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Consciousness without report: insights from summary statistics and inattention 'blindness'

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We contrast two theoretical positions on the relation between phenomenal and access consciousness. First, we discuss previous data supporting a mild Overflow position, according to which transient visual awareness can overflow report. These data are open to two interpretations: (i) observers transiently experience specific visual elements outside attentional focus without encoding them into working memory; (ii) no specific visual elements but only statistical summaries are experienced in such conditions. We present new data showing that under data-limited conditions observers cannot discriminate a simple relation (same versus different) without discriminating the elements themselves and, based on additional computational considerations, we argue that this supports the first interpretation: summary statistics (same/different) are grounded on the transient experience of elements. Second, we examine recent data from a variant of 'inattention blindness' and argue that contrary to widespread assumptions, it provides further support for Overflow by highlighting another factor, 'task relevance', which affects the ability to conceptualize and report (but not experience) visual elements.

This article is part of the theme issue 'Perceptual consciousness and cognitive access'.

1. Introduction

A major debate on the nature of visual consciousness is whether it is exhausted by cognitive access and thus can be operationalized by direct report measures or whether it *overflows* it. The *Overflow* position has been proposed by Ned Block, who argued that a distinction is to be made between phenomenal experience and cognitive access, as while the two often go together, they can also dissociate [1–4]. The dissociation that attracted the most attention and debate is that of phenomenal experience without cognitive access—a case of consciousness that overflows report, as suggested by some experimental data [2,4–6]. Countering the plausibility of this dissociation—a number of prominent articles have opposed the Overflow explanation of the above findings, proposing instead a no-Overflow (or *Impoverished Consciousness*) view. On this view, visual consciousness is severely limited by the attentional focus and by the capacity of the working-memory system (or Global-Workspace; [7–10]). For example, Cohen & Denett [9] have argued that the rich phenomenal visual experience we believe we have is only present at the focus of attention, with the rest of the visual field being blurred and, to a large degree, visually undetermined (see also [10]). The gap between this reality and our 'rich-experience' belief is therefore to be understood as a type of illusion caused by our continuous attentional scanning of the environment and (at any moment) experiencing a high visual resolution at the location we scan—a type of 'refrigerator-light illusion' [11].

Both sides of this debate have deployed a number of philosophical arguments and have appealed to empirical evidence to support their positions. Here we focus on the empirical evidence (but see also [2,10,12–19], for the philosophical arguments). The key evidence thought to support and motivate the no-Overflow position centres around two striking attentional phenomena: *change-* and *inattentional* blindness [20]. Change blindness (*CB*) occurs when a complex visual array is repeated after a brief blank interval with a small (but easily visible) change of detail. In such conditions observers are typically unable to detect the change, unless they happen to fixate on (or attend to) its location [21]. Inattentional blindness (*IB*) occurs when the task manipulates attention away from a prominent visual event (say a gorilla walking among a group of basketball players) with observers often failing to notice the prominent event and responding with surprise when it is brought to their attention [22]. Both *CB* and *IB* are therefore aimed to demonstrate that consciousness is extremely limited by attentional focus.

Empirical evidence *favouring* the Overflow position involves a number of variations of the seminal Sperling paradigm [23] and of divided attention paradigms ([24]; see [25] for review). In Sperling-type experiments observers are able to only report 3–4 items out of a visual array of 12 items in free report, but can report any item, if cued in time, after the display disappears (see [26,27], for more recent experiments, and [4] for review). Moreover, it is typically the case that the observers report seeing all items (i.e. they had a rich experience), but they 'lost' them before they were able to report [23]. In the divided attention paradigm, some visual discrimination (pink versus orange, or vehicle versus animal) can be performed outside the focus of attention, which is manipulated by an attention-demanding task (e.g. [24,28]). Both of these experimental paradigms are therefore aimed to show that conscious experience can take place outside the focus of attention.

Neither the pro- nor the no-overflow evidence are conclusive and a number of objections have been raised against each (see, e.g., [4,15]). For example, one can discount anti-Overflow CB-type arguments, by assuming that phenomenal experience is fragile and thus easily overwritten/erased by a novel display [29]. Similarly, one can seemingly discount the Sperling-type evidence by assuming that, in these tasks, the specific items (letters or shapes) are maintained in an unconscious iconic register and are only rendered conscious in a post-diction manner by the cue ([15]; but see [19]).

The aim of this paper is to examine the implications of some new psychophysical studies from our laboratories, which together with data from visual neuroscience and other behavioural studies, may allow us to refine the case for the Overflow position. We start with a review of a study [30], in which we used a Sperling type of experiment with coloured letters, and we showed that observers can report, in addition to about three letters, a summary statistic—the colour diversity (CD)—of the visual display. We discuss two interpretations of these results and present new data supporting a mild Overflow account. Finally, we examine data from a novel set of studies, which show a bare-bones form of 'blindness', which in many ways resembles IB [31–33], and argue that, unlike what is usually assumed, IB may actually support making a distinction between access and phenomenal consciousness.

2. Summary statistics outside the attentional focus

In a previous study, we argued that, when carrying out a Sperling-type task, observers have a transient awareness of some visual properties (colours) of some unattended letters, which they cannot report. To achieve this, we modified the Sperling experiment in the following way [30]. First, we presented a pre-cue before the onset of the display, indicating the row from which the letters should be memorized for future recall. This procedure focused observers' attention on a specific row, and thus diverted focal attention from the rest of the array. Second, we used multiple-colour arrays, which on different (randomized) trials had high or low colour diversity (figure 1).

