Social context alters metacognition

Authors: Ali Mahmoodi^{1,2,*}

Kai Ringwald^{1,2}

Marco K Wittmann³

Carsten Mehring^{1,2}

Affiliation:

¹ Bernstein Centre Freiburg, University of Freiburg, Hansastrasse 9a, 79104, Freiburg, Germany

² Faculty of Biology, University of Freiburg, Freiburg, Germany

³ Wellcome Integrative Neuroimaging (WIN), Department of Experimental Psychology, University of Oxford, Oxford, UK

* Corresponding author email: ali.mahmoodi1367@gmail.com

Abstract:

Metacognition is the ability to monitor and evaluate one's own cognitive processes. In social contexts, such performance evaluations are also influenced by the behaviour of others, e.g. others' decisions and actions. However, in tasks where feedback of the ground truth is provided (e.g. the correct decision), people's performance evaluations should be independent from others' behaviour. Here, we investigate this situation in an estimation task: participants made an estimate about the location of a visual stimulus, reported their confidence about that estimate and then observed a partners' stimulus estimate as well as the true location of the stimulus. Participants were asked to evaluate and report their performance regularly during the experiments. We found that participants overestimated their performance when their partner's stimulus estimates were less accurate than their own stimulus estimates and underestimated their performance when their partner's stimulus estimates were more accurate. In a second experiment, we showed that the results of experiment 1 also hold when people can benefit from accurately tracking their partner's and their own performance. In this experiment participants were allowed to revise their initial stimulus estimate after having seen their partner's estimate. In both experiments, participants reduced their confidence when their partner had superior accuracy and increased it when their partner had inferior accuracy relative to them. This effect was very small but the change in confidence correlated with the change in the performance estimates across participants. In summary, our result suggest that metacognitive accuracy is dynamically influenced by other people, potentially at the expense of our ability to accurately track our own performance. Our findings might have relevance to how we select partners to work with each other.

Introduction:

Humans are often able to distinguish their erroneous from their correct decisions and report their uncertainty about decisions^{1,2}. The ability to monitor and evaluate one's cognitive processes is called metacognition. Metacognition can be assessed for example by asking people's confidence about a decision, or by asking them about their overall performance. Previous research shows that despite a positive correlation between humans' confidence reports and their actual accuracy, confidence is not a reliable predictor of accuracy³⁻⁵. In line with this, humans have little insight into their abilities when it comes to evaluate their overall performance in a certain task⁶ and operate by various biases⁷. For example, in the better than average effect, humans evaluate their abilities more positively than most of the other people⁸. Good performers underestimate their abilities while bad performers overestimate their abilities⁹.

In social contexts, humans monitor the cognitive process of others and assess other people's abilities^{1,10}. Apart from learning about one's own abilities by direct experience¹¹, it has been suggested that, in social situations, humans estimate their competence by comparing themselves with others¹². Moreover, a previous study investigated how people learn about their own and others' competence over time.¹³ The study showed that memories of other people's performance have a negative effect on the assessment of our performance if we are competing with them: if a peer with whom we are competing, has a better performance than us, we tend to underestimate our own performance. If the peer is worse, we then overestimate our performance. This effect was reversed when a cooperative context was introduced¹³.

Here we assess the influence of other people's performance on the self-assessed performance during perceptual decision making. Perceptual decision making has long been known to be susceptible to social influence¹⁴. To our knowledge, no study has examined how humans evaluate their own performance when they can observe others' outcome as well¹³. In these occasions, others might have different relative performance compared to us. In the ideal case, in the presence of external feedback, other's ability should not affect our perception of our own ability. However, given the negative effects of others' incomes and wellbeing on us^{15,16}, we hypothesized that, other's bad performance might lead us to overestimate our performance. Conversely, a peer's good performance might lead us to underestimate our performance. Moreover, we hypothesized that the influence of others on the self-assessed performance is accompanied by a change in the confidence judgements.

