Consciousness and Cognition 18 (2009) 569–577

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

# Perceptual illusions in brief visual presentations

Vincent de Gardelle *, Jérôme Sackur, Sid Kouider

*Laboratoire de Sciences Cognitives et Psycholinguistique, CNRS/EHESS/DEC-ENS, Paris, France*

ARTICLE INFO

*Article history:*
Received 5 December 2008
Available online 14 April 2009

*Keywords:*
Phenomenal consciousness
Access consciousness
Illusion
Partial report
Sperling

ABSTRACT

We often feel that our perceptual experience is richer than what we can express. For instance, when flashed with a large set of letters, we feel that we can see them all, while we can report only a few. However, the nature of this subjective impression remains highly debated: while many favour a dissociation between two forms of consciousness (access vs. phenomenal consciousness), others contend that the richness of phenomenal experience is a mere illusion. Here we addressed this question with a classical partial-report paradigm now modified to include unexpected items in the unreported parts of the stimuli. We show that even in the presence of unexpected pseudo-letters, participants still felt that there were only letters. Additionally, we show that this feeling reflects an illusion whereby participants reconstruct letters using partial letter-like information. We propose that the feeling of seeing emerges from the interplay between partially accessible information and expectations.

© 2009 Elsevier Inc. All rights reserved.

## 1. Introduction

To address the difficult issue of the nature of consciousness, a conceptual advance has been proposed that distinguishes between access and phenomenal consciousness (Block, 1995, 2007). While phenomenal consciousness is meant to capture the quality of first person experience, the particular "what it is like" feeling of each experience, access consciousness relates to the global use of information, its availability for control mechanisms and verbal report. Importantly, phenomenal consciousness is assumed to precede and overflow access, reflecting a rich and detailed experience which cannot be reduced to the information we can report (Block, 2007).

This distinction between two forms of consciousness has raised a great interest among researchers, as it captures much of our intuition about conscious experience. In fact, early experimental psychologists using tachistoscopic presentations had already noted that subjects had the fleeting feeling of seeing a whole complex scene, while they were able to report only a small portion of it (e.g., Dallenbach, 1920). This phenomenon has been famously operationalized by Sperling (1960), who measured the information available in briefly flashed arrays of letters. When participants were asked to report all of the letters in an array of 12 letters (i.e., 3 rows by 4 columns), they could correctly report only between 3 and 4 of them. However, when an auditory cue was introduced at the offset of the array or shortly thereafter, instructing to report specifically one of the three rows in the array (i.e., high tone for upper row, medium tone for middle row, and low tone for lower row), participants could report nearly all 4 items in the cued row. This random sampling technique yields an estimate of the information available for a short period of time after the presentation of the array. It shows that participants have more information than the 3–4 items they can ultimately report. This is in agreement with their subjective feeling. In relation to the phenomenal/access distinction, one is tempted to identify the subjective feeling of seeing a complete array with phenomenal consciousness, while performance in partial report may be considered an index of conscious accessibility.

* Corresponding author. Address: Vincent de Gardelle, Ecole Normale Supérieure, 29 rue d'Ulm, 75005 Paris, France.
*E-mail address:* gardelle@ens.fr (V. de Gardelle).

1053-8100/$ - see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2009.03.002

However, this dissociative approach has also raised several concerns. In particular, it is difficult to reconcile with studies of change and inattentional blindness showing that observers can miss massive visual events, even in central vision (Levin & Simons, 1997; Mack & Rock, 1998; O'Regan and Noe, 2001; Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1997). Therefore, alternative accounts have described the richness of our phenomenal world as a (well-founded) "illusion of seeing" (Dehaene, Changeux, Naccache, Sackur, & Sergent 2006; O'Regan and Noe, 2001). This cognitive illusion reflects viewers' over-confidence that they see the whole scene because they can at will orient attention to any location and obtain conscious information from it (Dehaene et al., 2006).

Here we propose that participants in the classical Sperling paradigm are misled by a similar type of illusion when they report experiencing a whole array of letters. We reasoned that participants can be induced to feel that they see a whole array of letters, even if one of the items in the array is not a real letter, but a letter-like symbol (Kouider et al., 2007). To test this prediction, we used a modified version of the Sperling paradigm, in which non-cued rows could now occasionally include a "pseudo-letter" (i.e., a rotated letter, see Fig. 1). Besides, although reporting letters of the cued row remained the main task, we sometimes probed participants' perception of the non-attended parts of the array, in particular for pseudo-letters, by using an additional response procedure that we termed "free subjective report" (hereafter, FSR; see Fig. 1). Importantly, we also added a backward mask to the stimulus array, to eliminate possible retinal persistence of the visual information, which is not supposed to constitute phenomenal consciousness, but rather to input the phenomenal level (Block, 2007). Because the introduction of pseudo-letters can lead participants to search for odd items, we also occasionally introduced "catch symbols" on non-cued rows. We predicted that catch symbols should be easily noticed, leading participants into expecting either letters or very different symbols. Further, we predicted that pseudo-letters would be experienced as real letters, as they carry the same low-level geometrical information, yielding to the construction of the same percept.