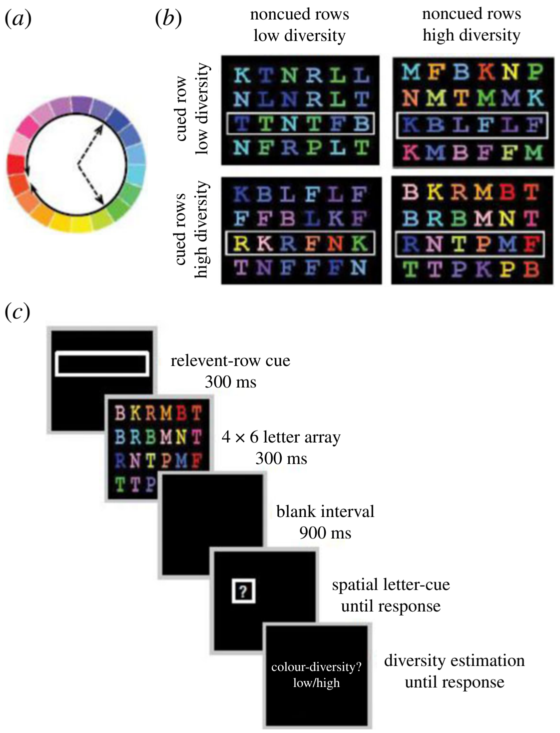

Figure 1. Experimental design of a modified Sperling task with colour letters; reproduced from Bronfman *et al.* [30]. (*a*) The colour wheel from which the colours of the letters were randomly sampled. On high-diversity trials, colours were sampled from the entire colour-wheel spectrum, while on low-diversity trials, they were sampled from a narrow range of adjacent colours (only 1/3 of the wheel), (*b*) Illustration of the four trial types comprising two levels of colour diversity (low/high) for the cued row and (independently) for the non-cued rows, (*c*) flow diagram of a trial. Participants were presented with a salient cue (white rectangle), indicating the row to which attention should be directed. Following, a 4 × 6 colour letter array appeared for 300 ms, after which a 900 ms blank interval appeared. A letter cue then indicated the letter that observers had to report. (Online version in colour.)

While the primary task, which the participants performed and for which they received feedback and reward, was to report a cued letter from within the pre-cued row (figure 1*c*), on some trials they were also probed about the colours of either the pre-cued (focal) *or* the non-cued (non-focal) letters (this was done exclusively, on different blocks). In particular, observers were required to indicate whether the colour diversity (CD) of the unattended letters was high or low (see figure 1*a*,*b* for a description of how the colours were generated, so as to create high/low CD, in either the cued row or in the non-cued row, independently).

The experimental results showed that observers were able to correctly detect the colour diversity of the unattended letters (67% in Exp. 1 and 62% in Exp. 3, which involved a stricter manipulation of CD; chance level = 50% (see Bronfman *et al.* [30]; supplementary materials). Importantly, there was no difference in letter recall accuracy between experimental blocks that only tested (the primary task of) letter recall and blocks where both the letter- and the CD task were probed, indicating that the colour task did not divert attentional resources from the letter task; also the performance on the letter task was far from the ceiling and close to the typical capacity estimate (of about three items) that is obtained in such tasks [34]. This indicates that while observers focus their attentional resources on a row of letters (for encoding them into WM), they are also able to report a high-order statistical property of the non-focal stimuli (colours). Recently, this result has also been replicated in another laboratory [35].

On its own, this result does not establish the Overflow conclusion—that observers experienced (even transiently) the colours of individual letters at non-focal locations. This is because a slightly modified no-Overflow view can concede that summary statistics, but not specific visual elements, can be extracted and experienced outside attentional focus [20,35]. This interpretation is also consistent with previous studies that have shown that observers can rapidly evaluate the average size of a set of objects ([36]; see also [37], and [38] for extension to other visual properties, such as orientation and emotional expression), although they cannot report whether a specific element is present or not. Thus, the average size (or average orientation or emotional expression) are summary statistics, which can be rapidly extracted from a visual display that contains a set of elements and can be represented with reduced attention [39,40]. Note that this does not show that the visual properties of the elements are not (at least momentarily) experienced, and possibly not encoded in WM and thus are unavailable for recall. By this interpretation then, colour diversity (*CD*) is another such summary statistic, albeit a more complex (second-order) statistic, which is analogous to variance; this is relevant to the Overflow debate because there is a simple neural mechanism—population averaging [41–43], which can recover the average of a set from highly degraded (blurred) representation of the elements. As we will show in §4, this is not the case for the CD.

Thus, there are two interpretations regarding the nature of the phenomenal experience, which grounds the summary statistic *CD* judgement. The first is the Overflow interpretation, according to which *CD* discriminations are grounded on a conscious, albeit *transient*, experience of some specific colours, with enough differentiation to allow the computation of *CD* to be carried out. The second, no-Overflow interpretation, asserts that the *CD* judgement is mediated solely by unconscious representations of the unattended colours outside of the attentional focus, and the judgement of high/low *CD* is not accompanied by any experience of the individual elements' colour. Put differently, this suggests that *it is possible to experience a relation, without experiencing the relata*. At least for cases such as colours or shapes, we find this assertion at odds with visual phenomenology; however, we will not rely on these considerations here (but see Bronfman *et al.* [19], for some arguments to this extent). Instead, we present an empirical test of one version of the relation-without-relata interpretation (§3) and briefly outline a computational argument for the Overflow interpretation, based on the precision of the representation of the colour elements and its implication to their conscious status (§4).

3. Can one experience a relation without experiencing the relata?

We set up to test the no-Overflow interpretation of the [30] results, according to which one can experience a relation (such as CD) without discriminating and experiencing its underlying relata, in a simplified experimental context. Note that in [30] the task design includes WM overload (limiting the ability to encode individual elements), and therefore the fact that people cannot report the individual items is expected and stands in contrast to remarkable ability to make CD discriminations. This contrast could mean that the experience of the summary statistic (relation) and of the elements (relata) dissociate, as per the non-Overflow interpretation, or that both the relation and the relata are experienced (albeit one of them transiently), as per the Overflow interpretation. There are two ways in which one can probe these issues further. One is to replace the WM load with an attentional one, using a divided attention task [24,28]. Here the rationale is to probe if, in 'near absence of visual attention' but without the WM load that blocks encoding into WM, observers can still report a relation without being able to report the relata. The second way to probe this potential dissociation between the experience of (and ability to discriminate) the elements and their relation is to limit perception on the basis of a data-driven manipulation (e.g. masking). While this test is not a critical one for the non-Overflow interpretation, note that it is critical for the Overflow one. If we find under masking that observers can report a relation better than they can report the elements that constitute that relation, this would pose a problem to the Overflow position, which posits that relations are computed based on (transiently) conscious representations of elements and that 'relations without relata' are, as a matter of fact, phenomenologically impossible.[1]

We also chose to probe the simplest relation between just two elements: same versus different. Note that the CD discrimination (especially in Exp. 3 of Bronfman *et al.*) is probing if the elements are similar/dissimilar, and thus this is the true analogue of this type of CD for a reduced set of two elements. Specifically, we asked if it is possible to discriminate that two simple visual elements (letters such as X, O, T) are same or different, without being able to identify them. We present the identical pairs of letters that could be either the same or different ones (e.g. 'X O' or 'X X'), but we probe, in different blocks, either same-different (S-D) or 'which-letter' (W-L) discrimination. To probe shape discrimination (in the W-L blocks), we only ask for the letters' identity but not their position (since we do not want to probe shape-location binding; thus, XO and OX are considered equivalent in terms of stimuli and response; we sample two out of three letter options, which results in six different stimuli pairs (see Method)).