We tested this idea by modifying a perceptual task that we used in a recent study¹⁷. We investigated the effect of a peer's performance on people's overall evaluation of their competence and their trial by trial confidence rating. In particular, we were interested in comparing a condition in which the performance of the interaction partner is better than one's own performance with a condition in which

the partner performs worse than oneself. Our results showed that, humans' trial by trial confidence and overall perception of their own performance is affected by the performance of another participant. Participants underestimated their performance when their peer was better than them and overestimated their performance when their peer was worse than them. They slightly reduced their confidence when their peer was of superior performance and increased it when their peer was of inferior performance relative to them.

Results:

In experiment 1a, 32 participants (15 females, mean age $\pm$ std 24 ± 3.7) were recruited in groups of 4-12 to perform a computerized task. They were seated in three adjacent computer pool rooms. They were told that during the experiment, they will first do the task by themselves (isolated condition) and then after the isolated condition they will be connected to other participants placed in one of the adjacent rooms with whom they will do the task together. In reality, each participant was paired with a computer algorithm that generated three distinct behavioural profiles that participants interacted with. These profiles corresponded to three experimental social conditions (better partner, equal partner, worse partner, see below) which were administered in a block design. Participants were not informed about this arrangement. After 11 isolated blocks, participants completed the three experimental conditions in 5 consecutive blocks per condition. The order of the social conditions was randomised across participants.

In each trial, the participants made a perceptual estimate about the location of a target on the screen (Figure 1A) and in addition reported their confidence on a scale from 1 (not confident at all) to 6 (very confident). In the isolated blocks, after stating their estimate and confidence, the participants received feedback about the true location of the target and then proceeded to the next trial. In contrast, in the social blocks, after participants stated their initial estimate and confidence, the partner's estimate of the target location was presented. After observing the estimate of the partner, they received feedback about the true target location. We used the error distribution of the participants in the initial isolated blocks to construct three different partners (see Methods), one with equivalent (equal partner), one with higher (better partner) and one with lower (worse partner) accuracy than the participants. At the end of each block, participants estimated their average angular error in the previous block on a semicircle (ranging from 0 to 180 degrees; Figure 1A). At the end of the social blocks, participants were asked to estimate their partners' average error in addition to their own error (Figure 1A). We computed the estimation bias as the angular distance between participants' actual and estimated error per block. A negative estimation bias means that a participant overestimated his/her error while a positive estimation bias means that a participant underestimated his/her error (Figure 1B).

Effect of others' performance on participants' own perceived performance

We first computed participants' error across conditions. There was no difference in participants' error across isolated and social conditions (Friedman test $\chi^2(3) = 1.87$ $p = .59$). We then checked whether our algorithm successfully generated partners' performances that were equal, better or worse compared to the participants. There was a significant effect of condition on the difference between the participants' and their partner's errors (Friedman test $\chi^2(2) = 58$ $p < .0001$). While equal partners were not different from the participants (Figure 2A, Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 316$, 95% CI $[-2.7^\circ \ 4.9^\circ]$, $p = .97$), the errors of the worse partners were significantly larger than the participants' errors (Figure 2A, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 37$, 95% CI $[8.3^\circ \ 18^\circ]$, $p = 2 \times 10^{-5}$), and the better partners' errors were significantly smaller than that of the participants (Figure 2A, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 728$, 95% CI $[-30^\circ \ -22^\circ]$, $p = 7 \times 10^{-7}$). After these manipulation checks, we went on to analyse whether the partner's performances had a systematic influence on participants' introspection regarding their own task accuracy. In particular, we tested whether participants' estimate of their own error was affected by the partner's performance. To this end, we computed the estimation bias. We averaged the estimation bias for each condition. There was a significant effect of condition on estimation bias (Friedman test $\chi^2(3) = 16$, $p = .001$). There was no difference between the estimation bias in the isolated condition and the condition with equal partners (Figure 2B, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 255$, 95% CI $[-6.4^\circ \ 4.6^\circ]$, $p = .86$), nor between the conditions with worse and equal partners (Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 206$, 95% CI $[-6^\circ \ 3.4^\circ]$, $p = .54$). Critically, the estimation bias in the condition with better partners was significantly larger than for worse partners (Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 445$, 95% CI $[5^\circ \ 15.6^\circ]$, $p = .002$) and also significantly larger than for equal partners (Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 416$, 95% CI $[3.5^\circ \ 14^\circ]$, $p = .01$). This shows that, when participants played with a better partner compared to a worse one, they overestimated their own errors.