## 2. Experiment 1

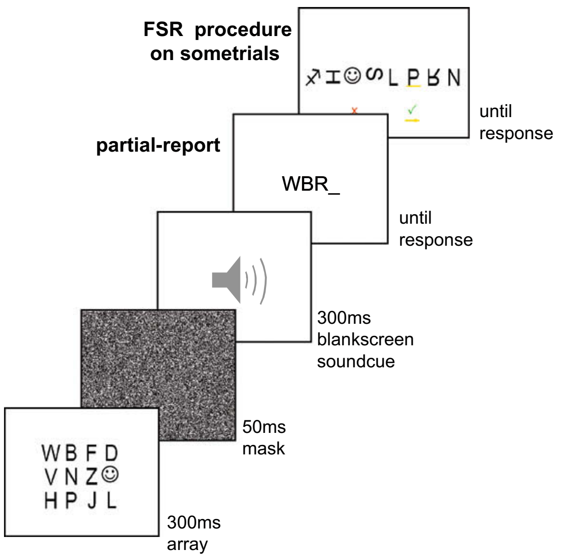
### 2.1. Methods

#### 2.1.1. Participants

Participants were 24 students (age range: 18–25 years) recruited from Paris universities. They reported normal or corrected to normal vision, and were paid for their participation.

#### 2.1.2. Stimulus

Both experiments were set up and run using the Matlab Cogent Toolbox. The stimuli appeared on a CRT 17" screen viewed at normal distance, such that the array occupied a visual angle of approximately 10°. Letters were only consonants in Arial font (X and Y were excluded). Pseudo-letters were created by randomly rotating (90°, 180° or 270°) and flipping (left-right) letters while ensuring that the result was not identical with an upright letter. For catch items we selected 19 Wingdings symbols. All visual items were coloured in 8 bits grey levels, with foreground and background colour set to 40% and 80% of maximum intensity. We wanted to use reduced contrasts to maintain task pressure on participants.




| FSR \ trial type | letter trials | catch trials | pseudoletter trials |
|---|---|---|---|
| ***Part 1: TRAINING*** | | | |
| no FSR | 90 | 0 | 0 |
| FSR | 0 | 0 | 0 |
| ***Part 2: INDUCTION*** | | | |
| no FSR | 60 | 9 | 0 |
| FSR | 12 | 9 | 0 |
| ***Part 3: TEST*** | | | |
| no FSR | 48 | 9 | 0 |
| FSR | 12 | 9 | 12 |
| *Example* | WBFD VNZG HPJL | WBFD VNZ☺ HPJL | WBFD VNZ[pseudo-letter] HPJL |

**Fig. 1.** *Left*: time-course of a trial. *Right*: summary of the design in Experiment 1. Here the numbers indicate the repartition of the trials in each part, according to the stimulation (different types of trials), and to the response procedure (with or without free subjective report – FSR).

Each trial was as follows (Fig. 1): a fixation cross (500 ms), a blank screen (500 ms), then the 3/4 array of letters (300 ms) and a backward random-noise mask (50 ms) covering the whole screen. The auditory cue (high: 1100 Hz, medium: 500 Hz, low: 150 Hz) was randomly selected and appeared at mask offset for 300 ms.

#### 2.1.3. Procedure

During the whole session, participants' main task was to report the letters of the row indicated by the auditory cue (partial report). Feedback (number of correct letters at the correct positions) was given immediately after participants validated their response. Before the main experiment, participants were trained to orient attention according to the cue sounds, with arrays containing XXXX, OOOO and TTTT randomly located (30 trials).

The experiment was divided in three parts: the first one was a classical partial-report task with arrays of letters, with no FSR, while in the second and third part we introduced in turn catch symbols and pseudo-letters in the unattended parts of the arrays, as well as the FSR procedure. The first and second parts were intended to create expectations about the possible content of the arrays (i.e., only letters in the first place, and then letters and catch symbols), while the third part contained the critical condition where we tested the perception of unexpected pseudo-letters. Each part was subdivided into 3 runs of 30 trials each. At the end of each run, participants were informed about their mean partial-report score.

At the beginning of the second part, we introduced the FSR procedure. In each run of parts 2 and 3, 11 trials out of 30 included FSR. For those trials, immediately after the partial report, participants were then presented with 3–8 items, and they were instructed to select those which were displayed in the previous array, according to their subjective feeling. Participants selected items with the mouse, or clicked on a red cross to respond "none", and validated their report with a green tick button. They were told that they were free to select as many items as wanted, or even none, and that contrary to the partial-report task, there was no matter of performance in the FSR procedure. The FSR alternatives were randomly selected among letters, pseudo-letters, and catches, while insuring that *at least* one item was indeed in the previous array. In particular, if the stimulus array included a critical item (i.e., a catch or a pseudo-letter), this critical item was always in the FSR alternatives (see below).