It is expected that at long stimulus-to-mask intervals the observers can both discriminate the elements and judge their (same/different) relation and that at shorter intervals, both of these processes are degraded. The question of interest concerns differences between these processes at intermediate intervals. The Overflow interpretation of summary statistics (i.e. without experience of underlying elements) entails that at *all* stimulus-to-mask intervals, the accuracy in the discrimination of the relation will be fully accounted for by the accuracy in the discrimination of the elements.

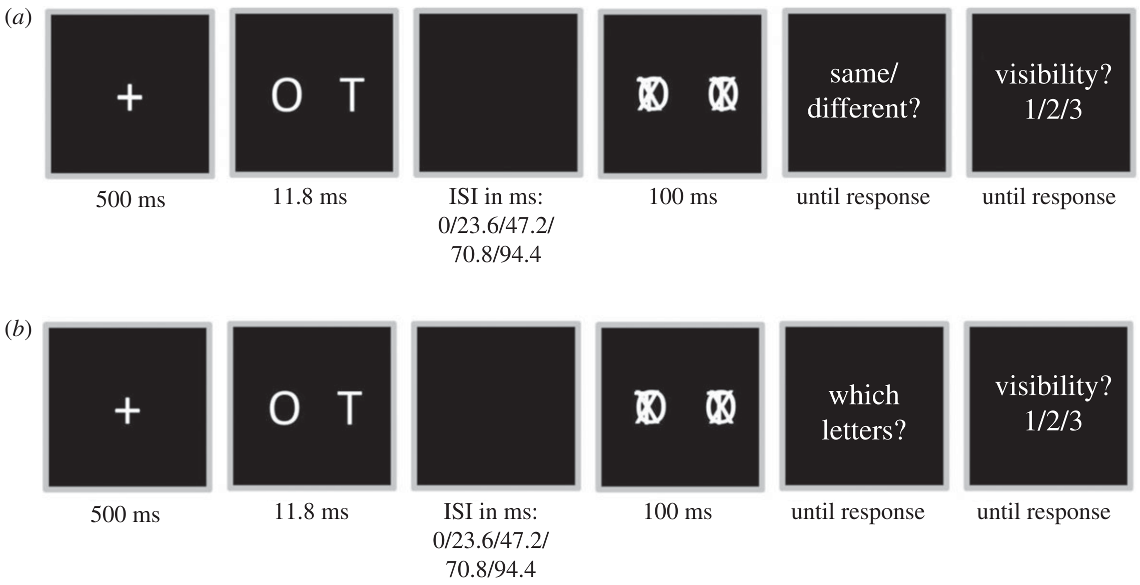

Figure 2. An example for 'same/different' condition (*a*), and 'which letter' condition (*b*).

(a) Experiment: letter versus same-different discrimination

(i) Method

Participants. A total of eight subjects ($M = 26.75$ years, s.d. $= 2.49$; four males, four females) took part in this experiment and received payment of 50 Israeli Shekels (approx. 15$) for participation. All reported normal or corrected-to-normal vision. All the participants provided their informed consent and the study was approved by the Ethical Board of Tel-Aviv University.

Materials. All instructions and stimuli in this experiment were presented on a 16-inch (ViewSonic) CRT-monitor, connected to an HP Compaq 8200 Elite Microtower PC. The screen's resolution was 1024 × 768 pixels, and the monitor had a refresh rate of 85 Hz. Stimuli were generated and presented using Matlab© and Psychophysics Toolbox. Responses were collected using the keyboard.

Stimuli and design. The stimuli consisted of a combination of two white letters (size: 1.45 cm) presented one next to each other on a black background. The letters were located at the centre of the screen with a distance of 5.30 cm from each other (2.65 cm horizontal distance of each letter from the centre of the screen). Each letter of the pair was either 'X', 'O' or 'T' (figure 2). Each pair of letters was randomly sampled from nine possibilities for the pairs of letters. The possibilities for the pairs were either 'same' letter pairs: 'X X', 'O O', 'T T', or 'different' letter pairs: 'X O', 'O X', 'T O', 'O T', 'X T', 'T X'. In the 'different' pairs we included both possibilities for each combination of each two letters to prevent any bias for the side on which the letters were presented. The frequency of 'same' appearances was doubled in order to ensure there were equal frequencies of 'same' and 'different' letters. The mask consisted of a superposition of the three possible letters (figure 2).

Procedure. Each subject was run on two sets of blocks (one for each condition; order counterbalanced between the subjects). Each set of blocks was composed of one practice block followed by five experimental blocks. The conditions differed only in the question that participants were asked in each trial. The practice blocks included 60 trials (120 practice trials in total), while the experimental blocks included 72 trials, each (720 experiment trials in total). Figure 2 shows the temporal sequence of a trial. A trial began with the participants fixating on a fixation cross (500 ms), after which the two letters appeared for 11.8 ms followed by a blank interval of varied inter-stimulus interval (ISI) (see below) and by the mask for 100 ms. Immediately following the mask, participants were presented with two questions. The first question differed between the two conditions: In the 'same-different' (S-D) condition (six blocks): participants were asked whether the stimulus consisted of the same or of different letters, and on the 'which-letter' (W-L) condition (six blocks) they were asked about the identity of the letters. The order of the conditions was counterbalanced. To answer the 'Same/Different' question, participants pressed a key marked with either 'same' or 'different'. For the 'Which letter' question, subjects pressed the keyboard twice (one for each letter) on marked keys according to their answer ('X', 'O', 'T'), regardless of the side which the letter was presented on—i.e. there were six possible answers (X X, O O, T T, X T, X O, O T). The second question, which was identical across the two conditions, probed the visibility of the stimuli, and immediately followed the 'Same/Different' or the 'Which letter' judgement. To answer this question, participants pressed the keyboard on a key marked as (1) 'total guess', or they (2) 'saw something', or they (3) 'saw the letters'.

