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Exploring the informational sources of metaperception: The case of Change Blindness Blindness

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ABSTRACT

Perceivers generally show a poor ability to detect changes, a condition referred to as "Change Blindness" (CB). They are, in addition, "blind to their own blindness". A common explanation of this "Change Blindness Blindness" (CBB) is that it derives from an inadequate, "photographical" folk-theory about perception. This explanation, however, does not account for intra-individual variations of CBB across trials. Our study aims to explore an alternative theory, according to which participants base their self-evaluations on two activity-dependent cues, namely search time and perceived success in prior trials. These cues were found to influence self-evaluation in two orthogonal ways: success-feedback influenced self-evaluation in a global, contextual way, presumably by recalibrating the norm of adequacy for the task. Search time influenced it in a local way, predicting the success of a given trial from its duration.

1. Introduction

1.1. What is metaperception, and why study it?

"Metaperception" is the dual capacity to predict one's dispositions to succeed in a given perceptual task and to retrospectively evaluate the validity of the perceptual content just obtained. Metaperceptual capacities have been studied through three types of tasks: (1) confidence judgments after a perceptual decision (Juslin & Olsson, 1997). (2) Assessments of comparative difficulty between pairs of stimuli (Barthelmé & Mamassian, 2009; Petrusic & Baranski, 1989). (3) Decisions to respond or not to a given stimulus ("opt-out paradigm", Smith, Shields, & Washburn, 2003). While the latter two tasks require a *prospective confidence judgment*, the first involves *a retrospective judgment* about the correctness of the decision. Metaperceptual calibration refers to the extent to which perceivers' estimations of capabilities are congruent with their actual performances (Pieschl, 2009). When estimated performances are higher than manifested ones, overconfidence prevails, and *vice versa*. While an overestimating bias has generally been found predominant in most metacognitive modalities (e.g. metareasoning, metamemory), a predominantly underestimating bias has been documented in the perceptual domain (Dawes, 1980; Juslin, 1993; Keren, 1988).

Later studies, however, have revealed the existence of overestimating biases (Petrusic, 1994), particularly in the domain of change detection (Levin, Momen, Drivdahl, & Simons, 2000). Observers' performances in detecting salient differences in

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visual images viewed successively are surprisingly poor, when motion cues are made unavailable – a phenomenon called "Change Blindness" (for a review, see Simons & Levin, 1997). Perceivers, however, also considerably underestimate the rate and degree of their own Change Blindness, whether in predicting or post-evaluating their ability to detect a change, a phenomenon called "Change Blindness Blindness" (CBB) (Levin, 2002; Levin, Drivdahl, Momen, & Beck, 2002; Levin, Momen, Drivdahl, & Simons, 2000). A popular explanation of this poor calibration is that folk-psychology guides self-evaluation (Levin & Angelone, 2008). In a naive, "photographic" understanding of visual perception (Noë, 2004), the world seems to be accurately and exhaustively presented to the passive observer. This commonsense viewpoint fails to take into account the respective roles of motion transients and of top-down attentional processes in change detection; a general overconfidence about performance ensues, applying indiscriminately to self and to others (Levin, 2004; Levin et al., 2000).

Although a folk-psychological explanation may in part explain observers' overconfidence in their ability to detect changes, it is worth examining other variables susceptible to influence it. A recent finding in metamemorial studies suggests that accuracy in self- and other-evaluations crucially depends on observers' having been allowed to perform the first-order task *before* they form a confidence judgment for this trial, whether concerning their own, or another's performance (Koriat & Ackerman, 2010). When offering an evaluation off-line, (i.e. without having first engaged in the associated task), participants rely on the naive theory that study time predicts successful performance: in a self-paced learning trial, devoting more time to a pair of words is taken to predict better retrieval for that pair. After having been performing the task themselves, in contrast, participants judge that spending more time to learn a given word pair predicts poorer retrieval ("memorizing effort heuristic"). This study shows that some diagnostic cues can only be learned in an "activity-dependent" way (a term coined by Koriat to refer to the information that can only be gained by performing a task).

On the basis of this result, it is plausible to expect that the methods used to elicit confidence judgments in change detection tasks should lead to substantially different outcomes when they are based on an actual engagement with the task, or on folk psychological views about what determines success in this task. At first blush, however, no such difference seems to have been documented in CBB studies. For example, Levin et al. (2000) find that subjects massively underestimate their CB, when invited to merely judge whether they would successfully detect changes (seen as still frames). Participants in Scholl, Simons, and Levin (2004), on the other hand, did engage in the change detection task before estimating their own Change Blindness in a given trial: they also considerably overestimated their performance. Considering, however, that the paradigms involved use different stimuli (still vs. flickering frames), and did not identify nor manipulate activity-dependent cues, it is difficult to measure a putative difference in the amount of CBB between the engaged and the theoretical conditions.

In addition, it should be emphasized that there may be a number of activity-dependent heuristics that participants can use to predict their CB. For example, large and salient changes are more likely to be taken to predict quick detection than changes involving a few nonsalient pixels (Scholl et al., 2004). It is plausible that participants infer, in such cases, that large changes should be easier to detect, which is generally true when motion transients are available. Overconfidence may also be more directly associated with the lack of experience of participants with the experimental task of change detection with no motion transients. It has been shown in metacognitive studies that insufficient prior engagement in a task, reliance on inadequate heuristics (using non-diagnostic cues), inadequate feedback, may contribute to overconfident judgments of performance (Bjork, 1994). In the particular case of CBB, any of these sources might explain overconfidence. It is therefore worth exploring what these activity-dependent cues are, and to which extent they are reliable.

1.2. Activity-dependent cues in metaperceptual self-evaluation

Among the various activity-dependent cues potentially available to observers, two are of a general interest across metacognitive studies.

1.2.1. Effort

The first variety of cues contributes to an effort heuristic: agents predict their success in a given perceptual or epistemic trial based on the ease of processing associated with it. Although the notion of "heuristic" tends to evoke a theory-based association, it is an association implicitly acquired while performing a task, of a procedural, rather than of a conceptual nature, as attested by a limited capacity to transfer to other tasks (Koriat, Bjork, Sheffer, & Bar, 2004; Proust, 2007). Metamemorial studies have shown that a heuristic of effort generally relies on temporal aspects of processing, such as latency – how quickly information is accessed – and persistence – how often the information comes to mind (see Benjamin and Bjork, 1996, for a review). An interesting feature of this heuristic is that the diagnostic cues that it exploits generally fail to be consciously accessible. Agents, rather, experience a global conscious feeling of fluency, with various contextual variants such as familiarity, fame, intelligibility, or beauty (Oppenheimer, 2008; Reber, Schwarz, & Winkielman, 2004). These feelings influence in turn prospective and retrospective self-confidence judgments relative to the associated task episode (Koriat, 1993; Koriat & Levy-Sadot, 1999), and motivate other normative judgments about the first-order task contents.