In the second part, critical catch trials were included by replacing one letter of the array with a catch item, on a row that was not cued for partial report. There were 6 catch trials per run, half followed by FSR. (see Fig. 1 for a summary of the design). In the third part, unbeknownst to the participants, we introduced pseudo-letter trials as a new set of critical trials (4 trials per run, all followed by FSR). In such a case, the alternatives of the FSR necessarily contained either the exact same pseudo-letter or its real letter counterpart. This manipulation allowed us to test not only whether participants saw the pseudo-letter, but also whether they would in fact report seeing it as its upright counterpart. The real letter and its associated pseudo-letter were not proposed as concurrent alternatives during the same FSR. This was done to avoid subjects from being focused on the comparisons between real and pseudo-letters, and then to develop expectations on the presence of pseudo-letters in the array. At the end of the experiment, participants were debriefed and asked whether they noticed the presence of catches and pseudo-letters in the arrays, and how they used the FSR procedure.

## 3. Results

### 3.1. Partial-report scores

On average, participants reported correctly 1.47 letters per row (min = 0.79, max = 2.13, sd = 0.29), which corresponds to an estimated average of 4.41 items in the whole array. Partial-report scores (see Table 1) show that introducing catch symbols in some trials impaired performance, though participants were able to recover in the third part. This effect was assessed by a significant interaction ($F(1, 23) = 20.48$, $p < .001$) between part and trial type (array with letters only, or with a catch). Additionally, we found that the introduction of pseudo-letters in the third part also had a significant impact on partial report: in particular, partial-report scores on pseudo-letter trials were worse than those on catch trials ($F(1, 23) = 7.44$, $p < .05$), even though most participants did not report perceiving pseudo-letters, as evidenced by both the debriefing and the FSR results (see below). This effect can be related to recent finding showing that even subliminal information outside the focus of attention can impair performance on a central task (Bressan & Pizzighello, 2008; Tsushima, Sasaki, & Watanabe, 2006).

### 3.2. Free subjective reports

During the debriefing, most participants reported being cautious about the use of the FSR procedure. Indeed, 34% of the FSR trials led to no selection. Besides, most participants reported having seen easily the catch symbols, but no pseudo-letters

**Table 1**
Partial-report scores (number of correct letters at correct positions) and standard errors (SE) for the different types of trials and parts of Experiment 1. Note that the first part only contained letter trials and the second part only contained letter or catch trials, but no pseudo-letter trials.

| Partial-report scores (SE) | Part 1 | Part 2 | Part 3 |
|---|---|---|---|
| Letter trials | 1.41 (0.06) | 1.56 (0.06) | 1.56 (0.07) |
| Catch trials | – | 1.15 (0.09) | 1.53 (0.08) |
| Pseudo-letter trials | – | – | 1.30 (0.11) |

**Table 2**
Analyses of the free subjective reports (FSR) in Experiment 1, for the different critical catch and pseudo-letters items: the perception index (i.e., hit rate minus false alarms rate) and the corresponding $d'$ (assessed at the group level). For pseudo-letters, we distinguished two situations: trials where pseudo-letters are proposed as pseudo-letters in the FSR (pseudo), and trials where pseudo-letters are proposed as real letters in the FSR (real).

| FSR alternatives | Part | | HIT rate – FA rate | | Corresponding $d'$ |
|---|---|---|---|---|---|
| | | | Mean | $p$ | |
| Catch symbols | Part 2 | | 0.53 | <0.001 | 1.74 |
| | Part 3 | | 0.25 | <0.001 | 0.88 |
| Pseudo-letters | Part 3 | (Pseudo) | 0.02 | ns | 0.12 |
| | | (Real) | 0.23 | <0.001 | 0.98 |

in the arrays. To assess how participants perceived catch and pseudo-letters items in the unattended parts of the stimulus array, we devised an index of perception on FSR results, by treating each alternative as a probe, to which the participants responded "yes, it was in the stimulus" or "no, it was not here". We computed the hit rates and the false alarm rates separately for catch items and pseudo-letters, and we used the difference between the hit rate and the false alarm rate during FSR as an index of perception.[1] We ran planned $T$-tests (one-tailed, across participants) to assess if this index was positive in the different conditions. Results of this analysis are reported in Table 2, and are summarized below.

#### 3.2.1. Catches

Catch items were reliably perceived by participants. Besides, perception was higher in the second than in the third part (effect of part: $F(1, 23) = 16.4$, $p < .001$). Corresponding $d'$s were, respectively 1.30 and 0.88.

#### 3.2.2. Pseudo-letters

In agreement with participants' comments during debriefing, pseudo-letters in the arrays were poorly detected as such: when they were proposed as pseudo-letters in the FSR, that is when the very same pseudo-letter item was proposed in the FSR alternatives, participants' sensitivity was not significantly greater than zero ($d' = 0.12$; $T < 1$). However, when the real letter counterpart of the pseudo-letter was proposed in the FSR, participants' sensitivity significantly increased, and it became reliably positive ($d' = 0.98$; $T = 4.7$, $p < .001$). This effect of the mode of presentation of the pseudo-letter was significant ($F(1, 23) = 8.2$, $p < .01$), reflecting that participants used the same information concerning a pseudo-letter in the stimulus more accurately when they were proposed a real letter than when they were proposed the very same item, that is a pseudo-letter.

