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Prior conscious experience enhances conscious perception but does not affect response priming

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ABSTRACT

Recent research shows that prior experience and expectations strongly enhance a visual stimulus' access to conscious awareness. However, whether such advance knowledge also influences this stimulus' indirect impact on behavior is poorly understood. The resolution of this question has the potential of providing strong tests between current models of conscious perception because these diverge on whether a factor that affects conscious access by a stimulus necessarily also affects the strength of this stimulus' representation and hence, its indirect impact on behavior. In five experiments we show that three different manipulations of prior experience with a stimulus boosted conscious perception of a similar stimulus (measured using both subjective reports and objective performance) but did not affect its indirect impact on motor action (measured by response priming). In particular, we observed a robust "awareness priming" effect: how clearly a stimulus was subjectively perceived on a recent trial irrespective of its physical strength, strongly affected conscious perception of a similar stimulus on the current trial but did not increase response priming. We discuss the implications of these findings for current models of conscious vision as well as for the study of unconscious processing.

1. Introduction

In everyday situations, we often fail to detect an object despite the fact that it appears in our field of view. This situation arises when this object is presented under impoverished conditions or if our attention is fully engaged elsewhere (e.g., Mack & Rock, 1998; Raymond, Shapiro, & Arnell, 1992; Rensink, 2004; Simons & Ambinder, 2005). The objective of the present study was to explore whether the factors that affect an object's access to visual consciousness[1] necessarily also affect its indirect impact on behavior. More specifically, we investigated whether prior visual experience with a stimulus, which is known to facilitate conscious access, also modulates this stimulus' indirect influence on subsequent behavior.

In the introduction that follows, we first review the fast-growing literature showing that various factors that increase the predictability or familiarity of an upcoming stimulus foster conscious perception of this stimulus. We then explicate the measures used here to assess a stimulus' conscious access and its indirect impact on behavior. Finally, we describe three prominent models of conscious perception (among many other influential models in this field, see Lau & Rosenthal, 2011, for instance, for a more comprehensive review) and their predictions with regard to the effect of prior conscious experience on conscious perception and its indirect impact on behavior.

1.1. Effects of prior experience on conscious perception

von Helmholtz (1867), cited in Gregory, 1997) described visual perceptions as unconscious inferences from sensory data and knowledge derived from the past. Consistent with this framework, a recent spate of empirical evidence suggests that prior experience and perceptual predictions not only bias the contents of conscious awareness (e.g. Chalk, Seitz, & Seriès, 2010; Chopin & Mamassian, 2012; Kok, Brouwer, van Gerven, & de Lange, 2013; see Panichello, Cheung, & Bar, 2013 for review), but also strongly influence whether a physically weak stimulus will gain conscious access (e.g., Gaillard et al., 2006; Lin & Murray, 2014; Melloni, Schwiedrzik, Müller, Rodriguez, & Singer, 2011; Schwiedrzik,

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[1] In this manuscript, the terms "consciousness" and "awareness" are used interchangeably.

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Singer, & Melloni, 2009) and how fast (Chang, Kanai, & Seth, 2015; Pinto, van Gaal, de Lange, Lamme, & Seth, 2015). For instance, Melloni et al. (2011) had participants rate the visibility of symbols embedded in white noise. The experiment consisted of fixed-length sequences of trials presenting the same symbol but with signal-to-noise ratio increasing during the first half of the sequence and decreasing during the second half. For equal noise levels, reported visibility of the target symbol was higher during the descending portion of the sequence, in which subjects had been preexposed to a strong exemplar of the target symbol and also knew which symbol would come next, than during the ascending one.