We examined in more detail potential reasons why better performing partners affected participants' metacognitive judgements about their own performance, but worse partners did not have a significant effect compared to the equal condition. One possibility is that our algorithm generating worse or better partners was better suited to generate performance profiles that were better compared to generating performance profiles that were worse than the participants. Indeed, even though the participants' overall error was on average smaller than their worse partners, there were several subjects which were actually performing worse than their partner in this condition. To generate the

partners' errors, we used an exponential distribution (see Methods). The average error that this distribution could generate was bound to be in the range of 18 to 87 degrees. However, three participants' average error exceeded 87 degrees and for them their worse partner had smaller average errors than themselves. For 11 participants the error difference between participants and their worse partner's error was less than 10 degrees, which may have been too small to be discernible by the participants. To deal with this issue, we ran a second experiment (experiment 1b), in which we made the task easier so that we can more easily construct partners with larger average errors than the participants. We recruited 37 participants (17 females mean age $\pm$ std 25 $\pm$ 3.8) to the lab who performed the easier version of the experiment under the same circumstances as before (see Methods). Again, there was no effect of condition on participants' true error (Friedman test $\chi^2(3) = 5.36, p = .14$). Instead, again, there was a significant effect of condition on the difference between participants' and their partner's errors (Friedman test $\chi^2(2) = 52, p < .0001$). Equal partners were not different from the participants (Figure 2C, Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 273, 95\% \text{ CI } [-5.6^\circ \text{ } 1.9^\circ], p = .23$), while worse partners had a significantly larger error than the participants' (Figure 2C, Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 13, 95\% \text{ CI } [12^\circ \text{ } 20^\circ], p = 3 \times 10^{-7}$), and better partners' had a significantly smaller error than the participants (Figure 2C, Wilcoxon signed-rank test, Holm-Bonferroni correction $W = 679, 95\% \text{ CI } [-10^\circ \text{ } -1.7^\circ], p = 7 \times 10^{-7}$). Again, there was a significant effect of condition on estimation bias (Friedman test $\chi^2(3) = 24, p = 2 \times 10^{-5}$). Replicating results from experiment 1a, the estimation bias in the better condition was more positive than in the worse condition (Figure 2D, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 71, 95\% \text{ CI } [-15.8^\circ \text{ } -6.4^\circ], p = 8 \times 10^{-5}$), suggesting again that people overestimate their error when being paired with better partners. In contrast to experiment 1a, the estimation bias in the worse condition was also significantly smaller than in the equal condition (Figure 2D, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 532, 95\% \text{ CI } [-13^\circ \text{ } -2^\circ], p = .01$), consistent with the aim of experiment 1b that used an easier version of the experimental task. The estimation bias in the better partner condition was not different from the equal partner condition (Figure 2D, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 255, 95\% \text{ CI } [-1^\circ \text{ } 7.6^\circ], p = .28$), which may be due to the fact that four participants' average error was smaller than their better partner. Notably for 10 participants the error difference between participants and their better partner's error was less than 10 degrees which may have been too small to be discernible.

To further corroborate these findings, we ran an analysis based on the error differences between participants and partners. We conducted a linear mixed model analysis with the participants' own performance rating in each block as the dependent variable and their own and their partners' average error in each block as well as an intercept as random effects allowing them to vary across subjects. We aggregated the data from experiments 1a and 1b and found a significant positive effect of participants'

error on their performance rating (parameter estimate .92, 95% CI [.81 1.03], $t(1207) = 16.22$, $p < .0001$) which shows that participants had insight in the degree to which they misjudged the target position. In addition, there was a significant negative effect of the error of the partner (parameter estimate -.24, 95% CI [-.31 -.17], $t(1207) = -6.83$, $p = 1 \times 10^{-1}$) and a significant effect of intercept (parameter estimate 21, 95% CI [14 29], $t(1207) = 5.55$, $p = 3 \times 10^{-8}$). The linear mixed model analysis thereby confirms that people's estimation of their performance is negatively affected by the performance of a peer whose error is presented to participants: participants underestimated their error when their partner was worse than them and overestimated their error when their partner was better than them. In the supplementary material we report the results of the same analysis performed on data from experiments 1a and 1b and worse and better blocks separately.