### 3.3. Pseudo-letters illusorily seen as real letters

The preceding analyses suggest that the presence of a pseudo-letter in the array leads participants to select the corresponding real letter counterpart during the FSR procedure. To ensure that this effect was not due to a global bias to report letters, and to confirm that pseudo-letters were truly seen as real letters, we regressed this "illusion effect" (i.e., the tendency to report the corresponding real letter when there was a pseudo-letter in the stimulus) against the False Alarm rate for letters, which reflects the tendency to select letters that were absent from the array (see Fig. 2). This linear regression analysis was run across participants on these critical pseudo-letter trials ($r = .40$; $slope = 0.54$, $T = 4.0$, $p < .001$; $intercept = 0.15$, $T = 3.1$, $p < .01$). Crucially, the intercept was significantly positive, revealing a perceptual illusion of real letters. Indeed, this intercept is an absolute measure of the illusion, because it measures, for an ideal observer that would always be correct in the selection of letters in the FSR, the tendency to see a letter when in fact its corresponding pseudo-letter appeared in the array.

## 4. Discussion

In this first experiment, in agreement with our predictions, we found evidence suggesting that participants illusorily perceived pseudo-letters in the unattended rows of the array as real letters. Indeed, our regression analysis has shown that even an ideal observer, i.e., an observer that would never hallucinate a particular letter if it was not present in the array, would still perceive pseudo-letters as real letters. Thus it seems that *some* information from the unattended parts of the array could reach consciousness. However, conscious access to this information was heavily biased by participants' expectations: as they were lead to expect either letters or catch symbols, they perceived pseudo-letters as letters. Indeed, by design, pseudo-letters share some lower level geometrical features with real letters, and could thus easily be construed as such.

Thus it seems that when participants have very strong top-down expectations about the possible content of a scene this can inform the subjective feeling of what is to be seen in the stimulus. In a second experiment, we wanted to assess whether we could manipulate the expectations, and in particular whether we could abolish the illusion of seeing only letters. To do so,

[1] Because of the nature of the FSR procedure (i.e., the fact that there is no forced-choice), it was not possible to compute a $d'$ index for each cell, since there were too many cells with null false alarm rates, in which we could not compute $d'$ values. The $d'$ scores were thus only assessable at the group level.

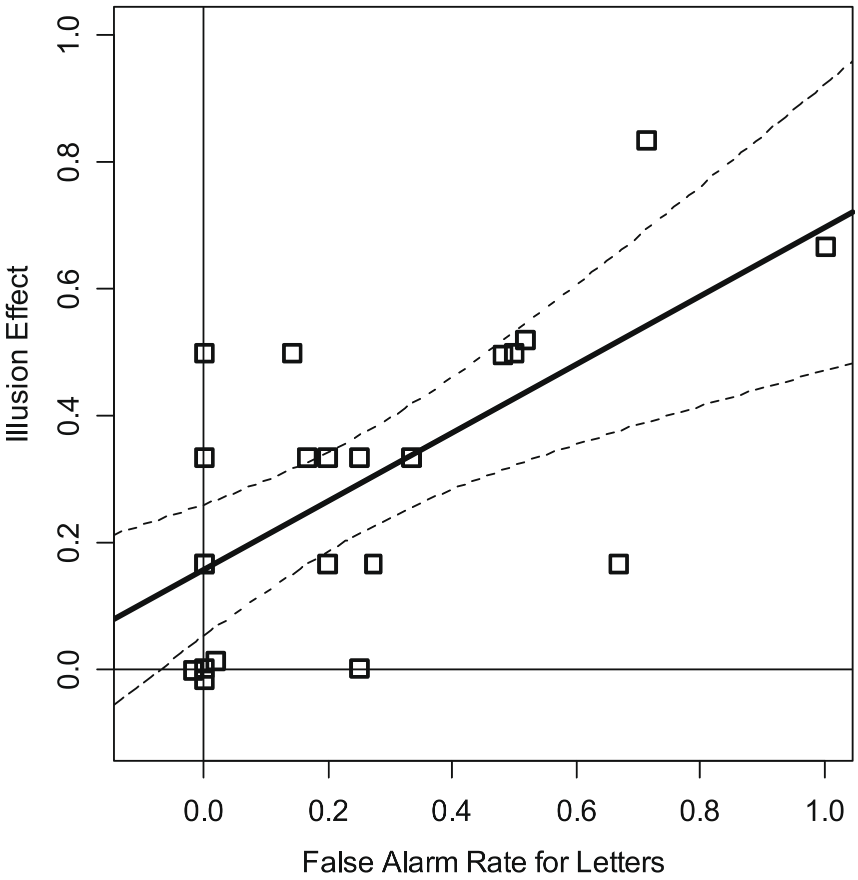



**Fig. 2.** Regression between participants, on critical pseudo-letters trials (Experiment 1). *X-axis*: false alarms rate for letters, i.e., proportion of letters that are chosen although they were not in the stimulus array. *Y-axis*: illusion effect, i.e., proportion of pseudo-letters that are chosen as real letters, although the corresponding real letters were not in the stimulus. Dot lines show confidence interval (95%) around the regression line. The positive intercept shows that the illusion effect holds even for a perfect observer who makes no false alarms for letters.

we organized the experiment in two sessions, the first one being a replication of Experiment 1, while the second one was devised to test if the illusion would still be present when participants were fully informed about the possible all stimuli used in the experiment. Thus, at the beginning of the second session, participants were explicitly told about the presence of pseudo-letters, and they were asked to study a printed copy of all of the possible stimuli (letters, pseudo-letters, and catch items) used in the experiment.