Feelings of fluency are also known to play a role in metaperception, in tasks such as detection, discrimination or recognition (Jacoby & Dallas, 1981; Petrusic & Baranski, 1989; Petrusic & Cloutier, 1992; Wurtz, Reber, & Zimmermann, 2008), whether in prospective, or in retrospective self-evaluations. No research has been conducted, however, about how the amount of effort engaged in a given change detection trial influences CBB for that trial. Based on metamemory studies, a

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plausible prediction is that participants will use an effort heuristic (i.e. relying on the comparative duration of a given search) to assess their performance.

How to operationalize the effort heuristic?

A first way of addressing this question consists in manipulating the duration of the search for a change in a given stimulus. The later a change is introduced, the longer the search, the more effortful a trial will be felt to be. If this heuristic is applied, participants' evaluations of the magnitude of Change Blindness should be more pessimistic in trials where the change is introduced late (e.g. 12 s after onset), as compared to trials in which the change is introduced early after onset (e.g. 4 s after onset). To investigate the effort heuristic, we will thus manipulate the time of change insertion, i.e. search time, and analyze its influence on Evaluations of CB (i.e. ECB).

An additional way of manipulating fluency consists in introducing contrasts in task difficulty across blocks of trials (Petrusic & Baranski, 1997). This can be done by organizing the sequence of trials according to their change-insertion times. Changes can be introduced either in increasing, or in decreasing effort sequences. If participants use a search time heuristic based on the gradient of effort within a block, CBB performances should differ in the increasing and decreasing effort groups.

Our experimental design is constructed so as to allow us to consider the respective influence of local and contextual effort heuristics on CBB.

1.2.2. Performance feedback

A second kind of activity-dependent cue consists in performance feedback.[2] While fluency-related cues are generally thought to operate in an implicit way (Koriat & Levy-Sadot, 1999), performance feedback seems to be consciously accessed. It grounds judgments about success in a given trial, and regulates control in further trials (Nelson & Narens, 1990). Recent studies suggest that, even when no explicit self-evaluation of performance is requested, perceivers rely on performance feedback to adjust their learning rate in a discrimination task (Shibata, Yamagishi, Ishii, & Kawato, 2009). Similarly, perceivers rely on the past frequency of "success-signals" in a discrimination task, to predict success in a new trial of the same task (Critchfield, 1994). No studies, however, have investigated the influence of performance feedback on CBB. A plausible prediction, which is tested in our experiment, is that participants will rely on performance feedback to assess their performance, even when this feedback is biased.

How to operationalize perceived success?

Perceived success rate is the perceived ratio of hits and total number of trials in performance feedback. According to the hypothesis that subjects' own perceived performance is influenced by past performance feedback, the more successful subjects have been in a perceptual task, the more they will tend to report success in future trials for that task. Granting that subjects are generally able to quickly detect the changes in their environment, it is plausible that performance feedback, i.e., perceived success, constitutes a major cause of CBB.

Another way of determining success in a detection task is relative to the quickness of change detection: the quicker the detection, the more successful a trial. In our design, perceived success will be manipulated by reporting to subjects the magnitude of their CB at the end of a trial.

In order to manipulate perceived success in two opposite directions, a bias can be introduced by the experimenter. For instance, the experimenter can create an "optimistic feedback" condition, in which the magnitude of CB that is reported to participants diminishes actual CB, and a "pessimistic feedback" condition, in which the reported magnitude of CB augments the amount of actual CB. Participants in the optimistic feedback group should have a more optimistic appraisal of their detection performance than those in the pessimistic feedback group.

1.3. Aim of the experiment

Our aim is to explore the possible influence on CBB, in addition to folk-theory and background beliefs about perception, of the two varieties of activity-dependent cues discussed above, search time and performance feedback, belonging respectively to "control-based" and to "monitoring-based feedback" (Koriat, Ma'ayan, & Nussinson, 2006). Effort is a control variable modulated by the time of change insertion, i.e. by the necessary persistence involved in performance. Performance feedback, on the other hand, is a monitoring variable, whose function is to track how effective a set of commands was in a particular trial.

1.4. Outline of the experiment: four phases

Each participant is successively subjected to four different versions of a Basic Task, involving a detection and an evaluation task, in which the subject is asked to report the Estimated Time of change Insertion in a given trial (hereafter, ETI). In the first phase of the experiment (P1), participants are merely subjected to the Basic Task, which allows us to calculate a baseline for CB and CBB. The second phase (P2) explores the contribution of local and contextual effort on self-evaluation. Two different groups of subjects are exposed to two inverse conditions, with a delay of change insertion after onset respectively

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[2] Although the term of an activity-dependent cue is generally meant to apply exclusively to "control-based" feedback (i.e. to cues based on executive commands), it is worth generalizing the term to any feedback gained through performance, in contrast with cues derived from task-independent beliefs and observation.

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increasing or decreasing across trials. The third phase (P3) explores both the influence of local effort and of perceived success on self-evaluation. The two different effort groups of P2 are divided in P3 into two performance feedback groups, (optimistic vs. pessimistic feedback). Finally, a fourth phase (P4) explores whether the influence (if any) of effort and performance feedback on self-evaluation persists, when feedback is no longer delivered.

Given that search time (short vs. long) and performance feedback (optimistic vs. pessimistic) are respectively manipulated in opposition, this design will make possible to determine whether, and to which extent, each type of cue independently or interactively contributes to shaping the observers' self-evaluations.

2. General method

2.1. Participants

The participants were 40 Japanese volunteer students, aged between 19 and 31, (mean age = 22 years and 8 months), 19 females and 21 males, paid for their participation. All of them reported normal, or corrected-to-normal, vision.

2.2. Materials

2.2.1. Stimuli

A set of 100 real-world scenes was modified in order to construct pairs with only one changed element across flickering. Twenty pairs of five kinds of original and modified pictures have been constructed: 20 pairs with a change in color, size, location of an object, respectively, as well as 20 pairs with object disappearance and 20 with object substitution, created by manipulating the original image using Adobe "Photoshop" Elements 6. Stimuli were all 1100 pixels wide and 700 pixels high. The presentation of the stimuli and the collection of the responses were achieved using Matlab and Psychtoolbox extension. All changes were designed to be easily found when no mask was presented between the pictures.

