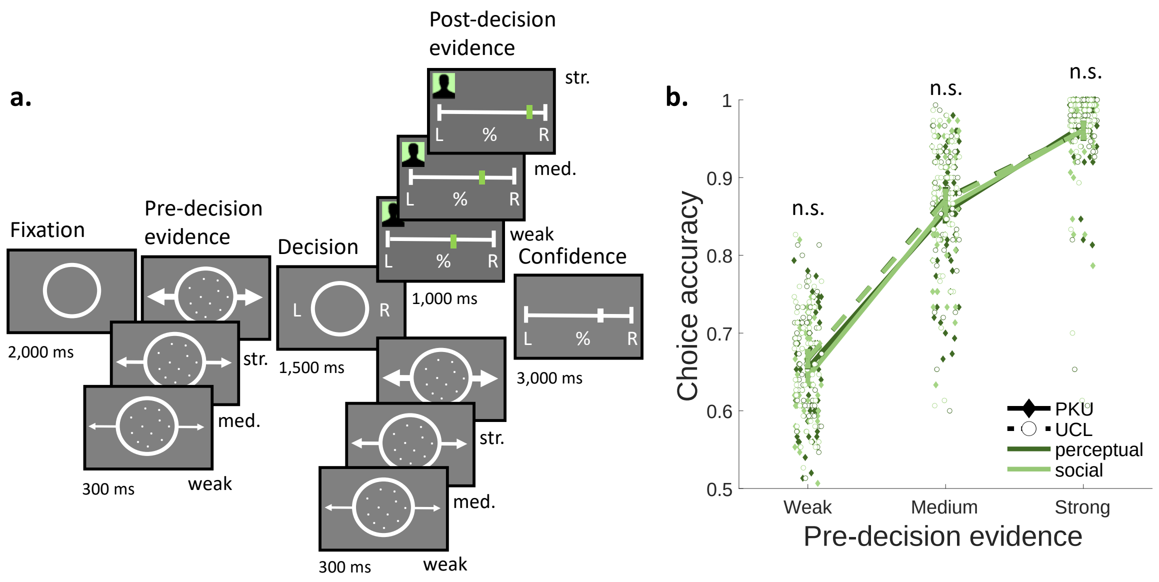

Figure 3. Task design and first-order performance in Experiment 2. a, *Participants were asked to make judgments about the direction (left, right) of random dot motion stimuli. Afterwards participants were either shown perceptual post-decision evidence or what an anonymous 'adviser' had decided on the same trial (social post-decision evidence, which was generated from a computational model). At the end of each trial, participants were asked to rate their confidence that the initial decision was correct on a scale from 100% left-stimulus to 100% right-stimulus.* ***b,*** *Choice accuracy was matched between sites (n.s.) and higher following stronger pre-decision evidence levels ($P < 0.001$, $N = 53$ at each site). Error bars represent group mean ± SEM.*

We replicated our findings from Experiment 1 that PKU participants, in comparison with UCL participants, show heightened metacognitive evaluation in the processing of post-decision evidence in the perceptual condition of Experiment 2. Specifically, perceptual post-decision evidence had a higher impact on confidence in the PKU dataset than in the UCL dataset (hierarchical linear regression, interaction perceptual post-decision evidence x site: $\chi^2(1) = 10.39$, $P = 0.001$, $\beta = 0.06$ (SE = 0.02), **Figure 4a**). This effect was again most evident on error trials, which in Experiment 2 led to a significant three-way interaction (hierarchical linear regression, interaction perceptual post-decision evidence x accuracy x site: $\chi^2(1) = 7.07$, $P = 0.008$, $\beta = -0.05$ (SE = 0.02).