Furthermore, we tested on a trial by trial basis whether participants had this subjective feeling of seeing the whole array as an array of letters. To this end, we modified the FSR procedure, so that in addition to a list of specific items it included a button "There were only letters in the array". Thus, we could assess whether participants report this feeling of seeing only letters even when the stimulus array included catch symbols or pseudo-letters.

Finally, in this second experiment we wanted to rule out a possible methodological objection: an alternative explanation for our results might be that there is no illusion whatsoever, but simply that participants misunderstood the instructions, and thought that real letters were appropriate choices in the FSR when they had perceived a pseudo-letter. For instance, participants might have thought that an inverted "D" is still a "D". This interpretation seems implausible considering the instructions we gave to participants. However, in order to definitely rule out this possibility, in the second experiment we devised a post-test debriefing included specific questions focused on that point.

## 5. Experiment 2

### 5.1. Methods

#### 5.1.1. Participants

Participants were 21 students (age range: 18–25 years) recruited from Paris universities. They reported normal or corrected to normal vision, and were paid for their participation.

*5.1.2. Stimulus*

The stimuli were the same as in Experiment 1, except for two minor modifications. The contrast was increased and foreground and background colours were set to 20% and 90% of maximum intensity, respectively (as opposed to 40% and 80% in Experiment 1). Also, the cue sounds were made more distinctive (high: 1500 Hz, medium: 500 Hz, low: 100 Hz) to avoid possible confusion.

*5.1.3. Procedure*

For the first session, the same procedure was used as in Experiment 1, except that the FSR included a possibility for the participant to respond specifically that there were "only letters" in the previous array. Indeed, it was still possible that participants in Experiment 1 deliberately decided to report letters when they consciously saw pseudo-letters, because of a misunderstanding of the instructions. This additional button was thus set up to assess this possibility. Further, at the end of the first session, participants were debriefed and asked specifically about this possible response strategy.

For the second session (which took place within a week after the first session), participants did the same training and first part as in Experiment 1. Then, they were told that in the previous session there were many pseudo-letters that they may have missed because they did not expect them, and they were given a printed copy of all the possible stimuli (letters, pseudo-letters, and catch items) that they could encounter during the rest of the experiment. They were instructed to carefully study these items for 5 min. before beginning parts 2 and 3. The second and third part of Experiment 2 both included catch trials and pseudo-letter trials. Thus in the second session there were no runs with only catch symbols and no pseudo-letters. Parts 2 and 3 of the second session had the same structure as part 3 of the first session.

## 6. Results

*6.1. Partial-report scores*

On average, participants reported correctly 1.52 letters per row (min = 0.98, max = 2.17, sd = 0.29), which corresponds to an estimated average of 4.56 items in the whole array. Partial-report scores (see Table 3) for the first session replicated the findings of the Experiment 1: compared to trials with only letters, catch symbols introduced in the second part impaired the partial reports, though participants were able to recover in the third part (interaction between part and trial type: $F(1, 20) = 6.86$, $p < .05$). As in Experiment 1, pseudo-letters in the third part significantly impaired partial-report scores, even compared to catch trials ($F(1, 20) = 5.38$, $p < .05$) though most participants did not report perceiving pseudo-letters, as evidenced by both the debriefing and the FSR results (see below).

In the second session, partial-report scores globally increased (from 1.43 to 1.62, main effect of session: $F(1, 20) = 48.59$, $p < .001$), and corresponded approximately to the level of performance achieved by participants at the end of the first session (see Table 3). The pattern of performance was qualitatively similar to the one in the first session. However, we did not find in the second session the interaction between parts and catch vs. letter trials reported above. In fact, an ANOVA between trial types (i.e., letters, catches, pseudo-letters) and parts (second and third) revealed main effects of trial types ($F(2, 40) = 4.75$, $p < .05$) and parts ($F(1, 20) = 4.81$, $p < .05$), but no interaction. Yet, when we compared the two sessions, the triple interaction between parts, trial type, and session was not significant. Thus, the additional instruction at the beginning of the second session did not impede participants' score on the main partial-report task, suggesting that they were treating the visual stimulus all the same in both sessions.