The ISI (randomized within each block) differed between the trials and varied between the following values: 0 ms, 23.6 ms, 47.2 ms, 70.8 ms, 94.4 ms. (These ISIs were set based on a pilot experiment on another group of six participants, so as to facilitate maximal variation in performance levels—from chance to ceiling.) See electronic supplementary material for additional experimental details.

Data analysis. The main contrast of interest involves the task performance under the two conditions: *S-D* versus *W-L*. As the two conditions have different chance levels (1/2 for S-D, and 1/6 for W-L), we made the comparison based on 'corrected for guessing' measures, P_{SD} and P_{WL}, computed as follows:

$$P^{c}_{\mathrm{SD}} = 2 \times (P_{\text{S-D}} - 1/2)$$

$$P^{c}_{\mathrm{WL}} = \frac{6}{5} \times (P_{\text{W-L}} - 1/6)$$

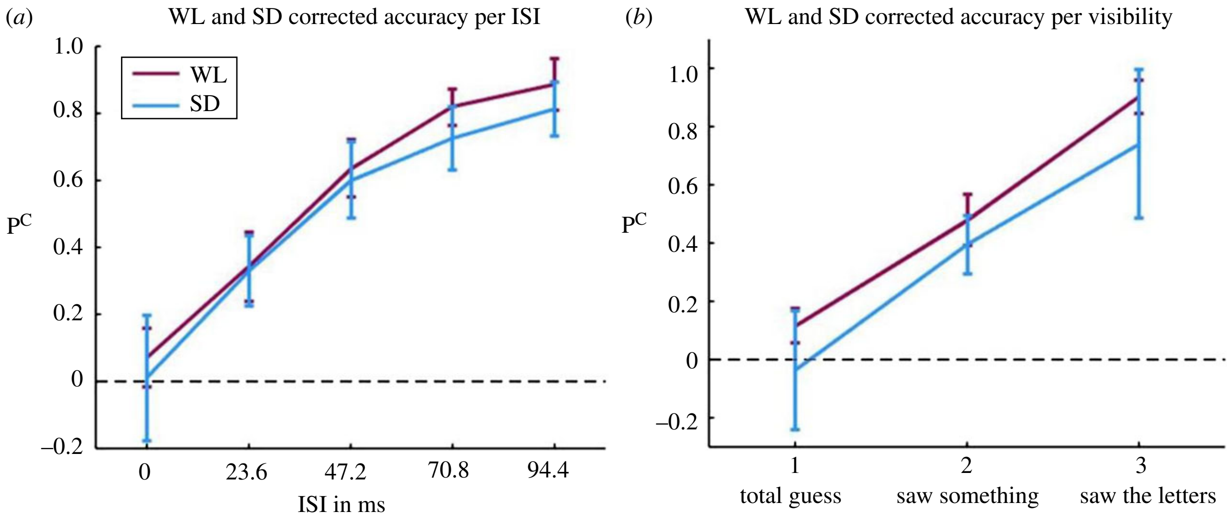

Figure 3. Corrected for guessing accuracy for the W-L and S-D tasks on the same stimuli as a function of ISI (*a*) and of visibility rating (*b*). Error bars correspond to within-S SE [44]. (Online version in colour.)

Thus, after correcting for guessing, chance level corresponds to a value of 0 and perfect accuracy to 1. This is equivalent to the estimation of accuracy from a multinomial model of guessing: $P_{\mathrm{exp}} = P^{\mathrm{c}} + (1 - P^{\mathrm{c}}) * \mathrm{g}$, where g is the chance level (1/2 for S-D, and 1/6, for W-L).

(ii) Results

The corrected for guessing accuracy for the W-L and the S-D tasks as a function of ISI and of visibility ratings are plotted in figure 3 for the group (see electronic supplementary material for individual data).

We first analysed the accuracy by ISI data with a 2 × 5 within-subject ANOVA. The group result shows a main effect of ISI ($F_{1.89,13.26} = 87.25$, p-value < 0.001), and no significant effect of task or interaction. However, since the number of subjects is relatively small, we also carried out a non-parametric test (Wilcoxon) on the performance collapsed across ISI. The results show the performance in the W-L task is significantly higher than in the S-D task ($T_8 = 2$, $p = 0.0023$). Furthermore, as shown in electronic supplementary material, figure S1, the effect appears quite consistent across the participants (none of them show numerically higher performance in the S-D condition). We then examine the accuracy grouped by visibility ratings (The distribution of visibility responses across ISI is shown in the electronic supplementary material, showing a gradual shift from 1 to 3 with ISI). We carried out a 2 × 3 ANOVA, showing that accuracy improves with visibility ($F_{2,14} = 75.56$, p-value < 0.001) and again we see that the performance is higher in the W-L compared with the S-D task ($F_{1,7} = 15.42$, p-value $= 0.01$).

This result is more consistent with the hypothesis that it is the conscious discrimination of the letters, which grounds the conscious *S-D* judgements, rather than the reverse—that conscious *S-D* judgements are based on responses of unconscious letter detectors. Furthermore, the hypothesis that *S-D* judgements are grounded in the conscious discrimination of the letters is supported by a consideration of the response bias in the *S-D* task: (63% versus 37%) in favour of ‘different’ at low ISI’s (when guessing is maximal) although the frequency of the same/different stimuli was equal (note that participants received feedback during practice). Interestingly, this is very close to the bias (2/3) that would be obtained if the participants first make an (often erroneous) guess about the identity of each of the letters and only then decide if the two are the same or not (such a process would have them responding twice as many ‘different’ responses than ‘same’).

(iii) Discussion

We set to test a prediction arising from the no-Overflow interpretation of the Bronfman *et al*. [30] findings; the prediction is that one can consciously discriminate a relation (Same/Different) without consciously discriminating the elements, in a simple design with only two elements (letters) under data-driven limitations (masking). We assumed that if summary statistics are estimated based on the perception of the individual elements (as the ‘Overflow’ theorists claim), then performance (corrected for guessing) in the W-L condition will be at least as good or even better than the performance in the S-D condition. Conversely, if the performance (corrected for guessing) is higher in the S-D condition than in the W-L condition, this would support the statement that the awareness of the specific elements is not necessary for extracting a simple summary statistic.

The results from the experiment showed a difference in discrimination between the S-D condition and the W-L condition. For every participant, the accuracy in the W-L condition was as high or higher than the accuracy in the summary statistic (S-D) condition; the same result is obtained when the accuracy of the tasks is presented as a function of visibility (rather than ISI to mask), and is also supported by a signal-detection computational model (figure 4). Therefore, these results support the Overflow interpretation of the Bronfman *et al*. results.