Effect of partners' performance on participant's confidence

We then tested our second prediction that working with peers with varying accuracy might affect participants' confidence. Again, we aggregated the data from experiments 1a and 1b. We found a significant effect of condition on confidence (Fig. 3, Friedman test $\chi^2(3) = 9$, $p = .02$). Consistent with our expectation, participants' were on average more confident when they played with a worse partner compared to a better partner (Figure 3, Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 1574$ 95% CI [.04 .21], $p = .03$). No significant difference was found between better and equal (Wilcoxon signed-rank test, Holm-Bonferroni correction, $W = 921$, 95% CI [-.01 .16], $p = .14$) and between worse and equal (same statistical procedure, $W = 1077$, 95% CI [-.15 .04] $p = .55$) partners. As it has hitherto been shown that confidence is correlated with error, we investigated the effect of condition on confidence by controlling for trial by trial error. To do that, we conducted another linear mixed model analysis with confidence as the dependent variable and participants' trial by trial error, condition (as dummy variable, i.e. 1=better, 2 = worse) and an intercept as random effects which allowed for variation across participants. Confidence was negatively correlated with error ($t(13796) = -6.08$, $p = 1 \times 10^{-9}$) and there was a positive effect of condition (parameter estimate .09, 95% CI [.01 .17], $t(13796) = 2.19$, $p = .02$) and a positive effect of intercept (parameter estimate 3.6, 95% CI [3.3 3.8], $t(13796) = 26$ $p < .0001$). This analysis confirmed that the difference in confidence between worse and better conditions is not due to fluctuations in the participants' errors.

Effect of an advisors' performance on participants' estimation of their own ability

So far, our results show that other people's performance has a negative effect on participants' judgement of their own performance and their confidence. They think they are better when the other player is worse than them and think they are worse if the other player is better. An important situation in social decision making is when we are doing a task together with other people and might need their

advice. We thus asked whether the effect of others on our confidence and performance estimates can be replicated in a social decision making task with a partner whose superior performance could benefit us. To this end, we recruited another 20 participants (7 females, mean age $\pm$ std 23 $\pm$ 4). After completing isolated blocks, participants were paired with a worse and a better partner each for three blocks like in experiment 1 but with an important modification: every five trials, after the participant observed the partner's response, they were given a chance to revise their initial estimate (Figure 1B). Hence, the partner became an advisor in this task. We computed the influence that participants took from their partners as the ratio of the angular displacement between their first and second estimate divided by the angular distance between their initial estimate and the estimate of the partner¹⁷ (Figure 1C). The influence that participants took from their partners was not significantly different between better and worse blocks (Wilcoxon signed-rank test, $W = 64$, 95% CI [-.1 .03], $p = .12$). Consistent with our previous experiments, we found that the estimation bias in the better condition was significantly larger than in the worse condition, (Figure 4A, Wilcoxon signed-rank test, $W = 162$, 95% CI [1° 22°], $p = .03$). We also found that the participants' confidence was significantly higher in the worse condition compared to the better condition (Figure 4B, Wilcoxon signed-rank test, $W = 112$, 95% CI [.03 .33], $p = .02$). We also compared the performance rating between worse and better conditions.

Correlation between change in confidence and change and estimation bias

So far, our results showed that the participants' confidence and their metacognitive ability (i.e. the ability to track their own performance) which was assessed by the estimation bias, both were affected by the accuracy of the partner. In addition, we found a correlation (Pearson $r = -.29$ $p = .004$, Figure 4C, aggregated data from experiments 1a,1b and 2) between the difference in estimation bias between worse and better conditions and the difference in confidence between worse and better conditions.

Discussion

Humans constantly evaluate their competence. When there is no ground truth, they do so by comparing themselves to others¹². In the ideal case, when there is accurate feedback about peoples' own performance, their perception of their ability should not be affected by how good other people are performing the task. But is this how we judge our performance? In this study we investigated whether others' competence affects people's perception of their own abilities.