We next asked whether these differences in metacognition between cultural backgrounds would generalize to a situation in which post-decision evidence is presented as social advice. In the social condition of Experiment 2, we calculated how often participants changed their mind towards the direction suggested by the adviser on trials in which the participant and adviser disagreed (note that these analyses cannot be done for the perceptual condition where the post-decision evidence is always in “agreement” with the pre-decision evidence). This tendency to change one’s mind and comply with the adviser was higher in PKU participants than in UCL participants ($M_{PKU} = 17.9\%$, $M_{UCL} = 12.6\%$, independent samples t-test, $t_{104} = 2.21$, 95% CI = [0.005, 0.10], $P = 0.03$). In keeping with a metacognitive advantage in PKU participants, this effect was restricted to trials on which the participant was wrong (and accordingly, the adviser correct; $M_{PKU} = 33.8\%$, $M_{UCL} = 24.1\%$, independent samples t-test, $t_{104} = 2.59$, 95% CI = [0.02, 0.17], $P = 0.01$), and was not seen on trials in which the participant was correct (and the adviser wrong; $M_{PKU} = 8.3\%$, $M_{UCL} = 6.5\%$, independent samples t-test, $t_{104} = 0.92$, 95% CI = [-0.02, 0.06], $P = 0.36$). This result suggests that the cross-cultural asymmetries in the efficiency of post-decision processing identified using perceptual stimuli generalize to cases in which new evidence is presented as social advice.

To further examine the drivers of cultural differences in advice-taking, we computed the impact (beta coefficient) of adviser confidence [low, medium, high] on participants’ confidence levels using a hierarchical mixed-effects model. Similar to the cross-cultural differences in perceptual post-decision evidence processing reported in Experiments 1 and 2, advice had a greater impact on the confidence ratings of PKU participants compared to UCL participants (hierarchical linear regression, interaction between social post-decision evidence x site: $\chi^2(1) = 8.38$, $P = 0.004$, $\beta = 0.04$ (SE = 0.02). As expected from the previous analyses, this asymmetry in the impact of adviser confidence was most evident on trials where the participant made an error (hierarchical linear regression, interaction social post-decision evidence x initial choice accuracy x site: $\chi^2(1) = 10.56$, $P = 0.001$, $\beta = -0.05$ (SE = 0.02), see **Figure 4a**), consistent with a hypothesis of cultural differences in the metacognitive evaluation of performance.

At both sites, social post-decision evidence had a lower impact on confidence than perceptual post-decision evidence (hierarchical linear regression, interaction evidence types x post-decision evidence strength: $\chi^2(1) = 77.34$, $P < 2.2e\text{-}16$, $\beta = 0.06$ (SE = 0.007). However, an enhanced susceptibility to post-decision evidence in PKU compared with UCL participants was found irrespective of whether the evidence was social or perceptual (no three-way interaction between evidence type, post-decision evidence and site: $\chi^2(1) = 3.35$, $P = 0.07$, $\beta = -0.02$ (SE = 0.01; **Supplementary Figure 6**).

The similar manner in which social and perceptual post-decision evidence was processed suggests a domain-general component to post-decision evidence processing (Rouault et al., 2018). In line with the pattern of confidence reports obtained in the perceptual version of the task, participants across both sites reported higher confidence after receiving more confident confirming advice and lower confidence after receiving more confident disconfirming advice (hierarchical linear regression, interaction-effect of social post-decision evidence and accuracy: $\chi^2(1) = 93.18$, $P = 2.2e^{-16}$, $\beta = 0.08$ (SE = 0.01; **Supplementary Material 2.3**). To further investigate this putative domain-generality, we next asked whether the impact of perceptual and social post-decision evidence was similar for any given individual. **Figure 4b** shows that this was the case: the impact of these two evidence types were positively correlated among both PKU participants (robust correlation, $r = 0.45$, 95% CI = [0.19, 0.64], $P = 0.0006$) and UCL participants (robust correlation, $r = 0.39$, 95% CI = [0.13, 0.64], $P = 0.004$), suggesting that participants who are more likely to integrate new perceptual evidence to update their confidence are also more likely to make use of social advice.