Other studies more specifically showed that pre-exposure to supra-liminal exemplars of a stimulus improves discrimination performance for a weaker version of this stimulus (e.g., Dolan et al., 1997; Gaillard et al., 2006), a phenomenon sometimes referred to as the ''Eureka" effect (Ahissar & Hochstein, 1997) or ''abrupt learning" (Rubin, Nakayama, & Shapley, 1997). For instance, Gaillard et al. (2006) presented each of 60 different backward-masked words once in each of five blocks. Masking strength was increased across successive blocks for half of the words and decreased for the other half. These authors found word-naming accuracy for identically masked stimuli to be higher in the former condition, where prior exposure to supra-liminal exemplars had already occurred, than in the latter, where such exposure had not yet occurred. Likewise, Dolan et al. (1997) showed that observers' performance at categorizing a degraded image as a face or a non-face object substantially improved after relative to before they viewed an undegraded version of the same image.

Finally, Lin and Murray (2014) examined whether participants' awareness of barely visible (strongly masked) targets improves when these targets are intermixed with clearly visible (weakly masked) exemplars relative to when they are presented alone. These authors found conscious perception of the target to be substantially higher on strongly masked trials when these were intermixed with weakly masked trials than when alone.

As we have seen, clearly perceiving a stimulus on a recent occasion increases the probability that a subsequent degraded version of this stimulus will gain access to conscious awareness. However, it is not clear what factor determines the effect: *pre-exposure to a physically salient version* of the critical stimulus or *prior conscious perception* of that stimulus, as the two were always confounded in previous studies. For instance, in hysteresis experiments (e.g., Gaillard et al., 2006; Melloni et al., 2011), the critical stimulus was preceded by physically *weak exemplars* in ascending sequences, in which the stimulus was considered to have been *unseen* early on, and by physically *strong exemplars* in descending sequences, in which the stimulus was considered to have been *seen* early on. Likewise, in Lin and Murray's (2014) study, prior conscious experience of a stimulus was operationally defined as exposure to a weakly masked version of that stimulus.[2] Here, we disentangle prior conscious experience from prior exposure to a physically strong stimulus in order to determine whether a genuine ''awareness priming" effect can be demonstrated.

[2] Lin and Murray (2014) were the first to refer to the notion of ''priming of awareness", which they describe as visible stimuli priming perceptual representations to boost otherwise invisible objects into awareness. However, visible stimuli in that study were weakly masked, whereas invisible stimuli were strongly masked. Therefore, physical salience and conscious perception were confounded – an issue we address here.

1.2. Direct measures of perception and indirect measures of perceptual processing

1.2.1. Direct measures of perception: Subjective and objective measures of conscious access

Conscious perception can be indexed using either subjective or objective measures. With subjective measures, awareness is assessed on the basis of the subjects' self-reports of their conscious experience. These might either refer to the contents of conscious awareness (for instance reports on how tilted a line appears to be) or to conscious access (reports of whether a stimulus is seen or unseen). With regard to conscious access, which is the focus of the present study, the field has recently moved from binary (yes/no) reports to more sensitive scales of subjective conscious perception, such as the Perceptual Awareness Scale (PAS) developed by Ramsøy and Overgaard (2004). With PAS, participants report on the quality of their subjective experience directly, using a 4-point scale of visibility ((1) 'No experience', (2) 'Brief glimpse', (3) 'Almost clear image', and (4) 'Absolutely clear image'). Using this measure, Melloni et al. (2011) as well as Lin and Murray (2014) showed that expectations about an upcoming stimulus and prior exposure to a strong exemplar of this stimulus increase its visibility (see also, Chang et al., 2015; Pinto et al., 2015, for evidence that these factors speed subjective conscious access).

With objective measures, awareness is assessed on the basis of the observers' ability to discriminate between different stimulus attributes (e.g., an arrow's direction, or a word's identity). The participants are required to respond on each trial and to guess if unsure. Gaillard et al. (2006) showed that prior exposure to a weakly masked word improved observer's accuracy at naming a degraded (strongly masked) version of this word (see also Dolan et al., 1997; Lin & Murray, 2014; Schwiedrzik et al., 2009 for related findings).