A continuously visible time bar was running (to a maximum of 30 s) during the detection task. The detection time bar was presented in a red rectangle located at the bottom of the screen. Its size was 20 px high; its width was gradually increasing from left to right, i.e. from 1 (beginning of the trial) to 1100 px (30 s after presentation of the first picture). The time bar froze as soon as a change was detected. This time bar was also used by participants for estimating the time of change insertion. In certain conditions, an additional green feedback bar of the same size was presented above the red bar.

2.3. Procedure

2.3.1. Basic task

The basic task, common to the four phases of the experiment, involves a Detection and an Evaluation task.

In the Detection task, the classical flickering paradigm is used to induce Change Blindness. Before a change is introduced, a single scene (240 ms) is repeatedly presented, interspersed with a gray mask (120 ms). Subsequently, the original and the modified pictures alternate. One difference with classical versions of the flickering paradigm is that the change is not inserted at the beginning of the trial.

In the Evaluation task, participants have to estimate when they think the change was introduced (cf. Fig. 1). This estimate provides an implicit Evaluation of Change Blindness (ECB). Rather than offering a numerical evaluation as in Scholl et al. (2004), participants are asked to click on the time bar.

The two main variables that are manipulated across the four phases of the experiment are the time of change insertion and the performance feedback.

P1. Changes are all introduced 4 s after onset; no performance feedback is delivered.

P2. The time of change insertion is manipulated so as to generate two inverse gradients of effort, i.e. "contextual effort" conditions. In the "increasing effort condition", the change is introduced at the successive delays of, respectively, 4, 8 and 12 s, for trials 1–10, 11–20, 21–30. In the "decreasing effort condition", the change is introduced at the successive delays of 12, 8, and 4 s, for trials 1–10, 11–20, and 21–30. The sequence of stimuli presented in the 4 s-, 8 s-, and 12 s-trials is the same for both groups of participants. Thus, the sequence of stimuli presented in trials 1–10 of the increasing effort condition is the same as the one presented in trials 21–30 of the decreasing effort condition, while the middle 11–20 trials involve the same stimuli in both groups. These trials, where time of change insertion and stimuli are common to all subjects, are thus target trials. The stimuli in the 4, 8 and 12 s- trials are of an equal average difficulty, as estimated by a pilot study. Performance feedback is not manipulated.

P3. The time of change insertion and performance feedback are both manipulated. The changes are introduced at three delays (4, 8, and 12 s) as in P2, but in a randomized order. Biased feedback reporting the supposedly Actual Time of change Insertion (ATI) is provided to the participants once they have delivered their own ECB reports. For the optimistic feedback group, the time of change insertion reported is the actual magnitude of CB divided by two. For the pessimistic feedback group, it is the actual magnitude of CB augmented by half. We chose to manipulate the reported time of change insertion based on the magnitude of CB rather than on estimated time of change insertion in order to make the manipulation independent of the accuracy of self-evaluation.

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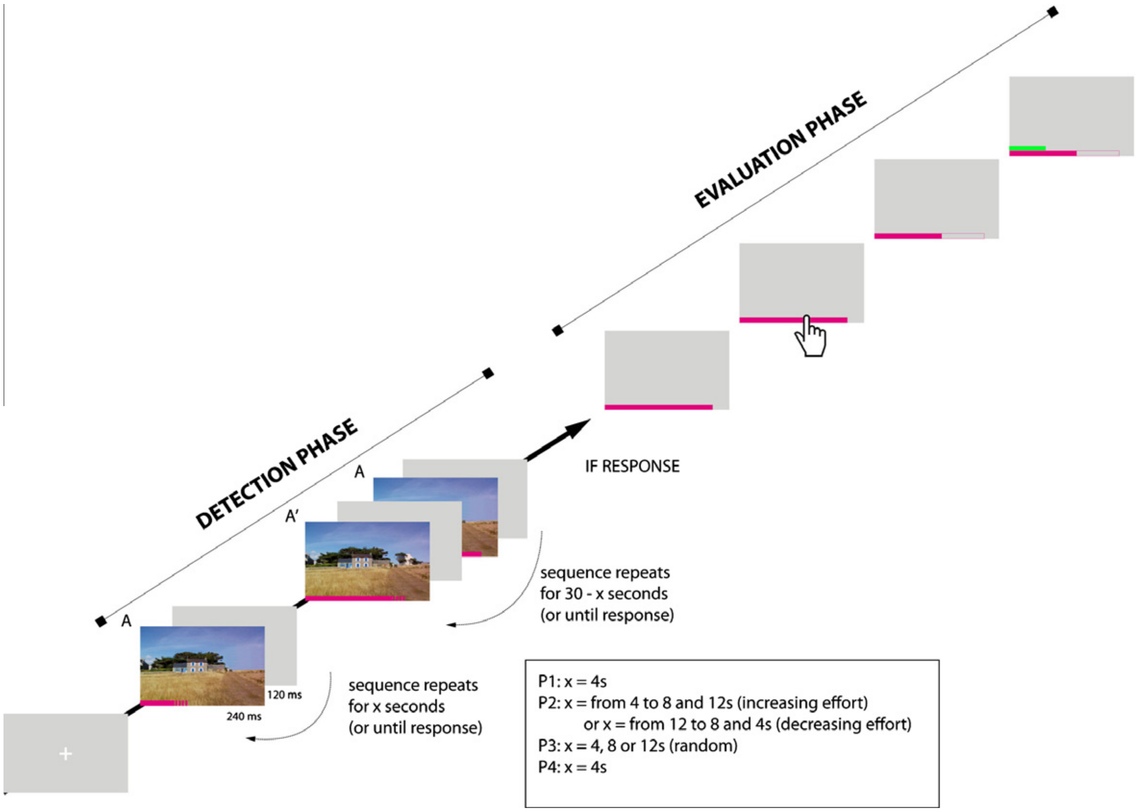

Fig. 1. Design of the task. Once the change is detected, participants are asked to estimate when they think the change was introduced, which allows calculating CBB for a trial.

To illustrate, if insertion time was +8 s, and detection time was +20 s, CB = 12 s. In the optimistic condition, reported time of change insertion = 14 s, so that reported CB = 6 (detection time minus reported time of change insertion).