This conclusion, however, needs to be qualified. First the stimuli here (two letters) are quite different from our previous study (arrays of colour letters) and the task probed letter identity and similarity, instead of colour similarity. However, quite similar results were obtained in our laboratory, in a similar task that uses arrays of colours.[2] Second, unlike in Bronfman *et al*. where information overload seemingly limited the access to consciousness, here we used masking. It is thus possible in principle that the way in which masking affects access to consciousness is different from the way in which information overload does. In particular, a prominent no-Overflow interpretation is consistent with these results. This

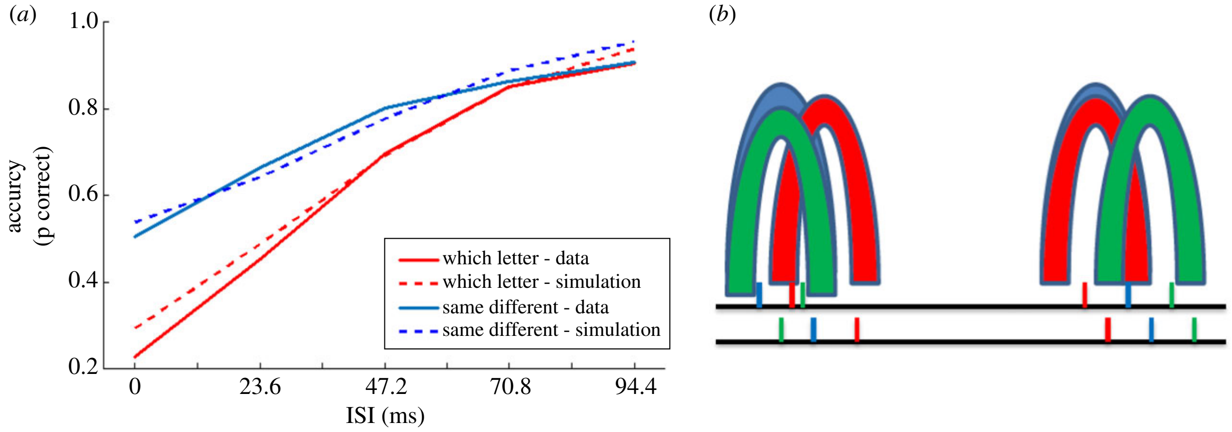

Figure 4. (*a*) Accuracy data (not corrected for guessing; solid lines) and signal-detection computational model (dashed lines) for the which-letter (red) and the same-different (blue) tasks. The model is based on three letter detectors (X,0,T), at each of the two locations (thus six detectors overall). Each detector receives a signal (proportional to the ISI in the experiment) and a Gaussian noise (SD of one). For a given trial, and in each set of three detectors, the one with a maximal activation determines the response. The amount of signal/ISI is a free parameter that is fit to the accuracy data in the W-L condition (red-solid), and the prediction for the same-different condition is then computed (blue-dotted), showing a good match to the data (blue-solid). We see that the model predicts chance accuracy in both tasks at short ISI, which increases with ISI in a way that matches the predictions (code available). (*b*) Illustration of the signal-detection model. Each letter (X shown with red, T with blue, and O with green) is represented by a signal distribution (three on the left and three on the right). The rightward displacement is proportional to the ISI (in this case the stimulus is XO). In each trial a sample is randomly selected from each distribution (two trials are shown), illustrated by the small vertical lines. In this case, the response is incorrect in trial-1 but correct in trial-2 with regard to the W-L task. For the S-D tasks, the corresponding responses are S (trial-1), D (trial-2). (Online version in colour.)

interpretation assumes that the type of dissociation we reported in Bronfman *et al.* [30] between the ability to report a relation and the relata only happens when the elements reach full access to the local circuit [5,6,45] but not to the Global-Workspace [7,8]. In the present experiment, however, this might not be the case, as the access to the local circuit itself is limited by the mask. Future research will be needed to fully establish that under conditions of divided attention, participants are also at least as good in discriminating elements as in judging their (same/different) relation. We therefore see the current results as only providing an important first step (had they shown better ability to report relation than relata, they would have provided evidence against Overflow). Nevertheless, our conclusion in favour of Overflow is supported by independent computational considerations, which involve the precision with which the elements are encoded and the relation between precision and the degree of awareness. We turn to these considerations in the next section.

(b) Colour diversity, precision and consciousness

Unlike most summary statistics, which have been shown to be rapidly evaluated for sets of elements (e.g. the average size), colour diversity is a second-order statistic (like variance). This difference has important implications for providing a lower bound on the precision with which the elements need to be encoded in order to allow the summary statistic to be estimated. For example, an average statistic can be computed based on simple pooling over the population (weighted average of the response in a population of detectors broadly tuned to different magnitudes; [41]), and hence can be estimated with high precision (figure 5, red line), even when the precision of each element is low (figure 5, blue line; from Bronfman *et al.* [19]). This is a simple consequence of noise averaging. However, noise averaging is far less effective when estimating a variance-type (second-order) statistic.

We demonstrate this in figure 5, which shows an ideal-observer simulation that is based on a single parameter—the precision with which a single colour element is encoded (*x*-axis, which has a cyclic range of 18 colours on a colour wheel—the separation between proximal colours is 20 degrees on the colour wheel). The simulation sets a bound on the detection accuracy that can be achieved for the binary discrimination of a single colour, of the average colour and of the CD performance. The binary discrimination of a single colour (blue line) is defined as the probability of correctly identifying the single colour's half-circle range (9/18). Here a reduction of precision corresponding to (±)60 degrees, results in a performance of about 70%. The red line shows the impact of the same reduction on single-element colour precision, now on a population estimate of the colour based on 18 (independently) noisy elements. The average colour is computed by vector summation on the colour ring (we assume that observers use the polar coordinate of the vector summation as their best estimate). We see that the population colour estimate is much better than the single element one (performance exceeds 0.95). Finally, an upper bound on the CD performance is obtained for Exp-3 in Bronfman *et al.* Three measures are used (black, cyan and magenta), which can distinguish between the high/low CD conditions (see supplementary materials and Bronfman *et al.* [19] for details). In all cases the CD score is computed, based on ideal-observer assumptions, by computing the probability of correctly identifying whether the CD score is above or below the median CD level, based on 1000 trials, half sampled from the low- and half from the high-CD conditions (Exp. 3); Here we observe that in order to obtain an accuracy consistent with the data (approx. 66% Exp-3 in Bronfman *et al.* [30]) the precision needs to be at least as good as that of two colour detectors on the population ring (separation less than 40 degrees—figure 5, dotted vertical line).