Using a perceptual task, we showed that others' performance has a negative effect on how our participants evaluated their own performance: they underestimated their own error when they were paired with a partner that performed worse at the task than themselves (worse partner). Inversely, they overestimated their error, when they were paired with a partner that performed better at the task than themselves (better partner). A previous study suggested that, in a competitive context,

others' performance has a negative effect on how people evaluate their own performance, consistent with what we found in the current study. However, the same study found that in a cooperation context, others' performance has a positive effect on how participants evaluated their own performance: they overestimated their performance when paired with a worse partner and underestimated their performance when they were paired with a better partner¹³. Importantly, our task was neither explicitly cooperative nor competitive. Participants were told that they will be paired with other people and their payment only depends on their own performance in the task (i.e. the accuracy of the target estimate and their performance rating accuracy). One interpretation of our result might be that, in a seemingly neutral condition, an implicit competition context might mediate humans' social interaction.

Given these findings, we asked whether we can replicate the result of experiment 1 when people can benefit from accurately tracking their peer's performance to adjust the advice that they take from them. Our results show that, even in a situation when people can benefit from others, especially from a better partner, others' performance has a negative effect on how participants assess their own performance. This may be explained by assuming that a seemingly cooperative situation may still elicit some hidden competitive context because participants may compete for having more influence in the group and being less influenced by others. This is consistent with previous studies which suggest that individuals compete for having more influence when they work together^{18–20}. While the influence that participants took from their partners was not significantly different between conditions, the large confidence interval (for the difference) shows that we cannot make a decisive conclusion. We did not investigate this any further as it was not the focus of this study.

Our results indicate that humans' confidence was also affected by the performance of other people: the participants reduced their confidence when they were paired with a better partner and increased their confidence when they were paired with a worse partner. The change of confidence was very small but correlated with the change in estimation bias across subjects. An influential hypothesis regarding confidence is that humans' confidence reports are resulting from the computations of a Bayesian decision maker and reflect the posterior probability that a decision is correct²¹. Alternatively, it has been suggested that in some people confidence reports can also reflect the variance of the stimulus²². Recent evidence suggests that humans' confidence reports are better explained by simple heuristics models and in certain situations only approximately Bayesian^{23,24}. Our results suggest that confidence is modulated by the participants' overall perceived accuracy. Therefore, our results point to the relevance and influence of the ability of other people around us on our confidence and perceived accuracy.

We conclude that others' performance has a profound effect on humans' perception of their own performance. Participants' altered metacognition due to social context might affect accuracy of humans' decision-making.

Methods

Overview

In total, 89 healthy (32 in experiment 1a, 37 in experiment 1b, and 20 in experiment 2) adults (mean age $\pm$ std 25 ± 3.8) participated in one of the three experiments after having given written informed consent. Each participant participated in only one of the experiments. The experimental procedures were approved by the ethics committee of the University of Freiburg. All experiments were performed using Psychophysics Toolbox²⁵ implemented in MATLAB (Mathworks). The experiments used a perceptual estimation task similar to a recent study on social influence¹⁷. The data were analysed using MATLAB and SPSS.

Experimental Task 1a: This experiment was designed to investigate whether the performance of a peer influences the participants' perception of their own performance. Participants were presented with a sequence of 91 visual stimuli consisting of small circular Gaussian blobs ($r = 5\text{mm}$) presented in rapid succession on the screen. The first item was presented for 30ms and every other stimulus was presented for 15ms each. Participants' task was to identify the location of the first stimulus. Participants were required to wait until the presentation of all stimuli was finished, and then indicate the location of the target stimulus using the computer mouse (Figure 1A). The reported location was marked by a yellow dot. After participants reported their initial estimate, they were required to report their confidence about their estimate on a numerical scale from 1 (low confidence) to 6 (high confidence). In the isolated blocks ($n = 11$ blocks), participants were then presented with their own estimate and the true location of the target for 3 seconds. In the social blocks (equal, better, worse), after reporting their estimate and confidence, participants were shown the partner's estimate of location of the same stimulus by a small dot on the screen. The section 'Constructing Partners' describes the algorithm used to generate the partner's estimates. At the end of each block, participants estimated their own and their partner's average error (the latter only in social blocks) for the block they just had finished. Participants were told that their payoff will be calculated based on the accuracy of their estimates plus how accurately they guessed the performance of themselves and their partners. However, everyone was given a fixed payoff at the end of the experiment.