Which measures, subjective or objective, are most valid to assess conscious perception has been and continues to be a matter of fierce debate (e.g., Eriksen, 1960; Hannula, Simons, & Cohen, 2005; Holender, 1986; Merikle, 1992; Reingold & Merikle, 1988; Sandberg, Bibby, Timmermans, Cleeremans, & Overgaard, 2011; Wiens, 2007). In particular, subjective measures have been criticized, mainly because of the ''criterion problem": for ambiguous signals, one subject may be ready to report having seen the critical stimulus, whereas another may be reluctant to do so, although their conscious experience of the stimulus may in fact be similar. On the other hand, objective measures of awareness have also been criticized because they do not reflect the phenomenological experience of being visually aware and do not allow monitoring of conscious perception on a trial-by-trial basis.

This controversy arises most acutely when one seeks to demonstrate unconscious processing, and guaranteeing null conscious perception is therefore crucial. However, it is also relevant to the question of what factors facilitate conscious access because prior experience with a stimulus may either genuinely improve the observers' conscious perception of that stimulus or only induce biases at the response level. Here, we used both a subjective and an objective measure of conscious perception (see Gaillard et al., 2006; Lamy, Alon, Carmel, & Shalev, 2015; Lin & Murray, 2014; Peremen & Lamy, 2014a; Wiens, 2007 for a similar approach) to test the effects of prior experience on conscious access.

1.2.2. Indirect measures of perceptual processing: Response priming

As the preceding review indicates, many studies showed that prior experience and expectations relative to a stimulus facilitate a similar stimulus' conscious access, whether such conscious access is probed using an objective or a subjective measure. However, the indirect influence of these factors on motor responses to that stimulus, if any, has not been systematically investigated to date (but see studies reviewed in '*The dual-stream model*' section below). In the present study, we examined the indirect impact of prior experience on behavior by measuring response priming. In a typical response-priming paradigm (e.g., Eimer & Schlaghecken, 1998; Neumann & Klotz, 1994), subjects are required to respond to a target that is associated with two responses (e.g., one finger press for the left-pointing arrow and a different finger press for the right-pointing arrow). It is preceded by a prime (e.g., a different arrow) that is associated with the same two responses. Response priming is said to occur if responses are faster when the target and prime elicit the same response (congruent trials) than when they elicit opposite responses (incongruent trials).

Unlike visibility and discrimination performance, which are direct measures of visual conscious perception (subjective and objective, respectively), response priming is an indirect measure of visual processing. As such, it is one of the primary measures of unconscious processing (e.g., see Kiesel, Kunde, & Hoffmann, 2007 and Kouider & Dehaene, 2007 for reviews). Specifically, finding response priming from a prime that is rated to be subjectively invisible or cannot be discriminated above chance is taken to demonstrate that unconscious processing of the prime has occurred.

1.3. Models of conscious perception and their predictions

1.3.1. The Global Neuronal Workspace model

The Global Neuronal Workspace model (e.g., Dehaene & Naccache, 2001; Sergent, Baillet, & Dehaene, 2005), which builds on Baars' (1988) Global Workspace theory, posits that conscious perception of a stimulus depends on its bottom-up sensory strength and on how much attention it receives. According to this model, when the neural activation resulting from bottom-up salience and top-down attentional amplification exceeds an ignition threshold, many distant areas are simultaneously activated and yield a long-lasting pattern of reverberating activity that is associated with conscious perception. As this model assumes that conscious perception critically depends on neural activation strength, it predicts that the factors that enhance a stimulus' conscious access (i.e. bottom-up sensory strength and how much attention it receives) should increase its impact on behavior. Two lines of research confirm this prediction. On the one hand, increasing a prime's physical strength increases response priming. For instance, Vorberg, Mattler, Heinecke, Schmidt, and Schwarzbach (2003) showed that the benefit of a masked prime instructing the same response as a subsequent target (response priming) increased as masking became weaker (see also Peremen & Lamy, 2014a,b).[3] On the other hand, directing spatial attention to a stimulus' location enhances response priming by this stimulus. For instance Kentridge, Nijboer, and Heywood (2008) showed that response priming associated with a subliminal stimulus followed by a visible target was larger when the prime appeared at an attended than at an unattended location. Accordingly, the Global Neuronal Workspace model predicts that if prior experience facilitates conscious access it should also magnify response priming.