*6.2. Free subjective reports*

Here again, during debriefing most participants reported being cautious about the use of the FSR procedure. Indeed, more than a half of the FSR trials led to no selection (52% in the first session, 50% in the second), and even when there were only letters in the array, participants used the specific "only letters" response in just 65% of the trials (66% in the first session, 64% in the second). Importantly, when asked for their response strategy, all participants responded that when of if they saw a rotated letter, they reported it as such, and not as its real letter counterpart. This reasonably rules out the possibility that we discussed above, that the illusion effect was due to some misunderstanding of the instruction. Besides, as in Experiment 1, most participants reported having seen easily the catch symbols, but almost no pseudo-letters in the arrays. Interestingly, this was also true for the second session, during which they were fully informed about the content of the arrays. In order to

**Table 3**
Partial-report scores in Experiment 2.

| Trial type | Session 1 | | | Session 2 | | |
|---|---|---|---|---|---|---|
| | Part 1 | Part 2 | Part 3 | Part 1 | Part 2 | Part 3 |
| Letters | 1.40 (0.03) | 1.48 (0.03) | 1.58 (0.03) | 1.70 (0.03) | 1.60 (0.03) | 1.65 (0.04) |
| Catch | – | 1.04 (0.06) | 1.40 (0.06) | – | 1.46 (0.06) | 1.60 (0.07) |
| Pseudo-letter | – | – | 1.16 (0.07) | – | 1.24 (0.07) | 1.49 (0.07) |

**Table 4**
Perception index in the FSR, Experiment 2.

| | FSR alternatives | Part | | HIT rate vs. FA rate | | Corresponding d' |
|---|---|---|---|---|---|---|
| | | | | Mean | p | |
| Session 1 | Catch symbols | Part 2 | | 0.54 | <0.001 | 1.68 |
| | | Part 3 | | 0.21 | <0.001 | 0.66 |
| | Pseudo-letters | Part 3 | (Pseudo) | 0.08 | <0.05 | 0.57 |
| | | | (Real) | 0.01 | ns | 0.04 |
| Session 2 | Catch symbols | Part 2 | | 0.48 | <0.001 | 1.66 |
| | | Part 3 | | 0.23 | <0.001 | 0.94 |
| | Pseudo-letters | Part 3 | (Pseudo) | 0.11 | <0.001 | 0.55 |
| | | | (Real) | 0.02 | ns | 0.11 |

objectively assess the reports obtained during debriefing, we now turn to the analyses of perception based on the same index as in Experiment 1, that is, the difference between hit rates and false alarm rates in the FSR (Table 4).

### 6.2.1. Catches

As in Experiment 1, catch items were reliably perceived by participants. An ANOVA with parts and sessions as within-participants factors revealed a main effect of part on perception ($F(1, 20) = 31.2$, $p < .001$), but no effect of sessions and no interaction (both Fs < 1). This confirms that catches were better perceived in the second part than in the third part, irrespective of session. Corresponding *d*'s were 1.66 in the second part and 0.77 in the third part.

### 6.2.2. Pseudo-letters

Perception of pseudo-letters was reliably positive and corresponded to $d' = 0.32$ at the group level. Participants' perception of pseudo-letters in the arrays was not significantly different during the first and second session, and that indicates that informing participants about the possible presence of pseudo-letters, and the study of the exhaustive list of stimuli was not sufficient to modify perceptual biases. Importantly, sensitivity to pseudo-letters was the same whether the pseudo-letter itself or its real counterpart was presented in the FSR alternatives and no interaction was found either with sessions. This is an important difference from the results of Experiment 1, where participants responded more often that they saw a pseudo-letter when it was proposed as its real counterpart than when it was present as such in the FSR. One possible explanation for this difference may be an influence of the "letter only" button introduced in the FSR of Experiment 2. Indeed, this possible response may have affected participants' confidence in their perception of the degraded visual stimulus, and accordingly they might have been more conservative in the selection of FSR alternatives. However, the presence of a bias of that sort in Experiment 1 was not affecting the regression analysis which showed the illusion effect. Thus, we expect to replicate the illusion effect found in the regression analysis in Experiment 2, at least for the first session.

We analysed more specifically in an ANOVA the use of the "letters only" response, as a function of session and trial type. Participants used the "letters only" response in 65% in the letter trials (66% in the first session, vs. 64% in the second session), in 50% of the pseudo-letter trials (51% vs. 48%), and in 26% of the catch trials (25% vs. 28%). The only significant effect was the main effect of trial type ($F(2, 40) = 49.48$, $p < .001$), and there were no effect of session ($F < 1$) and no interaction between sessions and trial types ($F < 1$). In other words, although in the second session participants perfectly knew that pseudo-letters were presented in the arrays, they reported having seen only letters as often as in the first session. These performances revealed that even when their presence is known by the participants that are conservative in their judgments, critical items might still be unnoticed and participants might still commit themselves and report that there were "only letters" in the stimulus.

## 6.3. Pseudo-letters illusorily seen as real letters

As in Experiment 1, we regressed the "illusion effect" (i.e., the fact that one subject reports a real letter when in fact there was the pseudo-letter in the stimulus) on the False Alarm rate for letters, to assess its magnitude in an ideal observer (see Fig. 3). We run two linear regression analysis across participants on critical pseudo-letter trials, separately for the first session ($r = 0$; $slope = 0.05$, $T < 1$, $p > 0.5$; $intercept = 0.10$, $T = 2.5$, $p < .05$), and for the second session ($r = .16$; $slope = 0.45$, $T = 2.8$, $p < .01$; $intercept = 0.09$, $T = 3.0$, $p < .01$). Again, we were particularly interested by the intercept, which was significantly above zero in both sessions, indicating that in both cases an ideal observer that would make no false alarm for letters would still illusorily perceive a pseudo-letter as its real upright counterpart. The two intercepts did not significantly differ.