During the course of the experiment participants were paired with three different partners. Partners varied in their accuracy relative to the accuracy of the participant. In equal blocks, the accuracy of the partner was matched to the accuracy of the participant. In worse blocks, on average, the partner produced larger errors compared to the participants. In better blocks, on average, the partner produced smaller errors than the participants. In each block, the participants interacted with only one partner and each block contained 20 trials. Participants interacted with each partner for 5 consecutive blocks. The order of the partners was randomly chosen at the beginning of the experiment. At the end,

we asked the participants whether they thought they interacted with real people or with a computer algorithm. All participants indicated that they believed they were interacting with real human partners.

Experimental Task 1b: This experiment was designed to make the task easier in order to achieve partners which were substantially less accurate than the participants. To this end, we increased the duration of the presentation of the target stimulus to 35ms. With regard to the number of blocks, 12 participants performed the same number of blocks as in experiment 1a. However, we then found that, participants' accuracy improved over the course of the experiment. As a consequence, the participants' accuracy used to design the partners was inaccurate and some participants were in fact more accurate than their better partners. Therefore, for another 25 participants, we increased the number of isolated blocks to 18 blocks and used only the last 10 blocks to estimate participants' error as by visual inspection we realised that participants' accuracy was stable after 8 blocks. By adding these extra blocks, we resolved the initial problem. Five participants in this experiment had already done another experiment using the same perceptual task¹⁷.

Partner's performance rating: The order of rating participant's own and their partner's performance was not randomised in our experiment. Participants always started by rating their own performance. As a consequence, the rating of the partner's performance may have been influenced by the preceding rating of the participant's own performance. A significant decrease in reaction time for the the partner's performance compared to own performance rating supported this suspicion and thus we excluded the rating of the partner's performance from the analysis.

Experiment 2: In experiment 2, participants completed 11 isolated blocks. They were then paired with a better and a worse partner each for three consecutive blocks. This experiment was identical to experiment 1a except that every 5 trials, after observing their partner's estimate, participants could revise their estimate after they were shown the estimate of their partner. No feedback about the true target location was presented at the end of these trials. Participants were required to put their second estimate between their own first estimate and that of their partner's. The acceptable range included staying on their first estimate or moving all the way to their partner's first estimate.

Constructing partners:

To generate the partner's error, we used an exponential distribution function. Pilot experiments, in which participants only performed the isolated blocks suggested that the participants' error could be approximated by an exponential distribution with an offset as follows:

$$error(x) = .001 + \frac{.82 \times \exp(\frac{180-x}{b})}{b \times (-1 + \exp(\frac{180}{b}))} \quad (1)$$

The parameter b controls the accuracy of the partner. It is related to the average error (m_x) as follows:

$$m_x = 16.2 + .82 \times b + \frac{147.6}{1 - \exp(\frac{180}{b})} \quad (2)$$

To construct the equal partner, we first computed the average error of the participant in the isolated blocks and then the value of b was found by solving eq. (2) numerically. For better and worse partners, b was computed to obtain an average error which was .6 (for better partner) or 1.4 (for worse partner) times the average error of the participant in the isolated block.

Multiple comparison: Notably, before starting the data collection we had clear hypotheses about expected results and planned comparisons. However, we corrected for multiple comparison where we did multiple comparison.

Authors Contributions: A.M., K.R., M.K.W., and C.M., designed the experiments. K.R. and A.M. collected the data. A.M. and K.R. carried out the data analysis. A.M., K.R., M.K.W., and C.M. interpreted the results. A.M. drafted the manuscript and M.K.W. and C.M. contributed to the final manuscript.

Acknowledgments: This work was supported by a PhD scholarship (AM) from the Graduate School Scholarship Program of the German Academic Exchange Service (DAAD), the Wellcome Trust (WT100973AIA) (MW), the German Research Foundation (DFG, grant no INST 39/1014-1 FUGG) (CM) and the “Struktur- und Innovationsfonds Baden-Württemberg (SI-BW)” of the state of Baden-Württemberg (CM).