1.3.2. Predictive-coding models

Predictive-coding models of perception (e.g., Clark, 2013; Friston, 2005; Mumford, 1992; Rao & Ballard, 1999) sharply depart from the Global Neuronal Workspace's conceptualization of cortical activity as coding sensory evidence that generates a perceptual decision (or conscious perception) when accumulated up to a certain threshold (e.g., Dehaene, Charles, King, & Marti, 2014). Instead, they consider conscious perception as an iterative matching process of top-down predictions, arising from expectations and prior experience, against bottom-up evidence, along the visual cortical hierarchy (see also Di Lollo, Enns, & Rensink, 2000; Lamme & Roelfsema, 2000; Lamme, Super, & Spekreijse, 1998; Neisser, 1967 for related suggestions underscoring the role of recurrent processing in conscious perception). They further suggest that cortical activity encodes bottom-up prediction error signals that are used to update predictions so as to bring prediction error to a minimum.

Consistent with these ideas, accumulating evidence has shown that relative to unpredicted stimuli, predicted stimuli are associated with weaker neural activity in early sensory areas (e.g., Alink, Schwiedrzik, Kohler, Singer, & Muckli, 2010; Egner, Monti, & Summerfield, 2010; Kok et al., 2013; Todorovic & de Lange, 2012). Predictive-coding models do not make specific predictions with respect to the relationship between conscious visual access and response priming. However, if one assumes that the strength of the neural representation of an object in early visual areas determines this object's impact on behavior, predictive-coding models predict that prior experience should actually reduce response priming.

1.3.3. The dual-stream model

By contrast with the previous models, the notion that vision for conscious perception can be dissociated from vision for motor action is at the core of the model put forward by Goodale and Milner (1992; see also Milner & Goodale, 2006; Goodale, 2014). Relying on a variety of dissociations, these authors proposed that the ventral and dorsal streams process information for perception and for action, respectively. They further suggested that "the dorsal stream does not use the high-level perceptual representations of the object constructed by the ventral stream, but instead relies on current bottom-up information from the retina to specify the required movement parameters..." (Milner & Goodale, 2008, p. 776). The findings reported by Ganel, Tanzer, and Goodale (2008), for instance, clearly illustrate this view. Participants were required to judge two lines' sizes as well as open their fingers in order to grasp these lines. The lines were embedded in a Ponzo display, which creates an illusion of depth that distorts size perception. Subjective reports indicated that the longer line appeared to be the shorter (i.e., they showed the Ponzo illusion), yet the participants' grip aperture was tuned to the line's actual size (see Goodale, 2014 for a review of related findings).

Such findings suggest that prior experience may not affect vision for action in the same way as it affects conscious perception, yet several remarks are in order. First, although illusions are thought to result from misapplication of knowledge (Gregory, 1997), the effects of enduring knowledge, that drives the reliance on depth cues, for instance, do not allow making direct inferences on the effects of more episodic prior experience and expectations. Second, perceptual illusions refer to misinterpretations and therefore speak to modulations of conscious contents, not of conscious access. Finally, dissociations of the type demonstrated by Ganel et al. (2008) may be specific to motor actions involving direct

[3] It should be noted that Vorberg and colleagues' findings (e.g., Schmidt & Vorberg, 2006; Vorberg et al., 2003) do not support the Global Neural Workspace model. Indeed, while they showed that response priming increased as the mask became temporally removed from the prime (and this prime's bottom-up activation therefore became stronger), they also reported that conscious perception of the prime followed a different time course. Note however that these authors measured conscious perception and response priming in different blocks of trials. As a result, the participants' attention was likely to be allocated mainly to the prime in the conscious-perception block and mainly to the mask in the response-priming block. Using similar stimuli and tasks, Peremen and Lamy (2014a) replicated Vorberg et al.'s (2003) initial findings but showed that when both conscious perception and response priming were measured simultaneously on each trial (and therefore under the same attentional conditions), the dissociation was no longer observed: the two measures of processing followed the same time course. Nevertheless, the longer RTs characteristic of dual tasks relative to single tasks might also account for the difference between the two experiments. This issue is addressed in the general discussion.

and online interaction with the critical object (e.g., manual grip), that benefit from relying on actual rather than perceived objects' characteristics. Therefore, it is important to determine whether a similar dissociation occurs between conscious access (rather than only conscious content) and response priming (in which the association between a stimulus and a response is arbitrary and dictated by the object's category rather than by its specific physical properties).