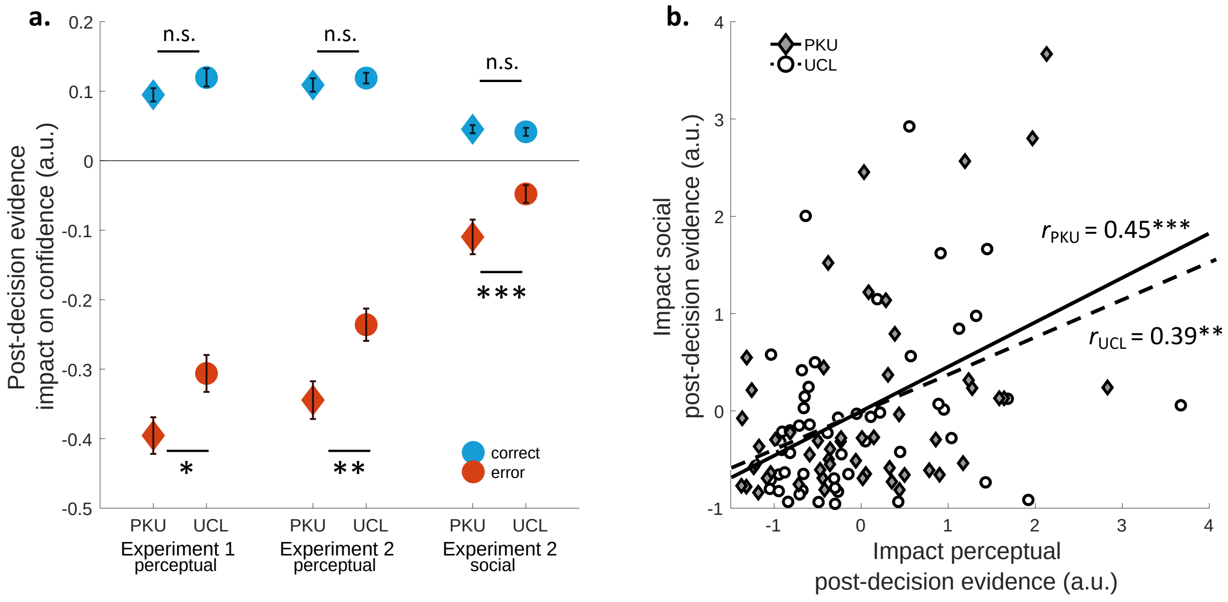

Figure. 4. Post-decision evidence processing across domains. a, *Impact of perceptual and social post-decision evidence on confidence on error trials (red) and correct trials (blue) across sites and experiments. The coefficients from Experiment 1 (**Figure 2b**) are replotted for comparison.* ***b,*** *Standardized beta-coefficients for the impact of perceptual and social post-decision evidence on confidence for each participant from a hierarchical mixed-effect regression model standardized within each site. Error bars represent the group means ± SEM, *** $P < 0.001$, ** $P < 0.01$ and * $P < 0.05$.*

Finally, we asked whether a heightened sensitivity to post-decision evidence in the PKU group was also reflected in increased metacognitive efficiency (meta-d'/d' or Mratio). We note that the calculation of a metacognitive efficiency estimate in a post-decision evidence task departs from the usual usage of the meta-d' model in a task where sensory evidence is only available before a decision. However, fitting the model to the final confidence rating data provides a compact summary of the differential influence of various factors (including post-decision evidence) to metacognition across sites. We estimated metacognitive efficiency within a hierarchical model that was fitted to the PKU and UCL samples separately.

Full results of these comparisons are reported in **Supplementary Material 2.4**. We indeed found that metacognitive efficiency was higher in the PKU compared to UCL groups in all three datasets (Bayesian probability of a difference between groups, Experiment 1 – 0.91; Experiment 2, perceptual – 0.85; Experiment 2, social – 0.98).

DISCUSSION

Across two behavioral experiments we show that Chinese participants were more susceptible to post-decision evidence than UK participants. In particular, Chinese participants changed their minds more after errors than their British counterparts, consistent with enhanced metacognitive evaluation of performance facilitated by adaptive post-decisional processing. Using a psychophysical task that enabled the separation of first-order and metacognitive processes in simple perceptual decisions, our data supports a proposal that metacognition is sensitive to socio-cultural variation. Strikingly, these differences in confidence were found specifically on error trials and were associated with consistently increased metacognitive efficiency, suggesting that cultural background may shape a metacognitive faculty to evaluate one’s own performance.