P4. All changes are introduced 4 s after onset; no performance feedback is delivered.

2.4. Instructions

Participants are instructed that they will be presented with a task of detection and of evaluation. In the Detection Task, they will have to search for a change *that might occur at any point after onset*. Before a change is introduced, a single scene will be presented repeatedly. When they have detected a change, they are instructed to click on it as soon as possible. It is specified that one and only one change will occur in every trial. If no change is detected, a new trial will automatically begin.

If detection occurs, participants are requested to click on the time bar to estimate the time of change insertion; then they should press the keyboard spacebar to start the next trial.

In P3, participants are instructed that the task is the same as in the two previous sessions, except that after their evaluation is delivered, a feedback bar appears on the screen indicating the actual time of change insertion.

Participants are tested individually in a quiet room.

3. Results

3.1. Detection

3.1.1. P1. Replicating results on CB

Change were detected in 70.8% of trials. When the change was detected, the average magnitude of CB was 9.8 s.

3.1.2. P2. The influence of time of change insertion on CB

Changes were detected in 77.58% of the trials with a rate of 89.75, 63.75, and 79.25 for the 4, 8, and 12 s-trials, respectively. An ANOVA was performed, investigating the effect on the rate of detection of (1) the Contextual effort condition and (2) the Time of change insertion. No effect of the Contextual effort condition was found ($F(1, 38) = 2.05$, $p = .16$). A main effect

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of Time of change insertion was found ($F(2, 76) = 57.4$, $p < .0001$). t-tests with Bonferroni corrections showed that all times of change insertion were significantly different of others ($p < .001$ for all), 8 s-trials being associated with the lowest rate of detection.

An ANOVA was further performed, investigating the influence on CB of (1) the Time of change insertion and (2) the Contextual effort condition. No effect of the Contextual effort condition was found ($F(2, 76) = 0.62$, $p = .54$). Change Blindness was on average 6.6 s and 6.8 s for participants in the decreasing and in the increasing effort condition. However, we observed that a later change insertion correlates with a lesser Change Blindness ($F(2, 76) = 3.663$, $p = .03$). The magnitude of Change Blindness was 7.25 s for the 4 s-trials, 6.5 s for the 8 s-trials and 6.1 s for the 12 s-trials.

3.1.3. P3. The influence of time of change insertion and performance feedback on CB

3.1.3.1. Rate of detection. Taking all participants together, changes were detected for 82.67% of the trials. A 2-factor ANOVA using partially repeated measures was conducted, investigating the effect on the rate of detection of (1) Time of change insertion and (2) Performance feedback. No effect of Performance feedback was observed ($F(1, 38) = 0.01$, $p = .91$). A main effect of Time of change insertion was found ($F(2, 76) = 11.3$, $p < .0001$). t-tests with Bonferroni corrections showed that the main difference lies between the 4 s-trials and the two other conditions ($p < .0001$ compared to 8 s-trials, $p < .05$ compared to 12 s-trials, the 4 s-trials leading to a higher rate of detection, the rate of detection being of 88.5, 77 and 82.5% for the 4, 8 and 12 s-trials, respectively).

3.1.3.2. The magnitude of CB. A 2-factor ANOVA using partially-repeated measures was conducted in order to analyze the respective effects on CB of (1) Performance feedback and of (2) Time of change insertion. No effect of Time of change insertion was found ($F(2, 76) = 3.832$, $p = .25$), neither was an effect of Performance feedback ($F(1, 38) = 2.944$, $p = .09$). CB = 7.9 s in the optimistic feedback condition vs. 9.4 s in the pessimistic feedback condition.

3.1.4. P4. Changes were detected in 66% of trials

A 2-factor ANOVA assessed the respective influence on the rate of detection of: (1) Phase (P3 vs. P4) and of (2) Persistence of prior performance feedback. Given that the time of change insertion common to P3 and P4 is 4 s, the only trials taken into account from P3 were the 4 s-trials. The ANOVA revealed a main effect of Phase ($F(1, 38 = 88.73$, $p < .0001$). The rate of detected changes decreased from 82.67% in P3 to 66% in P4. No effect of performance feedback on detection rate was found ($F(1, 38) = 0.03$, $p = .86$); the detection rate is 63.5% in the optimistic group vs. 66.3% in the pessimistic group). Given the presence of this fatigue effect, we compared the rate of detection across the four phases. A one-way repeated measures Anova was performed on the percentage of detected trials across experiments taking into account only trials in which the change occurred at 4 s. An effect of Phase was found ($F(3117) = 52.0$, $p < .001$). t-tests with Bonferroni corrections showed that there were significantly less detected trials in P1 as compared to P2 and P3 ($p < .001$ in all these comparisons), which presumably reflects a training effect. However, P4 has a lower detection rate as compared to P2 and P3, which presumably reflects a fatigue effect.

All subjects taken together, the magnitude of CB was 9.96 s (SD: 2.53 s). In the optimistic group, the mean CB was 10.3 (SD: 2.30), vs. 9.53 (SD: 2.74) in the pessimistic group.

3.2. Change Blindness Blindness

In order to compute CBB for a particular trial, one method consists in subtracting the estimated CB from the actual CB. However, the effect of the Time of change insertion as well as the effect of CB on CBB need to be neutralized. For example, for a given trial in which the change occurs at 4 s and detection occurs at 20 s after onset, it is probable that the estimated time of change insertion will be later than in a case where detection occurs at 10 s after onset. For this reason, CBB will be measured by the ratio between the neglected and the actual CB:

> [Estimated Time of change Insertion – Actual Time of change Insertion]/[Detection time – Actual Time of change Insertion] (see Fig. 2).

In the rare cases of underconfident evaluation, the adequacy of metaperceptual evaluations can be calculated by the proportion of actual CB that is over-attributed in Estimated CB.

3.2.1. P1. Replicating classical results on CBB

The average time of estimated change insertion was 10.0 s (SD: 2.9), with an average CBB of 54.0% (SD: 19.63) of CB total duration. t-tests performed between estimated and actual time of change insertion (4 s) were highly significant ($t(39) = 13.24$, $p < .0001$). There was no under-confident evaluation.