2. Outline of the present research

Our primary objective was to compare the effects of prior experience on conscious perception and on response priming. The basic paradigm used in the present research is depicted in Fig. 1. On each trial, a prime arrow pointing to either the right or the left was masked by a larger arrow after a variable time interval. Conscious access of the prime was measured by either visibility reports on a 4-point (PAS) scale or by forced-choice performance at discriminating the prime direction. The prime's indirect impact on behavior was measured by comparing performance at discriminating the masking arrow's direction when it was the same as the prime's direction vs. when it was different (i.e., response priming).

We manipulated prior experience in three different ways. In Experiments 1 and 2, we examined awareness priming, that is, whether seeing a stimulus clearly on a recent trial affects conscious perception of a similar stimulus and its impact on behavior, on the current trial. Crucially, we dissociated prior conscious perception of a stimulus from prior exposure to a physically strong stimulus (with stimulus strength being operationalized as the prime-target SOA). In Experiments 3 and 5, we compared a no-prior-experience condition to two prior-experience conditions. In the no-prior-experience condition, prime-to-target stimulus-onset-asynchronies (SOAs) increased across blocks, such that masking became weaker and the prime became clearer as the experiment progressed. One prior-experience condition involved randomly mixed SOAs, such that clear exemplars of the stimuli were encountered recurrently across the experiment and from its beginning (Experiment 3). The other was similar to the no-prior-experience condition except that participants were presented with a few highly visible exemplars of the prime during practice (Experiment 5). Experiment 4 was a control experiment.

To preview, our results revealed a clear dissociation: prior experience increased the visibility and the discriminability of the prime but did not affect response priming.

3. Experiment 1

In this experiment we examined whether clearly perceiving a stimulus on a recent occasion increases the probability that a similar stimulus will gain access to conscious awareness. To do that, we investigated awareness priming by disentangling prior conscious experience from prior exposure to a physically strong stimulus. Then, having established that awareness priming indeed occurs, we addressed our main research question and tested whether prior conscious experience not only promotes conscious access but also increases response priming.

3.1. Methods

3.1.1. Participants

Thirteen undergraduate students from Tel Aviv University (13 right-handed, 8 women), age 20–29 years (M = 24.46 SD = 2.63) were tested in one session for course credit. All participants reported normal or corrected-to-normal vision.

3.1.2. Apparatus

Stimuli were presented in a dimly lit room on a 17-in. 85-Hz CRT monitor. A chin rest was used to set the viewing distance to approximately 50 cm from the monitor.

3.1.3. Stimuli

Sample displays are presented in Fig. 1. The fixation display consisted of a plus sign ($0.2° \times 0.2°$ of visual angle). The prime and target-mask displays consisted of a small ($1.6° \times 0.8°$) and a larger ($2.1° \times 1.1°$) horizontal arrows, respectively, centered at fixation. Thus, the target-mask arrow completely covered – and masked – the prime arrow. Both arrows were gray (RGB 127, 127, 127) against a black background (RGB 0, 0, 0), and pointed either leftwards or rightwards. Thus, the prime and target arrows pointed either in the same direction (congruent trials) or in opposite directions (incongruent trials). On *go* trials the target arrowhead was intact, whereas on *no-go*[4] trials, it was truncated.