Our results are consistent with the recent theoretical proposal that explicit metacognition, the ability to self-evaluate one’s perceptions, memories and decisions, is subject to cultural variation (Heyes et al., 2020). The routes by which these differences emerge, and their stability over time, remains to be determined. One possibility is that the extent to which a culture places emphasis on the group over the individual may make it more likely that the skills needed to question and doubt one’s beliefs and decisions are culturally inherited. For instance, in more collectivist societies there may be greater advantages to be gained by honing the sharing and communication of accurate confidence estimates (Bang et al., 2017; Mahmoodi et al., 2015). In contrast, in more individualistic societies, cultivating distorted metacognition for one’s own ends (e.g., an overconfident style) may be prioritized. It also remains unclear as to what aspects of self-evaluative processing are affected by culture. In previous studies using related tasks within cultures, a distinction has been drawn between brain areas that are sensitive to post-decision evidence (in posterior medial frontal cortex) and those in more anterior frontal regions that mediate a mapping between private and public aspects of confidence (Bang et al., 2017, 2020; Fleming et al., 2018; Gherman & Philiastides, 2018). Either or both of these levels of processing may plausibly be affected by culture and, at both an individual and group level, contribute to the current results.

The differences between cultural milieus in susceptibility to new evidence reported here complement and extend previous findings that Chinese populations are more affected by social influence than German and British populations (Korn et al., 2014; Mesoudi et al., 2015). Indeed, it is possible that such differences in susceptibility to new evidence may partly be explained by heightened metacognition, rather than normative social compliance. In other words, recognizing the potential for error may prompt a search for corrective information (Schulz et al., 2020). Notably, while Chinese participants were more susceptible to both social and perceptual forms of post-decision evidence, such effects were most prominent on trials where mistakes had been made. This interaction between the impact of post-decision evidence on confidence and accuracy is a key signature of metacognition (Fleming et al., 2018), and accordingly, the Chinese participants had consistently heightened metacognitive efficiency than UK participants in all three datasets. We note that the more pronounced impact of post-decision evidence on error trials in PKU versus UCL participants did not vary significantly across sites. Our finding that cultural differences consistently, and selectively, occurred on error trials (**Supplementary Figure 6**) indicates that these cultural differences are primarily driven by metacognition, rather than a greater susceptibility to social influence irrespective of self-performance. Together, these findings suggest that the informativeness of the evidence—rather than mere social compliance—underpinned the cultural differences observed in the current study.

As perceptual post-decision evidence always disconfirmed a previous decision after errors (i.e., was always helpful), an alternative explanation of these findings is that Chinese participants simply processed disconfirming evidence to a greater extent than UK participants—in other words, they were less prone to confirmation bias (Kappes et al., 2020; Talluri et al., 2018) . However, additional analyses of the social task data nuance this interpretation. The social task allowed us to distinguish between cases of disagreement when advice was correct (‘good advice’) as well as when advice was wrong (‘bad advice’). Notably, both Chinese and UK participants were equally susceptible to bad advice that agreed with their wrong decision (suggesting similar susceptibility to confirmatory social information) and to bad advice that disagreed with their correct decision (suggesting similar susceptibility to social disagreement). Instead, differences between cultural backgrounds selectively manifested in a heightened susceptibility of Chinese participants to ‘good’ advice, even when it disagreed with their decision (**Supplementary Material 2.3**). This finding suggests that Chinese participants had heightened metacognitive evaluation of their performance, allowing them to selectively follow the advice when it is most beneficial.