To summarize, these results indicate that observers experience and discriminate a second-order statistical summary—CD—outside focal attention, whose computation requires differentiated (i.e. not too broad) representations of the elements. The Overflow interpretation is that this experience is grounded on a transient (but fragile) awareness of the visual

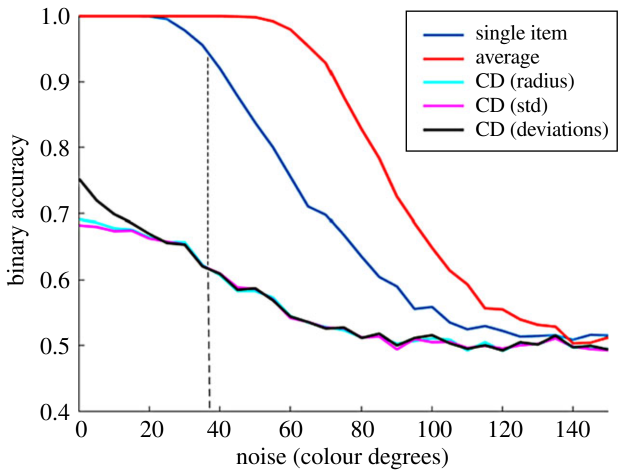

Figure 5. A population-code ideal-observer bound on precision. The simulation assumes a set of $n = 18$ colour detectors, which are arranged around a circle. The *X*-axis corresponds to the level of noise, on a scale that goes from 0 to 140 degrees (where a single colour spans 20 degrees on a 360-degree colour wheel). The *Y*-Axis corresponds to simulated precision. Precision is simulated by adding a Gaussian variable to a specific colour (all wrapped around the colour circle). The blue line shows the impact of reduced precision on a single element (binary choice). If a set of 18 elements are used instead and the colour is decoded via population averaging (vector summation), the precision is enhanced to more than 95% (red line). The other three lines correspond to the impact of a single-element precision on the ideal-observer CD performance, based on three different measures for Exp-3 reported in Bronfman *et al.* [30]. The three measures used are: (i) sum of distances square (black line), (ii) the magnitude of the population vector (cyan), (iii) the SD of the population vector (magenta). (Online version in colour.)

elements. By contrast, the no-Overflow account requires that the generic CD experience is not accompanied by any differentiated colour experience of the elements, and that its computation, which requires high-precision representations of the specific colours of individual letters is entirely unconscious [15,16].

While one may contend that such precise and well-differentiated representations can be fully unconscious, we believe that experimental data in visual neuroscience are more consistent with the idea that a main factor distinguishing between conscious and unconscious representations of visual properties is the precision (which can be linked to neural activation in relevant visual areas). For example, in a recent article, King and Dehaene conclude that ‘discrimination performance is typically better on seen than on unseen trials, even when the physical stimuli are physically identical’ [46, p. 2]. The authors further stated that ‘although objective discrimination can be above chance with subjectively invisible stimuli, such unconscious discrimination performance is at best mediocre’. In many studies, objective discrimination performance improves dramatically when the stimuli are reported as ‘seen’ compared with unseen, even when sensory stimulation is identical (p. 4; see the article for additional references and Bronfman *et al.* [19] for additional arguments based on *Neural Correlates of Consciousness*[3]). Thus, based on recent psychophysical research, there is support for the assertion that in most cases of unconscious perception the precision of the unconscious representation is much lower than that which can be obtained under conscious perception with identical stimuli. This suggests that CD discriminations require a well-differentiated encoding of individual elements, which is more likely to involve conscious rather than unconscious representations. This interpretation is also supported by the new data we reported showing that under masking—limiting conscious access—even a simple summary statistic of the relation between two elements requires the discrimination of the elements themselves.

Finally, this interpretation is consistent with results from divided attention paradigms which demonstrate that observers can discriminate colours (e.g. pink versus orange; [24]) and categorize objects ([28]; but see objection by Cohen *et al.* [47]; and reply by Tsuchiya *et al.* [48]) outside of focal attention; importantly, as predicted by prominent attention theories that posits attention to be needed for visual binding [49], the participants cannot discriminate colour conjunctions (a red–green versus green–red discs) or letters (T versus L) under the same (divided attention) conditions (see [25], for review). While we do not think these arguments are indisputable (they may be subject to a number of objections), strong objections can also be raised towards the typical arguments deployed to support the no-Overflow position. We wish to end with a consideration of an important anti-Overflow argument, based on the IB phenomenon. In our final section, we review a number of results from a novel version of this paradigm, which (contrary to some common beliefs) further increase the support for the Overflow.

4. Inattentional blindness and phenomenal consciousness without access

In a typical *IB* experiment, participants instructed to attend to a specific property of a visual display (or movie) fail to notice the presence of a prominent visual property or event (e.g. a gorilla) that is irrelevant to their task [50].[4] The no-Overflow interpretation of these results assumes that due to the *information overload* created by the rich visual display, participants must rely on attentional selection to filter a small part of the information for reaching their cognitive system, with the rest failing to reach conscious access and thus not experienced [8,11,20]. Moreover, a recent study has used an IB design to test the ability of observers to detect summary statistics [51], such as CD in the design of Bronfman *et al.* [30]. The rationale of this study is that, since divided attention methods are not sufficient for concluding that observers allocate no attentional resources to the secondary task (i.e. CD), it is possible that the CD discrimination in previous studies [30,35] was mediated by residual attentional resources. To probe for an attention-free CD detection, Jackson-Nielsen *et al.* [51] have presented a sequence of seven trials in which the task is to report the letters only (and no mention of colours is made) and in the 8th, surprise trial, the observers were queried about the CD. As the detection accuracy was low, the authors concluded that without attention, it is not possible to detect CD-type summary statistics; the authors concede, however, that it is difficult to distinguish between this (non-Overflow) interpretation, and an (Overflow) interpretation based on forgetting (or *attentional amnesia*; [52]).