## 7. Discussion

Several theoretical frameworks propose that when strong biases point to the wrong interpretation of a sensory stimulation, observers can erroneously experience an event for another. This suggests that "perception is an inference", an idea that goes back to von Helmoltz, and is now widely reflected in modern works including Bayesian models of perception using pre-

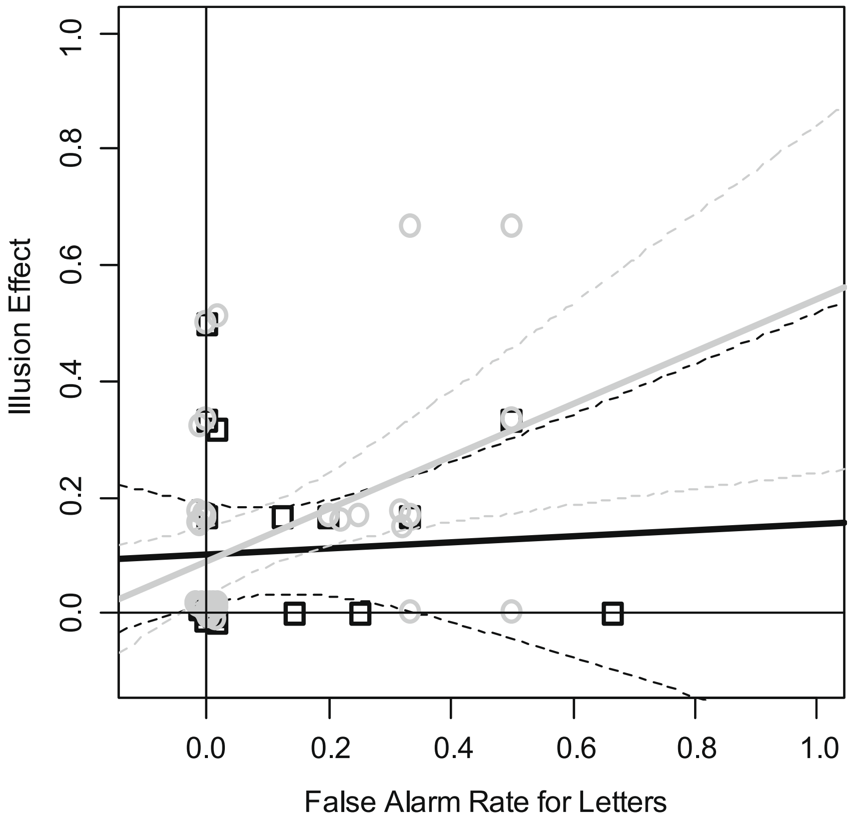



**Fig. 3.** Regression analyses in Experiment 2, between participants, on critical pseudo-letters trials, separately for the first session (dark grey) and the second session (light grey). Here again, in both sessions the positive intercepts show that even an ideal observer would have the illusion effect.

dictive coding (Friston, 2005; Kersten, Mamassian, & Yuille, 2004; Rao & Ballard, 1999; Summerfield, Trittschuh, Monti, Mesulam, & Egner, 2008; Weiss, Simoncelli, & Adelson, 2002). In workspace theories of consciousness, access to the workspace and thus conscious perception is also shaped by the context in which the stimulus appears (Baars, 1997).

Here, we presented participants with flashed arrays of letters and engaged them in a partial-report task, while sometime introducing some non-letter symbols on the non-cued rows. Catch items were easily detected and led participants to expect either real letters or very different symbols. In stark contrast, pseudo-letters were hardly noticed, although they were presented for 300 ms too, and participants often confirmed that there were only letters in the stimulus array even if this was not the case. Importantly, as shown by the analysis of the free subjective report, participants actually tended to perceive the pseudo-letters as real letters. We insist that this illusory perception occurred while subjects used the FSR procedure cautiously, reliably detected catch items, and even when regressed to an ideal observer. Importantly, this phenomenon still holds even when participants were fully aware that they might be misled in their perception.

According to us, this effect results from the interaction between perceptual difficulty and the strength of priors: the poorer the evidence, the more the elaboration of the percept will depend on priors. Priors can be depicted as strong internal representations and/or context-dependant expectations acting as attractors that bias perceptual mechanisms (e.g., Summerfield & Koechlin, 2008). This process usually benefits the observer, as it allows for observers to make fast decisions on complex but ecologically relevant visual stimuli (Thorpe, Fize, & Marlot, 1996). Here, letters probably benefited from high relevance caused by strong expertise developed by years of reading. Thus, as participants are biased towards treating letter-like symbols as real letters, they illusory perceived pseudo-letters as their upright counterpart. One interesting hypothesis related to this issue is that using unpractised symbols (e.g., for instance unknown alphabets) in our paradigm will lead participants to notice the appearance of rotated items, without illusion.