3.1.4. Procedure and design

On each trial, participants provided two responses: they first made a speeded response to the target-mask arrow direction by pressing designated keys as fast as possible on the numerical keypad with their right hands ('1' when it pointed to the left and '3' when it pointed to the right). Then, they provided a subjective report of the prime visibility using a scale ranging from 0 ("I saw nothing at all") to 3 ("I saw the arrow clearly"). This scale is similar to PAS (Ramsøy & Overgaard, 2004) except that it starts with 0 instead of 1 – which we take to be more congruent with the experience it describes. Subjects pressed designated keys ('z', 'x', 'c' and 'v' which were covered with stickers labeled 0, 1, 2 and 3, respectively) on the keyboard with their left hands.

Each trial began with a 500-ms presentation of the fixation display. The prime display then appeared for 24 ms, followed after a variable inter-stimulus interval (0, 24, 47, 71 or 94 ms) by a 94-ms target-mask display, corresponding to stimulus-onset asynchronies (SOAs) of 24, 47, 71, 94, or 118 ms, respectively. Then, a blank screen appeared until participants provided the second response or after 1500 ms had elapsed. Finally, a question mark in the middle of the screen prompted the participants to provide the second response. A new trial began immediately after the second response.

All prime-target SOAs were randomly mixed across trials presented in 10 blocks of 50 trials each. In addition, before running on the experimental trials, participants underwent 10 practice trials in which the prime and target displays were presented for 188 and 282 ms, respectively. Participants were allowed a short break after each block.

An additional 4% of the trials were catch trials, in which the target was presented alone, without a prime and 4% were *no-go* (truncated-target) trials in which observers had to press the space-bar with no time pressure instead of providing the responses pertaining to the prime and target (see footnote 3). The four possible combinations of prime and target arrow directions were equiprobable and randomly mixed. The five possible SOAs were equiprobable.

3.1.5. Statistical methods

As is to be expected when using multi-point scales for subjective reports, different participants used each visibility rating on a different proportion of the trials. In order to overcome the resulting

[4] Although these trials did require a response (pressing the spacebar), we refer to them as no-go trials in the sense that participants were required to refrain from performing the direction-discrimination and visibility-rating tasks that they had to execute on the remaining trials. The rationale for adding a go no-go task is explained in Experiment 2's methods section.

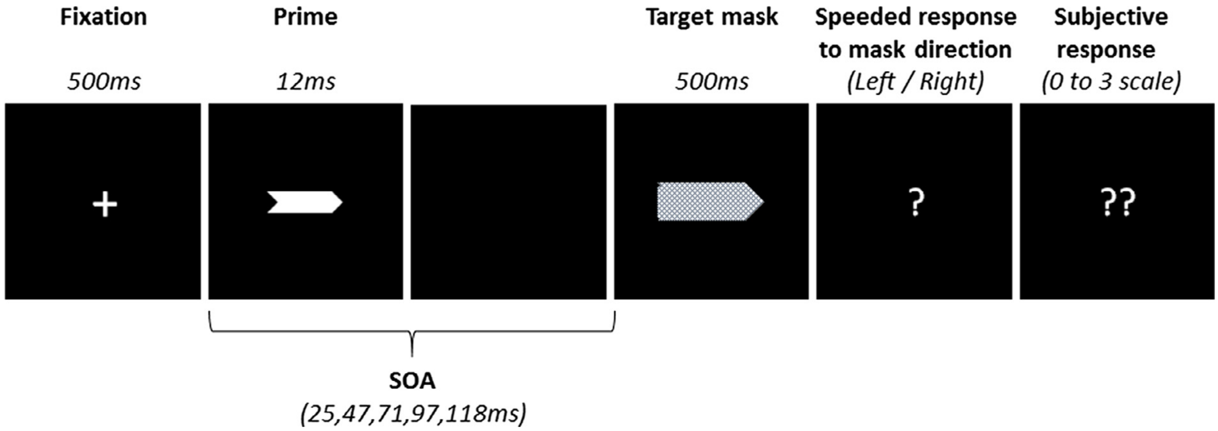

Fig. 1. Sequence of events in Experiment 1. Participants were required to make a speeded response to the target-mask arrow direction (left or right) and then rate the subjective visibility of the prime arrow (on a 0-to-3 scale). In this example, the directions of the prime and target arrows are congruent.

distortions, in all experiments we used a linear mixed-effects model in analyses including prime visibility (on the current trial or on a previous trial) as a factor.