The aim of this section is to discuss recent findings in the IB paradigm, which raise questions on the rationale of using IB to probe attention-free task performance. This association between IB failure and ‘attentional selection’ has recently come under pressure from findings that demonstrate inattentional blindness in the total lack of information overload

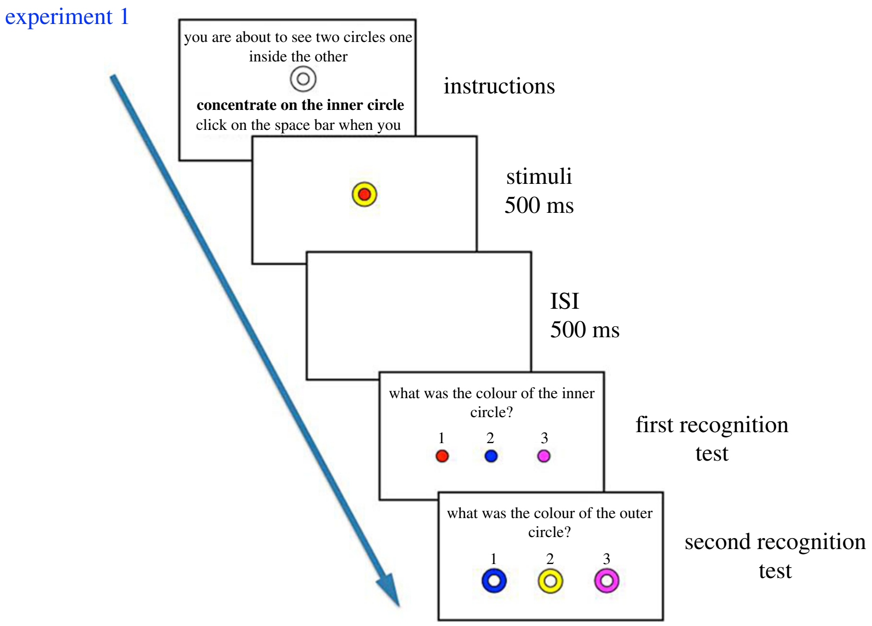

Figure 6. Adapted from [32]. Participants were presented with simple stimuli, centrally presented for a relatively long duration (500 ms). Still, when surprisingly probed for the colour of the irrelevant circle (here, yellow) up to 25% of the participants failed to correctly respond. (Online version in colour.)

(and thus, seemingly, undercutting the rationale that report failure in IB can only be caused by lack of visual attention during encoding). For understanding the relevance of this issue to the phenomenal/access distinction, it may be helpful to remember that one of the properties that Block has associated with states of phenomenal consciousness without access is that this does not involve a conceptualization or categorization of its content [1,4,5,17]. This is especially relevant to the way we interpret the IB findings for two reasons. First, there is an additional critical property (other than attentional load) that makes *IB* tasks prone to report failure—*task relevance*, which is believed to modulate the degree with which visual experience activates 'knowledge' [53–56]. Put simply, task-irrelevant knowledge was postulated to fail to be 'functionally activated'—and hence, to not participate in even simple cognitive processes. Second, in order to experimentally induce the phenomenon of *IB*, researchers often capitalize on *both* task irrelevance (presenting something which is out of the task 'set') *and* on creating a substantial amount of mental load—both executive and perceptual [22,50]; for example, in Simons & Chabris [50] participants were required to track rapid dynamic events (e.g. ball passes) and keep mental tallies of them.

The consideration of task relevance as a potentially critical factor in *IB*, is thus likely to turn the overflow debate on its head by placing the locus of selection for report in categorization (i.e. in the activation of semantic representations) rather than in attentional selection. This opens the possibility that phenomenal consciousness 'overflows' *reportability* because the irrelevant stimuli were simply not (or at least not sufficiently) categorized and hence cannot be spoken (or thought) of. As we will see, this casts doubt on whether the fact that stimuli go unreported is evidence that they were not phenomenally experienced, as is often assumed.

To test the possibility that knowledge activation and conscious awareness can only be dissociated on the basis of their sensitivity to task relevance, Eitam and colleagues created a situation—labelled *irrelevance-induced 'blindness'*, in which resources are clearly abundant—simple stimuli are presented for a reasonably long period of time, and are well attended (and are not *surprising*)—and only the task relevance of the stimuli is manipulated. If people still fail to report on a salient feature of a simple stimulus under these conditions, one would be hard pressed to argue that failure to report is due to lack of attentional selection or to WM *capacity limitations*. Such a failure to report could then be credited to the lack of conceptualization or perhaps to forgetting ([52]; but see also [32]).

(a) Irrelevance-induced 'blindness'

In a set of experiments Eitam *et al.* [32] presented participants with the outlines of two concentric circles with the diameter of the outer being about 3 degrees of visual angle (figure 6).

Participants were instructed that they would immediately see another two concentric circles and were asked to focus on the area of the outer (or inner) circle. They were then presented with two differently coloured concentric circles (colour was not mentioned before), in the centre of the screen for a duration of 500 milliseconds. Five hundred milliseconds after the circles had disappeared, participants were probed about the colour of the task-relevant (irrelevant) circle and then about the colour of the task-irrelevant (relevant) circle (figure 6). The order of the questions was counterbalanced between participants.

Given this set-up, up to 25% of the participants, who correctly reported the colour of the circle at the relevant location failed to report its colour in the irrelevant condition (independent of the order of probing). Additional (yet unpublished) data from our laboratory shows that increasing the number of trials on which participants report on the relevant dimension quickly increases 'blindness' rates.[5] Similar results have been recently reported from different laboratories. For example, a striking example is a recent study by Chen *et al.* [31], who, using a similar type of experimental procedure, reported that one-third of the participants who are tracking a ball for half a minute do not remember its colour. To summarize, these findings supply evidence that people show 'blindness-like' behaviour, even when their WM and attention system is free