Our results are consistent with previous findings (Kouider & Dupoux, 2004) showing that a false colour word (e.g., GEREN) can produce a Stroop effect comparable to a real colour word (GREEN), but only under conditions of perceptual difficulty, because of short presentation delays or pattern masking, and only when participants are expecting to see real colour words. Similarly, in our experiment participants' priors favoured letters compared to pseudo-letters, and the stimuli were difficult to see because of the reduced contrast and the additional backward mask. However, one notable difference is that the illusion effect in our Experiment 2 could not be modulated just by the instruction given to the subjects. One explanation for that could be that letter detectors are more encapsulated than word form representations, and that accessing words might be more permeable to top-down modulation. There is also a notable difference between the two studies, since words were centrally presented in the study by Kouider and Dupoux, while the partial-report technique allowed us to introduce critical pseudo-letters outside the focus of spatial attention.

Although it is not directly demonstrated by the present study, our findings suggest that this illusion occurs directly and automatically during the elaboration of the percept, and not during a post-perceptual stage of introspection triggered by the report. Indeed, in the second session of Experiment 2 participants were fully aware of the possible presence of pseudo-letters, and even if partial report of letters remained the main task, their introspection could be attuned to detect odd items in the arrays. In that case the illusion would have been eliminated, contrary to what we found. In other words, it suggests that our subjects truly experienced letters, rather than experienced only the feeling of having seen letters (see Block, 2007). Nonetheless, it is possible that the illusion reported here also benefits from the cognitive illusion of seeing (see O'Regan and Noe, 2001; Dehaene et al., 2006). Indeed, the construction of the perceptual content might be also modulated by the confidence that "we saw the whole scene". Specifying further how cognitive factors might impact the dynamics of perceptual elaboration will be an interesting question for future research on visual consciousness.

Finally, our findings challenge the view that there is something like a rich phenomenology in brief visual presentations such as those used in the Sperling task, and more generally in our visual world (Block, 2007). Rather, the present results suggest that visual experience captures only a limited set of all the information in the environment: attentional selection allows only a limited part of the information to enter working memory (see for instance Rayner, 1975). Yet, importantly, this limitation remains unnoticed, and the feeling of seeing the whole array holds even after the decay of the information in the array. Such a phenomenon is probably produced by a process that takes over the limitation of top-down access, and constructs an enriched perceptual experience from partial information in the periphery. This process relies on low-level information (in our experiment the basic geometrical features of the array) to fill-in the whole visual scene, and it includes expectations and context-related information (here the letter category). Thus, we envision phenomenology as a sophisticated elaboration based on partially accessible or preconscious information and priors about what there is to be seen in the scene. That is, visual experience of the whole scene, or phenomenology, is not more basic or immediate than conscious access. Quite the contrary, it rather reflects a more complex mode of access to the visual world.

## Acknowledgements

We thank Emmanuel Dupoux for very useful discussions. This work was supported by a doctoral fellowship from the Direction Générale de l'Armement (France) to Vincent de Gardelle.

## References

Baars, B. J. (1997). In *The theater of consciousness*. Oxford University Press.
Block, N. (1995). On a confusion about a function of consciousness. *Behavioral and Brain Sciences, 18*, 227–247.
Block, N. (2007). Consciousness, accessibility and the mesh between psychology and neuroscience. *Behavioral and Brain Sciences, 30*, 481–548.
Bressan, P., & Pizzighello, S. (2008). The attentional cost of inattentional blindness. *Cognition, 106*, 370–383.
Dallenbach, K. M. (1920). Attributive vs. cognitive clearness. *American Journal of Psychology*, 183–230.
Dehaene, S., Changeux, J.-P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences, 10*, 204–211.
Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society of London Series B – Biological Sciences, 360*, 815–836.
Kersten, D., Mamassian, P., & Yuille, A. (2004). Object perception as Bayesian inference. *Annual Review of Psychology., 55*, 271–304.
Kouider, S., de Gardelle, V., & Dupoux, E. (2007). Partial awareness and the illusion of phenomenal consciousness. *Behavioral and Brain Science., 30*, 510–511.
Kouider, S., & Dupoux, E. (2004). Partial awareness creates the "Illusion" of subliminal semantic priming. *Psychological Science, 15*(2), 75–81.
Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin and Review, 4*(4), 501–506.
Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.
O'Regan, J. K., & Noe, A. (2001). A sensorimotor approach to vision and visual consciousness. *Behavioral and Brain Sciences, 24*, 883–975.
Rao, R. P. N., & Ballard, P. H. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience, 2*(1), 79–87.
Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 75–81.
Rensink, R., O'Regan, K. J., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*, 368–373.
Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences, 1*(7), 261–267.
Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74*(498) [whole issue].
Summerfield, C., & Koechlin, E. (2008). A neural representation of prior information during perceptual inference. *Neuron, 59*(2), 336–347.
Summerfield, C., Trittschuh, E. H., Monti, J. M., Mesulam, M. M., & Egner, T. (2008). Neural repetition suppression reflects fulfilled perceptual expectations. *Nature Neuroscience, 11*(9), 1004–1006.
Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature, 381*, 520–522.
Tsushima, Y., Sasaki, Y., & Watanabe, T. (2006). Greater disruption due to failure of inhibitory control on an ambiguous distractor. *Science, 314*, 1786–1788.
Weiss, Y., Simoncelli, E. P., & Adelson, E. H. (2002). Motion illusions as optimal percepts. *Nature Neuroscience, 5*(6), 598–604.