3.2.2. P2. The influence of time of change insertion on CBB

All participants taken together, the magnitude of CBB was 56.45% (SD: 13.36). A 2-factor ANOVA using partially repeated measures with (1) Time of change insertion and (2) Contextual effort condition revealed no effect of the latter on CBB ($F(1, 38) = 1.59$, $p = .214$). CBB was 60.24% (SD: 16.24) for the increasing effort condition, and 52.66% (SD: 8.51) for the

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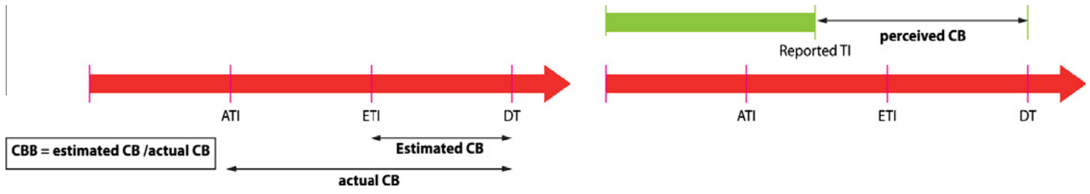

Fig. 2. Description of the successive steps in a trial. ATI is the actual time of change insertion. DT, Detection time is the time at which participants click on the change as localized. ETI is the estimated time of change insertion. Reported TI (green segment) is the time of change insertion as reported to participants in P3, where biased feedback is introduced.

decreasing effort condition. However, this ANOVA revealed a main effect of the Time of change insertion on CBB ($F(2, 76) = 12.14$, $p < .001$). A difference of 12% in CBB was observed by comparing 4 s- with 12 s-trials (4 s: 52% CBB, 8 s: 45% CBB; 12 s: 39% CBB) (Fig. 3).

Since 8 s-trials were presented in the same conditions both in the increasing and in the decreasing effort groups, *t*-tests were thus performed to assess the effect on CBB of contextual effort in the 8 s-trials (preceded respectively by 4 or 12 s-trials). They revealed no effect ($t(38) = -1.25$, $p = .21$). In the 8 s-trials, CBB = 59.2% in increasing effort condition vs. 59.4% in the decreasing effort condition. *t*-tests performed on the 4 s- and 12 s- trials did not reveal any difference between the groups either (respectively $t(38) = 1.28$, $p = .21$, and $t(38) = 1.39$, $p = .17$).

3.2.3. P3. Influence of Performance feedback on CBB

We performed a 3-factor ANOVA with repeated measures exploring the effects on CBB of (1) the Contextual effort condition in P2, of (2) the Performance feedback condition in P3 and (3) the Time of change insertion in P3. The first trial was excluded from the analyses. The ANOVA confirmed the results obtained in P2: assignment to gradually increasing or decreasing effort conditions did not affect CBB ($F(1, 36) = 0.83$, $p = .363$). A major effect of Performance feedback was found ($F(1, 36) = 42.39$, $p < .0001$). *t*-tests with Bonferroni corrections show that this effect is mainly due to the pessimistic feedback group ($p < .0001$), the difference in the magnitude of CBB in the optimistic feedback group being non-significant ($p = 1$). The percentage of CBB only slightly increases from P2 to P3 in the optimistic feedback group (P2: 51.12%, SD 13.56; P3: 51.79%, S.D: 16.43). Conversely, the percentage of CBB decreases by two in the pessimistic feedback group (P2: 40.3%, SD: 14.01 vs. P3: 22.89%, S.D: 10.97) (Fig. 4).

Since no feedback had been delivered in the first trial, the overestimation of performance was almost equivalent between the optimistic and pessimistic conditions for this specific trial, with a difference of only 6%. In the subsequent trials, the difference of overestimation was on average 29%, which is significantly above the first trial (*t*-test for single means: $t(28) = 17.67$, $p < .0001$).

An effect of Time of change insertion ($F(2, 72) = 26.4$, $p < .0001$) was also found, CBB progressively decreasing when the change was introduced later (Fig. 5). The percentage of CBB is respectively of 49%, 40%, and 35%, for trials where changes were respectively introduced 4 s, 8 s, and 12 s after onset. None of the interactions were significant, neither between the Contextual effort condition and the Performance feedback condition ($F(1, 36) = 1.49$, $p = .23$), nor between the Contextual effort condition in P2 and the Time of change insertion in P3 ($F(2, 72) = 0.89$, $p = .41$), nor between the Performance feedback and the Time of change insertion in P3 ($F(2, 72) = 0.25$, $p = .78$), nor between the three factors ($F(2, 72) = 0.3$, $p = .69$) (Fig. 5).

An interesting result concerns trials in which Evaluation of CB reveals an over-attribution of Change Blindness. Participants in the optimistic feedback group underestimated their detection performance in 14% of trials, against 42% in the pessimistic feedback group. *t*-tests revealed that the difference is highly significant ($t(38) = -6.8$, $p < .0001$).

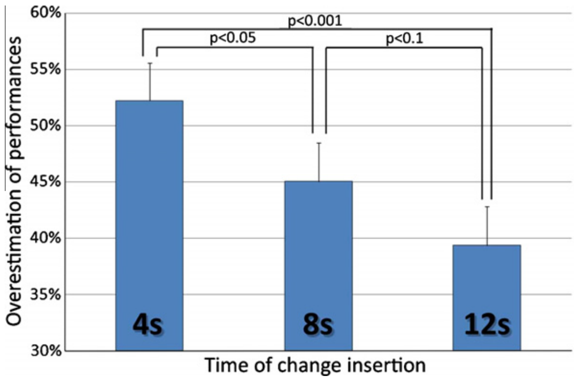

Fig. 3. Evaluation of the occurrence of the change in P2. Participants present a higher CBB when the change insertion occurs earlier in a trial.