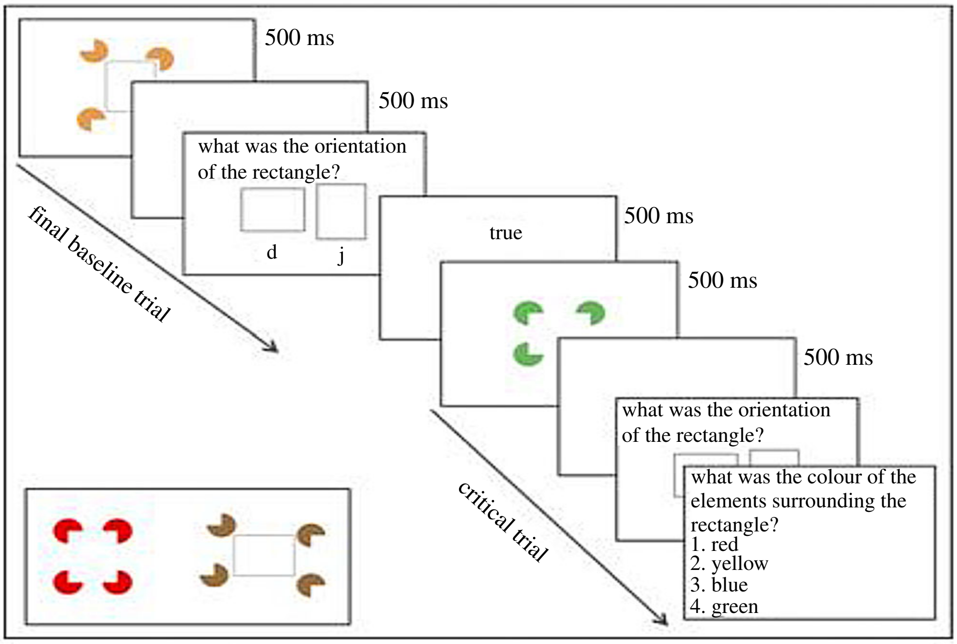

Figure 7. Seeing without knowing: task relevance dissociates between visual awareness and recognition. Participants performed seven trials in which they responded to the orientation of a real rectangle. On the (8th) critical trial they responded to the orientation of an illusory rectangle and then were probed about the colour of the inducers. Close to 30% of the participants who correctly performed the orientation task failed to correctly answer the question about the inducers' colour. Reproduced with permission from Eitam *et al.* [33] (Copyright 2015 The New York Academy of Sciences). (Online version in colour.)

enough and is actually focused to represent all the presented stimuli. We thus propose that people fail to report in these tasks, not because they are phenomenally unconscious of a simple stimulus which is fully attended, but rather because, being task-irrelevant, the stimuli are not categorized, or if they are categorized, they are then rapidly forgotten.[6]

(b) Seeing without knowing

A sceptic could (counterintuitively, we believe) argue that even if people stare at a two concentric circles' stimuli and attend to the outer circle (under no attentional or WM overload), they somehow do not experience the colour of the inner circle. To test this possibility, Eitam and colleagues ran a second experiment [33] in which they capitalized on a number of recent studies, showing that amodal completion occurs only when the inducers of the illusory shape are consciously experienced [58–60].

Specifically, in this experiment ([33]; Exp. 1) participants were presented with unicoloured Kanitza-like inducers surrounding a non-illusory rectangle (figure 7; yellow shapes). Participants were instructed to classify the rectangle as being 'horizontal' or 'vertical' using a key press. On the critical (8th) trial, participants were presented with an illusory rectangle (figure 7; green shapes), and following the completion of the focal (orientation) task, they were probed about the colour of the inducers.[7] The results showed that among the participants who had successfully performed the orientation task on the illusory rectangle (96% of the participants) and thus have consciously experienced the coloured inducers, close to 30% failed to correctly report their colour.

We believe that the most coherent interpretation of these results is that although the participants had consciously perceived the inducers (including their colour property), these colours are not categorized as being (say) 'red' because knowing the colour was task-irrelevant. These findings demonstrate that failure to report in IB tasks may stem not only from a lack of attentional processing, but also from 'seeing without knowing' (or categorizing) in cases in which the probed material is task-irrelevant. It is possible, then, that categorization or knowledge activation is more sensitive to relevance than phenomenal visual awareness is [33].

5. Conclusion

Together, these results provide additional support for the position that phenomenal consciousness overflows encoding into WM and report. The type of Overflow we support here is a mild one, involving a transient (non-robust) access, grounding evaluations of summary statistics of visual elements that cannot be reported. Finally, task relevance and its effect on categorization appear as a critical variable that determines report accuracy in tasks such as *IB* that are often taken as support for no-Overflow. While this does not provide a full refutation of the no-Overflow position, it does show that its proponents fail to supply a unitary explanation of alleged cases of consciousness without reportability. Since the relation between consciousness and reportability is precisely what is at stake, we take it that proponents of no-Overflow would not wish their view to be based on an insistence that 'whenever represented stimuli are not reportable, they are not conscious'. In this context, the fact that different mechanisms and different factors underlie cases of lack of reportability appears to be significant. Specifically, we believe that the discovery of an additional variable that is critical for report (e.g. task relevance), but about which we have no independent reasons for accepting its criticality for consciousness, poses a challenge for no-Overflow. Future studies will need to examine if the experience of visual elements and their relations can be dissociated under reduced attention—an issue that appears pivotal in the Overflow debate.

Data accessibility. Additional results and the code for the model simulation are provided as electronic supplementary material.

Authors' contributions. Z.Z.B. and S.T. and M.U. designed the experiment. S.T. programmed and executed the experiment. Z.Z.B. developed the computational model. M.U. and B.E. wrote the paper. All the authors read and improved the paper.

Competing Interests. We declare we have no competing interests.

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Endnotes

[1] We take this second approach here (an experiment based on the more complex, divided attention design, is under preparation).

[2] Summary statistics are in the details: Approaching the rich/impoverished experience debate with simple stimuli: Shiri Talmor, MA dissertation, Tel-Aviv University.

[3] The argument involves evidence linking conscious perception of visual properties to the level of activation in high visual areas, and the level of neural activation with the precision of neural decoding.

[4] For a demo see: https://www.youtube.com/watch?v=IGQmdoK_ZfY.

[5] For example, in an adaptation of Eitam *et al.* [32], after being exposed to more than a hundred concentric circles (sequentially) for which they were randomly probed regarding the colour at the relevant (e.g. outer circle) location; participants were at chance level when they were surprisingly probed about the colour of the irrelevant location (e.g. inner circle).

[6] We believe that there are three independent factors that contribute to IB: (i) lack of attentional processing, (ii) forgetting, and (iii) task irrelevance; see Ward & Scholl [57], for a study that minimizes forgetting but which involves both high load of attentional processing and (as in all IB tasks) differential task relevance. To supply further evidence countering the attentional-amnesia interpretation, future studies could look at priming effects caused by the irrelevant object.

[7] A second group of participants were asked to report on the inducers' colour and were asked about the orientation of the rectangle in the surprise (8th) probe; replicating Eitam *et al.* [32], 43% of these participants failed to correctly report the orientation of the illusory rectangle compared to approximately 4% when it was relevant.

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