Several of our critical predictions rely on null effects. As classic significance tests do not allow one to evaluate the evidence in favor of the null hypothesis, we used Bayesian statistics (see Rouder, Speckman, Sun, Morey & Iverson, 2009 and Hoeting, Madigan, Raftery, & Volinsky, 1999 for details). To perform these analyses, we used the R software and more specifically, the BayesFactor package with the default parameter settings and the BAS package with the uniform prior. In the following analyses, the Bayes Factor BF01 (i.e., evidence in favor of the null hypothesis) is reported.

3.2. Results

The data from one subject were excluded from analysis because of a technical failure. In all RT analyses, trials in which responses to the target direction were inaccurate were excluded (1.5%) and so were trials in which the RT exceeded the mean of its cell (resulting from crossing the factors included in the relevant analysis) by >2.5 standard deviations (fewer than 1% of the trials). Preliminary analyses confirmed the reliability of the participants' subjective reports: these rated 74.5% (range = [57.8%, 100%], SE = 7.3%) of all catch trials with a visibility rating of 0 and only 2.5% (range = [0%, 5.5%], SE = 2.2%) with a visibility rating of 3. In all the experiments of the present study, prime-absent (or catch) trials and no-go trials (as well as trials in which the previous trial relevant for the analysis of a sequential effect was a catch trial or a no-go trial) were excluded from all RT and accuracy analyses.

3.2.1. Prime visibility

We conducted a linear mixed model with prime visibility on the previous trial and SOA on previous trial as within-subject factors, and mean prime visibility on the current trial as the dependent measure (Fig. 2A). There were not enough trials to include SOA *on the current trial* as an additional factor in this analysis. Although this variable obviously had a very strong impact on visibility on the current trial (because it determined the strength of masking), it is important to underscore that it was entirely independent of the SOA on the previous trial and of the visibility on the previous trial, since SOAs were randomly mixed (see Table A3 of the Appendix A for details). Thus, any significant effect in the present analysis could not be accounted for by variations of the SOA on the current trial.

The main effect of prime visibility on the previous trial was significant, $F(3,33) = 86.36$, $p < 0.0001$, indicating that prime visibility on the current trial increased as a function of prime visibility on the previous trial. The effect of SOA on the previous trial was also significant, $F(4,44) = 4.37$, $p = 0.0046$ and was modulated by a significant interaction with prime visibility on the previous trial, $F(12,122) = 2.02$ $p = 0.028$. Follow-up comparisons revealed that the effect of SOA on the previous trial was significant only when prime visibility on the previous trial had been 3, $F(4,36) = 4.59$, $p < 0.0043$, all other ps > 0.3. By contrast, the effect of prime visibility on the previous trial was significant for all conditions of SOA on the previous trial, all ps < 0.0001.

Mean visibility ratings do not provide information about the distribution of visibility ratings. Thus, the finding that current prime visibility increased with prime visibility on the previous trial might not reflect better access of the prime to consciousness but instead indicate higher visibility only for primes that were consciously perceived (albeit not in the clearest form) without awareness priming. In order to test this possibility we examined whether the proportion of 0-visibility ratings on the current trial was significantly reduced when visibility on the previous trial had been 3 relative to when it had been 0, independently of the stimulus' physical strength (i.e., of the SOA) on the previous trial. Accordingly, we conducted a linear mixed model analysis with visibility on the previous trial (0 vs. 3) and SOA on the previous trial as within-subject factors, and the proportion of 0-visibility ratings on the current trial as the dependent measure. Only the main effect of visibility on the previous trial was significant, indicating that there were fewer 0-ratings following a high-relative to a low-visibility trial, 16.52% vs. 35.81%, respectively, $F(1,11) = 54.90$, $p < 0.0001$. Paired comparisons showed that this effect was significant for each condition of SOA on the previous trial, all ps < 0.02. Neither the main effect of SOA on the previous trial nor the interaction between the two factors approached significance, $F(4,44) = 1.04$, $p = 0.40$ and $F(4,36) = 1.53$, $p = 0.21$, respectively. Thus, awareness priming increased the probability that masked primes cross the limen of consciousness.