Declaration of conflict of interest: The authors declare no conflict of interest.

Figures:

Figure 1: Experimental paradigm: **A** Experiment 1a and 1b: participants first observed a series of dots on the screen. Participants indicated the estimated location of the initial dot (the target) using a computer mouse (yellow dot) and then reported their numerical confidence. In isolated blocks, after making their individual estimates and reporting their confidence, participants received feedback about the true location of the target (white dot). In the social blocks, after making their individual estimates and reporting their confidence, they were presented with the estimate of a partner (red dot) concerning the same stimulus. At the end of each block, they reported their average error, and their partner's average error (only in social blocks), on a semicircle. **B** Illustration of positive and negative estimation bias. For a negative estimation bias participants overestimate their error while for a positive estimation bias the participants underestimate their error. **C** Experiment 2: the isolated blocks were identical to experiment 1. However, in the social blocks, in some trials, they were given a chance to revise their estimate after participants observed their partner's estimate. **D** In experiment 2, influence was computed as the angular displacement towards the partner's estimate divided by the initial distance between both estimates.

Figure 2: True and estimated performance in experiment 1. In all boxplots, the black vertical band inside the box shows the median, whiskers reach until the most extreme data samples which lie within the intervals extending 1.5 times the inter-quartile range from the 25th and 75th percentile and red dots show data samples outside the intervals covered by the whiskers. **A:** Difference between participants' and partners' actual error in different conditions (equal, worse, better partner) of experiment 1A. **B:** Pairwise differences in estimation bias (i.e. the difference between the actual and the estimated error) between different conditions in experiment 1A. E-I: equal - isolated, E-B: equal - better, E-W: equal - worse, B-W: better - worse **C:** Same as A for experiment 1B **D:** Same as B for experiment 1B. Wilcoxon sign-rank test * $p < .05$, ** $p < .005$.

Figure 3: Difference in participants' average confidence across experiments 1a and 1b shown for different conditions (isolated (I), equal (E), worse (W), better (B) partner). Wilcoxon sign-rank test * $p < .05$

Figure 4: **A** Experiment 2. Estimation bias (participants' average error minus the error they estimated at the end of each block) plotted for two conditions. **B** Participant's average confidence is depicted across worse and better conditions. **C:** Difference in estimation bias (y axis) is plotted against difference

in confidence (x axis) between worse and better conditions. Each data point indicates a participant; the line was obtained by linear regression. Wilcoxon sign-rank test * $p < .05$.

References:

1. Frith, C. D. The role of metacognition in human social interactions. *Phil Trans R Soc B* **367**, 2213–2223 (2012).
2. Fleming, S. M. & Dolan, R. J. The neural basis of metacognitive ability. *Phil Trans R Soc B* **367**, 1338–1349 (2012).
3. Nelson, T. O. Metamemory: A theoretical framework and new findings. in *Psychology of learning and motivation* **26**, 125–173 (Elsevier, 1990).
4. Fleming, S. M. & Lau, H. C. How to measure metacognition. *Front. Hum. Neurosci.* **8**, 443 (2014).
5. Koriath, A. *Metacognition and consciousness*. (Institute of Information Processing and Decision Making, University of Haifa, 2006).
6. Zell, E. & Krizan, Z. Do people have insight into their abilities? A metasynthesis. *Perspect. Psychol. Sci.* **9**, 111–125 (2014).
7. Hoorens, V. Self-enhancement and superiority biases in social comparison. *Eur. Rev. Soc. Psychol.* **4**, 113–139 (1993).
8. Colvin, C. R., Block, J. & Funder, D. C. Overly positive self-evaluations and personality: Negative implications for mental health. *J. Pers. Soc. Psychol.* **68**, 1152 (1995).
9. Kruger, J. & Dunning, D. Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. *J. Pers. Soc. Psychol.* **77**, 1121 (1999).
10. Chang, S. W. *et al.* Neuroethology of primate social behavior. *Proc. Natl. Acad. Sci.* **110**, 10387–10394 (2013).