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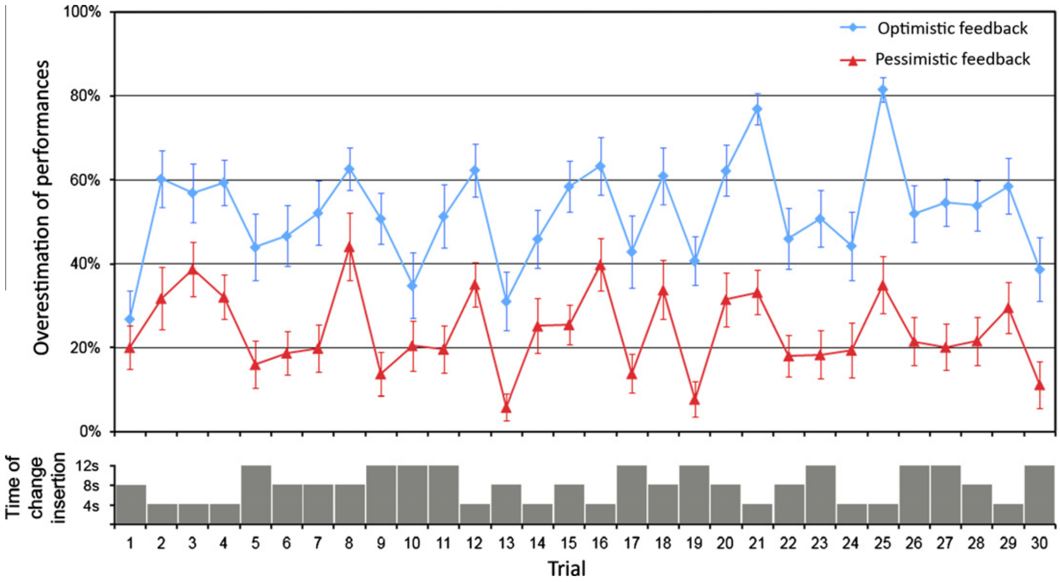

Fig. 4. Trial by trial magnitude of CBB in P3 for the optimistic and the pessimistic feedback condition. The bottom line indicates the respective times of change insertion for a trial. The insertion times for each stimulus are constant, rather than randomized, across participants.

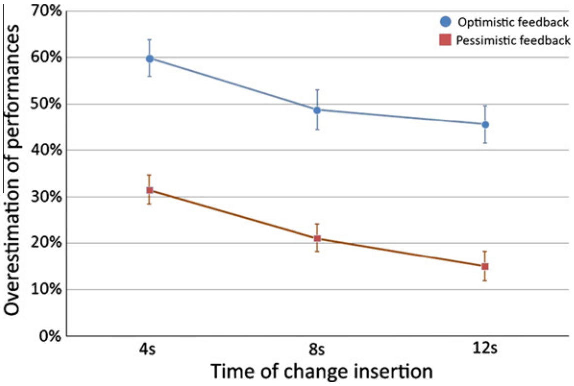

Fig. 5. Magnitude of CBB in P3 as a function of time of change insertion. Time of change insertion modulates CBB in the same way in the two biased-feedback conditions.

3.2.4. P4. The persisting influence of the Performance feedback delivered in P3

A 2-factor ANOVA was conducted in order to assess whether the difference in CBB observed in P3 between the two performance feedback groups would still be found in P4, when no performance feedback is delivered anymore. It was also conducted to assess whether the magnitude of CBB would be stable inside each group, across P3 and P4. The respective influence on CBB of (1) Phase (P3 vs. P4); and (2) Prior performance feedback was analyzed. Concerning the first factor, given that changes always occurred 4 s after onset in P4, and given that Time of change insertion was found to influence CBB in P3, only the 4 s-trials of P3 were used in the analyses. As expected, participants previously assigned to the pessimistic feedback condition in P3 presented significantly less CBB in P4 than participants previously assigned to the optimistic feedback condition in P3 ($F(1, 38 = 41.2$, $p = .0002$). The former had a mean of 32.9% CBB (SD: 17.6), while the latter had a mean of 64.7% CBB (SD: 18.2). No effect of Phase was found ($F(1, 38) = 0.02$, $p = .22$). The pattern of reported CBB is stable between P3 and P4 (Fig. 6).

4. Discussion

4.1. Detection rate

In P2, a lower rate of detection was found at 8 s than at 12 s. In P3, the rate of detection was higher at 4 s than in the two other delays. It is possible that changes are more difficult to detect at earlier insertion times because a reduced scanning of

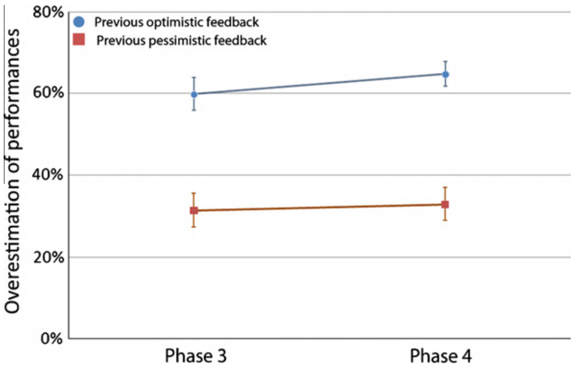

Fig. 6. Comparing CBB magnitudes for P3 (biased feedback) and P4 (no feedback) in 4 s trials. The performance feedback condition assigned in P3 continues to influence ECB reports in P4.

non-changing stimuli makes a change more difficult to detect, even though the participants have more time to do so. Future studies would be necessary to test the respective effects on detection of a shorter/longer search duration and a lower/higher familiarity generated by a shorter/longer sequence of unchanging flickerings.

4.2. Change Blindness

The magnitude of CB found in this experiment was higher than in Scholl et al. (2004): 9.8 s were needed to detect a change, while Scholl's participants needed 5.15 s. This difference probably reflects a difference in stimulus difficulty. An interesting result from P2 is that the gradient of effort in a block of trials has no effect on CB, which, as will be seen shortly, is associated with an absence of effect of CBB as well. Equally interesting is the finding that, in P3 and P4, performance feedback has no effect on detection of a change, in contrast with the finding that optimistic feedback boosts perceptual learning (Shibata et al., 2009).

4.3. Change Blindness Blindness

In the first phase of the experiment, we replicated the classical CBB effect. However, the magnitude of CBB was higher in this experiment than in Scholl et al. (2004), (54% vs. 43.4% of CBB). Given that our detection rate is also lower, this difference might reflect a "hard-easy" effect (Lichtenstein & Fischhoff, 1977): the more difficult the first-order task is, the larger the over-estimation tends to be (Harvey, 1997; McClelland, Bolger, & Tonks, 1992).

P2 investigated whether CBB depends on the relative effort expanded in detection trials encountered earlier, on the local effort for detecting a change in the current trial, or on neither. A contextual effort heuristic hypothesis failed to be confirmed: no difference in CBB was found between the increasing effort and the decreasing effort conditions for the 8 s-target trials. This result converges with Petrusic and Baranski (1997) in a perceptual comparison task. It can be explained in two ways. (1) Given that change detection is a challenging task, subjects do not attend to the gradient of difficulty across blocks of trials. (2) The temporal variations may have been too limited to elicit a feeling of contrastive difficulty in participants. In order to adjudicate between these explanations, further experiments would be needed.