Another line of evidence supporting a metacognitive explanation of our findings between sites is an association between our task-based index of metacognitive processing (the tendency to specifically process new evidence on error trials) and an independent questionnaire-based measure of cognitive insight (BCIS; Beck et al., 2004). Chinese participants had substantially higher baseline levels of self-reported cognitive insight than UK participants (**Supplementary Material 1.1**). In addition, inter-individual differences in cognitive insight, but not differences in sociocultural flexibility (as measured with the self-construal scale; Choi et al., 2007), predicted the effect of post-decision evidence on error-trials in the sample as a whole (**Supplementary Material 2.6**).

In Experiment 2, we were also able to evaluate the domain-general nature of the cultural difference. On half of the trials post-decision evidence was perceptual, whereas on the other half it was presented as social advice. Differences between sites in post-decisional processing were similar across the social and perceptual forms of post-decision evidence, and the impact of both types of evidence was correlated across participants. Indeed, one interesting prediction of the cultural origins hypothesis of metacognition is that any cultural difference should be relatively domain-general, because the skills that are being acquired are metacognitive in nature rather than how to handle a particular type of information. A useful analogy is with the cultural acquisition of reading: even though a person might learn to read via information provided by others, they can subsequently apply that skill to read a variety of different books about topics that no longer have relevance for the social group. In this light, our finding that the impact of cultural variation on metacognitive ability generalizes to different types of evidence is expected from the theory.

Despite this similarity, participants at both sites adjusted their confidence levels to a lesser degree in response to social compared to perceptual evidence (**Figure 4a**), a difference that may have been due to the model generating simulated advisers with generally lower confidence levels than the participants (see **Supplementary Material 2.1** for further discussion). Whether social and perceptual evidence have a similar impact on post-decision processing when advisers' confidence is matched to that of the participant could be investigated in future experiments. Future studies could also seek to replicate these results using a confidence task without post-decision evidence, which we believe would give similar results (Rollwage et al., 2018). Another limitation of this study is that neither Experiment 1 nor 2 was pre-registered. Future studies should replicate the current findings in a larger sample and following pre-registration of hypothesized cultural differences.

This study aimed at a robust and replicated assessment—using new, sensitive and specific methods that provide an in-depth analysis of individuals' metacognitive processes—to compare two closely-matched samples drawn from distinct cultural milieus (for which *a priori* evidence suggested cross-cultural differences) and so provide evidence for or against an important hypothesis regarding human metacognition. We do not claim that either China's or any other state or region’s culture is monolithic, or that our samples are representative of all Chinese or UK citizens, and instead we chose two well-matched subgroups. The strengths of such a tightly controlled, robust and replicated approach to explore a specific hypothesis can be complemented by future work using other approaches, which can, for example, look across broader groups of samples drawn from other ages, different socio-economic backgrounds, different levels of education (including adaptations to semi-literate populations) and other regions (within Northern Europe, within China and globally). Combining diverse types of study—both tightly controlled studies and those testing greater generalizability (Tiokhin et al., 2019)—will likely provide greater advances in understanding of human cognition and its cultural contributions than either type of study alone.

In summary, across two behavioral experiments we demonstrate that Chinese participants show heightened metacognitive evaluations of performance in comparison with UK participants. These differences manifested in boosts to post-decisional processing following error trials, in the absence of differences in first-order performance. This pattern was also obtained in a new task where post-decision evidence was replaced with equivalent social advice, suggesting that socio-cultural background shapes a domain-general tendency to evaluate and reflect on previous decisions.

CONTEXT

This research formed the first part of EvdP’s doctoral research on the social and cultural malleability of metacognition. The idea that metacognition may be shaped by one’s social and cultural environment had been brought into focus by a theoretical proposal developed by SMF, DB, Nicholas Shea, Chris Frith and Cecilia Heyes, but direct empirical evidence for cultural differences in metacognitive sensitivity has been lacking (Heyes et al., 2020). Thanks to a collaboration fostered and funded by the UCL-PKU Strategic Partner Fund, we were able to put in place the infrastructure necessary for the collection of data in student samples at both PKU and UCL. Our results sit at the intersection between cross-cultural and cognitive psychology, although we recognize that the cultural differences here are restricted to closely matched student samples. We hope that it will inspire further research on the (cultural) origins of metacognition.

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