11. Bandura, A. Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* **84**, 191 (1977).
12. Festinger, L. A theory of social comparison processes. *Hum. Relat.* **7**, 117–140 (1954).
13. Wittmann, M. K. *et al.* Self-other mergence in the frontal cortex during cooperation and competition. *Neuron* **91**, 482–493 (2016).
14. Asch, S. E. & Guetzkow, H. Effects of group pressure upon the modification and distortion of judgments. *Groups Leadersh. Men* 222–236 (1951).
15. Fliessbach, K. *et al.* Social comparison affects reward-related brain activity in the human ventral striatum. *science* **318**, 1305–1308 (2007).
16. Vogel, E. A., Rose, J. P., Roberts, L. R. & Eckles, K. Social comparison, social media, and self-esteem. *Psychol. Pop. Media Cult.* **3**, 206 (2014).
17. Mahmoodi, A., Bahrami, B. & Mehring, C. Reciprocity of social influence. *Nat. Commun.* **9**, 2474 (2018).
18. Mahmoodi, A., Bang, D., Ahmadabadi, M. N. & Bahrami, B. Learning to make collective decisions: the impact of confidence escalation. *PLoS One* **8**, e81195 (2013).
19. Bang, D. *et al.* Confidence matching in group decision-making. *Nat. Hum. Behav.* **1**, 0117 (2017).
20. Hertz, U. *et al.* Neural computations underpinning the strategic management of influence in advice giving. *Nat. Commun.* **8**, 2191 (2017).
21. Sanders, J. I., Hangya, B. & Kepecs, A. Signatures of a statistical computation in the human sense of confidence. *Neuron* **90**, 499–506 (2016).
22. Navajas, J. *et al.* The idiosyncratic nature of confidence. *Nat. Hum. Behav.* **1**, 810 (2017).
23. Adler, W. T. & Ma, W. J. Limitations of proposed signatures of Bayesian confidence. *bioRxiv* 218222 (2017).
24. Adler, W. T. & Ma, W. J. Comparing Bayesian and non-Bayesian accounts of human confidence reports. *PLOS Comput. Biol.* **14**, e1006572 (2018).
25. Brainard, D. H. The psychophysics toolbox. *Spat. Vis.* **10**, 433–436 (1997).

Supplementary Material:

Effect of condition on participants' performance rating:

we conducted a linear mixed model analysis with the participants' own performance rating in each block as the dependent variable and their own average error, their partners' average error in each block as well as an intercept as random effects allowing them to vary across subjects. In experiment 1a, we observed a significant positive effect of own error (parameter estimate .92 95% CI: [.76 1.08] $t(477) = -6.83$ $p < .0001$) and significant negative effect of partner's error (parameter estimate $\pm$ 95% CI: $-.3 \pm .1$, $t(477) = -6.13$ $p = 1 \times 10^{-9}$). Importantly, to show that this effect is not only because of the better blocks, we removed the better blocks and did the same analysis with inclusion of isolated, equal and worse blocks. The results were again replicated: positive effect of own error (parameter estimate $\pm$ 95% CI: $.92 \pm .18$, $t(317) = 9.99$ $p < .0001$) and negative effect of partner's error (parameter estimate $\pm$ 95% CI: $-.27 \pm .15$, $t(317) = -3.66$ $p = .0002$). We then ran the same linear mixed model on experiment 1b. Again, we found that there was a significantly positive effect of own error (parameter estimate $\pm$ 95% CI: $.9 \pm .14$, $t(727) = 12.2$ $p < .0001$) and negative effect of partner's error (parameter estimate $\pm$ 95% CI: $-.21 \pm .1$, $t(727) = -4.41$ $p = 1 \times 10^{-5}$). Importantly, here we excluded the worse blocks and confirmed that the effect still existed when we only included isolated, equal, and better blocks: positive effect of own error (parameter estimate $\pm$ 95% CI: $.96 \pm .16$, $t(542) = 11.63$ $p < .0001$) and negative effect of partner's error (parameter estimate $\pm$ 95% CI: $-.1 \pm .09$, $t(542) = -2.19$ $p = .02$).