Our second "local effort heuristic" hypothesis was confirmed: a later time of change insertion leads to a reduced overestimation of performance. The assessment value of time-related effort has been documented in metamemory research (Koriat & Ackerman, 2010). Phases 2 and 3 of the experiment shows that this heuristics is also used in the metaperceptual domain: a longer search time correlates with a reduced CBB.

Four difficulties inherent to our results need to be addressed. The first concerns a putative selection effect that might be induced on CBB by the important and variable rate of non-detection. Given that the rate of non-detection was significantly lower in the 4 s-trials than in the 8 s- and 12 s- trials, cannot the supposed effect of time of change insertion on CBB actually stem from a selection effect? This is implausible, however, if one considers that the time insertion effect is replicated in Phase 3, in trials no longer associated with a high rate of non-detection. Furthermore, the correlation between CBB and Time of change insertion is linear, both in Phases 2 and 3 (see Figs. 3 and 5).

Second, one might object that properties of the stimuli explain the CBB results rather than reliance on a local effort-heuristic. Although, as reported earlier, we controlled the difficulty of our stimuli, such a possibility cannot be a priori excluded. To address this, we plotted stimulus difficulty against CBB for each time of insertion. We observed that CBB is inversely correlated to search time, but is not correlated with stimulus difficulty.

Finally, one might wonder whether participants could not have used a perceptual strategy, in which a non-changing object is noticed as turning into a changing one. Would not a perceptual change constitute the best evidence that participants could use to make their CB assessments? In response to this objection, let us remind that in a flickering paradigm, it is very

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unlikely that subjects, in the absence of transients, can notice the first occurrence of the modified picture. In their post-experiment interviews, indeed, subjects did not mention having used a perceptual change as a cue.

Two interesting results emerge from Phase 3. The first is that, when subjected to a systematically biased feedback, participants adjust their CB ratings accordingly. It is compatible with Scholl et al.'s (2004) finding: when no feedback is offered, CBB remains constant across trials. Here, however, participants have access to their past supposed success rate, and revise their estimations accordingly. The feedback on reported magnitude of CB across trials appears to be used by subjects as a calibration cue: a larger perceived CB will be associated with increased pessimism in further reports of ECB, and conversely.

There are two ways, however, of explaining the biasing influence of feedback on calibration. One is that it is an anchoring effect induced by the absolute amount of CB reported to the participant on the time bar (Tversky & Kahneman, 1974). On this interpretation, the segments of CB that are perceived across trials respectively in the optimistic and pessimistic feedback conditions should work as an absolute anchor for calibrating judgments under uncertainty about what is the case in subsequent trials, independently of their respective times of change insertion. In this case, the effect should appear merely in the value of the intercept of the regression of perceived on actual CB. If, on the other hand, calibration is sensitive to performance control, it should affect the slope of the regression. If, however, we compare the influence of positive and negative feedback in our three time insertions conditions, we see that self-evaluation is both sensitive to biased feedback and to time of change insertion. Thus, calibration is not based merely on an absolute numerical value of reference, but proves sensitive to trial variations (such as an early or late insertion time).

A second interesting result is that participants rely on an effort-cue in addition to performance feedback to evaluate their performance. Does one of them dominate the other? Our paradigm allows us to conclude that ECBs are independently influenced by local search time and by performance feedback. The question motivating Phase 4 was whether the biased feedback that affected self-evaluation in P3 would still do so when external feedback is no longer delivered. This question was investigated by subjecting the participants to the same basic task used earlier, with a constant time of change insertion and no performance feedback. A first finding concerns the stability of the metaperceptual calibration reached at the end of P3. This remarkable stability can be explained by the absence of discrepancy between expected and observed outcome during P3: receiving no external feedback about their CB, and no variation in sensed effort, the participants seem to have merely formed their ECB reports as a function of antecedent feedback.

5. General discussion

Our experiment was designed to study the respective roles of effort and performance feedback on self-evaluation in a change detection task. Effort was manipulated by introducing the changes to be detected at various delays after onset (in Phases 2 and 3). Performance feedback was manipulated (in Phase 3) by reporting to the participants a systematically biased time of change insertion for a block of trials, once they had reported their own estimated time of change insertion. Phase 4 aimed at assessing whether previous manipulation of performance feedback would persist influencing self-evaluation.

Three major results emerge. First, the Evaluation of Change Blindness (ECB) does not rely merely on the sensory information present in the stimuli. It is influenced in part by the implicit heuristic that a longer search time is diagnostic of a poorer change detection performance. Second, ECB exploits information contained in prior feedback. Our subjects are sensitive to the performance feedback offered in Phase 3; self-evaluation in Phase 4, when no performance feedback is provided, robustly preserves the acquired bias. Third, these two factors independently influence self-evaluation, with no interaction effect. We will discuss below each of these results.

5.1. R1. The influence of search time on self-evaluation

When a change is introduced later in a trial, search time is automatically longer than when a change is introduced sooner. A longer search time was used as a cue by participants in their ECB reports to predict poorer detection performance. This suggests that participants' metaperceptual evaluations rely on an effort heuristic similar to the memorizing effort heuristic that more learning effort predicts poorer recall performance (Koriat & Ackerman, 2010; Koriat et al., 2006).

Our results show, in agreement with Petrusic and Baranski (1997) finding in a task of visual discrimination, that effort is appreciated locally, rather than by reference to previous interactions with the task. Trials of intermediate difficulty led to the same amount of overestimation in the decreasing and the increasing contextual effort conditions.

There are, however, two apparently contradictory ways of using the local effort cue in order to assess one's performance in a change detection task. Beck, Levin, and Angelone (2007) found that perceivers tend to reason that more effort allocation in a change detection task is predictive of *better* performance. On the other hand, our study shows that a larger amount of effort in a given trial is used as a diagnostic cue of *poorer* performance (in agreement with Borg & Noble, 1974; Petrusic & Baranski, 1989). Our results thus seem prima facie to conflict with Beck et al's. However, they can be reconciled if one considers that Beck's subjects were required to form their predictions *in abstracto*, while subjects involved in our and in the other studies had to form them *on line* (i.e. after having been exposed to the task). If more effort is allocated when one is

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motivated to succeed in a given task, it may in abstracto seem rational to conclude that effort predicts success. On-line self-evaluations, in contrast, seem to rely on the procedural knowledge that effort is driven by task difficulty: an increase in effort allocation is seen as predicting a poorer performance. Interestingly, a similar dissociation has been found in metamemory judgments concerning the memorizing effort heuristic (Koriat & Ackerman, 2010). Granting the existence of such a dissociation, it is plausible to assume that naive beliefs about perception and an effort heuristic are exerting an opposite influence on self-evaluation in a change detection task, and in other cognitive tasks as well.

In summary, our study revealed that metaperceptual evaluations do not necessarily rely on naive views about perception, but might also be based on activity-dependent cues. An effort heuristic constitutes an alternative informational source of metaperceptual evaluations.

5.2. R2. The influence of biased performance feedback on self-evaluation

A second activity-dependent cue was used in participants' ECB reports, namely the performance feedback collected in the past interactions with the detection task. Expected success rate can be computed as a function of the reported magnitude of CB across trials. Perceived success in a given trial can be seen as inversely correlated to CB magnitude. The discrepancy between expected and observed values theoretically allows agents to revise their representation of task demands. In the pessimistic feedback condition, subjects seem to have promptly recalibrated their norm of evaluation: the proportion of Change Blindness Blindness (CBB) decreased in the first five trials, and a tendency to underestimate performance emerged. In the optimistic feedback condition, in contrast, participants persisted in strongly overestimating their performances. This result complements the earlier finding that, when offered no feedback, subjects present a constant CBB across trials (Scholl et al., 2004).

Our study demonstrates that recalibration of the norm for evaluating one's performance only occurs when the prior representation of one's success rate conflicts with newly acquired performance feedback.

One might object that the causal relation of performance feedback to CBB does not depend on metaperception, but rather merely reflects anchoring: participants might only learn, across trials, to match a segment of the time bar with the mean reported CB. We observed in the previous section, however, that, in Phase 3, the interval between detection time and the time of change insertion was randomized across trials. Participants' ECB reports display a sensitivity to the time of change insertion in a trial, which is incompatible with the "anchoring" hypothesis.

A closely related objection is that performance feedback used by participants to assess their CB magnitude does not *ipso facto* induce in them broader optimism or pessimism. Post-experiments interviews bring useful evidence to address this objection. When asked to estimate the difficulty of the Detection task in the interview, the number of participants reporting that it was "very difficult" was twice larger in the pessimistic than in the optimistic feedback condition, where participants favored a "difficult" answer (45% vs. 20% of participants, respectively). Furthermore, 90% of the participants from the optimistic feedback group reported having significantly improved in the detection task across blocks, vs. 55% in the pessimistic feedback group. Although these data should be read with caution, they suggest that variation in ECB reports is not best explained by a mere anchoring effect of participants' estimates on the performance bar.

5.3. R3. The independent influence of effort and performance feedback on CBB

Contextual effort turned out to have no influence on CB and on CBB. Therefore, the question to be raised is whether the two remaining types of information – local effort and performance feedback – interact in guiding self-evaluation. If such was the case, the influence of the optimistic feedback should be modulated by the local effort condition. Similarly, the influence of local effort cues should be modulated by the performance feedback condition. We found, however, that the two informational sources exert an independent influence on self-evaluation. Considering ECBs as a function of the time of change insertion, the response curves are parallel for participants in the two performance feedback conditions, indicating the stable influence of both kinds of feedback on self-evaluation (Fig. 6).

Our results also allow the distinctive contributions of the cues respectively involved in the effort heuristic and in performance feedback to be clarified. A far as the effort heuristic is concerned, search time is a cue inherent to the control exerted by perceivers within a trial: it contributes to the *resolution* of a given ECB report, i.e. to the validity of a given self-evaluation. Performance feedback, in contrast, cannot predict the amount of CB in a subsequent trial, because the stimuli used in the various trials are different. It offers, rather, a stable estimation of success across subsequent trials, by *calibrating* predictions on the basis of general task requirements. This contextual effect on subjects' ECB reports was found to have an important inertia (the effect being present in P4 when no feedback is provided).

In summary, metaperceptual judgments in change detection tasks seem to involve two intricated self-evaluations. First, one's general competence for the task at hand is assessed on the basis of perceived success in past interactions with similar tasks. Performance feedback seems to influence self-evaluation structurally, by moving up or down the norm of competence for a type of task. It thus seems mainly responsible for perceivers' general overconfidence in their ability to detect changes. Second, performance in an individual trial is assessed within this general success framework, based on comparing search times, i.e. effort expanded, across individual trials. Sensed effort thus seems to exert a local influence on self-evaluation: within a given norm of competence for that task, it helps categorize performance in a specific trial with respect to a typical successful trial.

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6. Concluding comments

In the present study, two activity-dependent cues were shown to be used by participants in a change detection task: (1) an effort heuristic, that a longer search for a change predicts a poorer performance; (2) a performance cue, based on past perceived success. These two types of cues were found to influence self-evaluation in two orthogonal ways: success-feedback influenced self-evaluations in a contextual way, by calibrating the norm of competence for the task at hand. Search time influenced self-evaluation in a local way, by predicting the relative level of performance for a trial.

These results are compatible with the view that, although folk theories about perception may be used to derive "off line" predictions about successful performance (for self and others), they might not be the only, or the most reliable guides to retrospective evaluations of performance. A full demonstration of this claim, however, is not provided here: it would require a systematic comparison between online (retrospective) and offline (attributive) forms of self-evaluation, as conducted by Koriat and Ackerman in the domain of metamemory (Koriat & Ackerman, 2010). Our results only indicate that perceivers' overconfidence in their change detection ability, as documented in Levin et al. (2000), Levin, Drivdahl, Momen, and Beck (2002) and Scholl et al. (2004), reflects their reliance on the perceived success of earlier performances, rather than exclusively on their beliefs about perception. When presented on line with evidence defeating their expectation of success, participants in our study adaptively recalibrated their norm of evaluation. It cannot be excluded, however, that the two sets of cues that we manipulated could compete with acquired beliefs about task, self-efficacy in that task or about cognitive competence. Further experiments would be necessary to assess the existence and outcome of such a competition.

Two conclusions can be drawn from the present study. First, evaluations of performance in a change detection task do not rely exclusively on analytic processes (as is also the case for memorial tasks). It is therefore compatible with the finding that subjects with no mindreading ability, such as dolphins and macaques, can still reliably evaluate their discrimination performance (Smith (2009), for a review). Second, different sources of information might respectively guide contextual norm recalibration and local confidence judgment.

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