We also examined the influence of a trial further back than the previous trial (Fig. 2B). To do so, we assessed the effect of prime visibility on trial *n-i* on prime visibility on the current trial when prime visibility had been null on all intermediate trials. This effect was significant for trial *n-2*, $F(3,26) = 11.21$, $p < 0.0001$, approached significance for trial *n-3*, $F(3,32) = 2.54$, $p = 0.073$, and was no longer significant for trial *n-4*, $F(3,26) = 1.43$, $p = 0.256$.

3.2.2. Response priming

We conducted a linear mixed model analysis with prime visibility on the previous trial, SOA on the previous trial and response

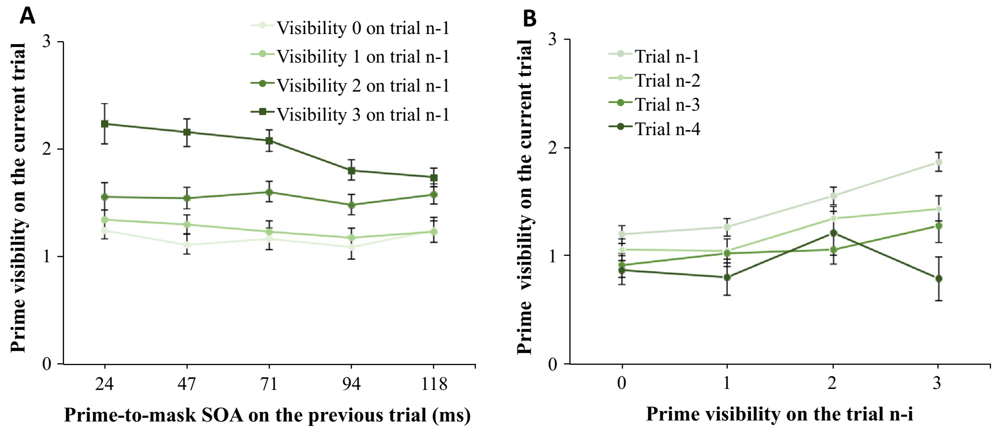

Fig. 2. Effects of awareness priming on prime visibility in Experiment 1. Panel A: Mean prime visibility on the current trial as a function of prime-target SOA on the previous trial for each condition of prime visibility on the previous trial. Panel B: Mean prime visibility on the current trial as function of prime visibility on trial *n-i* (with *i* varying from 1 to 4), when visibility had been null on all intermediate trials. Error bars represent within-subject standard errors (Morey, 2008).

congruency on the current trial as within-subject factors, and performance on the current trial as the dependent measure. Only effects involving response congruency are of interest in this analysis. Mean RTs and accuracy are reported in Table A1 of Appendix A.[5]

3.2.2.1. Reaction times. Congruent trials were faster than incongruent trials, M = 549 ms, SD = 44.1 vs. M = 586 ms, SD = 43.9, $F(1,11) = 34.76$, $p < 0.0001$. Crucially, this response priming effect did not interact with prime visibility on the previous trial, $F < 1$ – if anything, the results show a numerical trend towards smaller response priming as visibility on the previous trial increased (Fig. 3A). In order to further examine the claim of a null interaction between response priming and visibility on the previous trial, we used Bayesian Model Averaging (BMA, Hoeting et al., 1999) and found the marginal posterior inclusion probability of the interaction to be 0.038. There was no other significant effect, all Fs < 1.

3.2.2.2. Accuracy. Only the 3-way interaction approached significance, $F(16,154) = 1.61$, $p = 0.073$. Yet, follow-up analyses showed that the interaction between response congruency and visibility on the previous trial were non significant for all SOAs on the previous trial, Fs < 1.

3.3. Discussion

Experiment 1 yielded two main findings. First, we showed that the more clearly a stimulus is seen on a recent trial the higher the visibility of a similar stimulus on the current trial, and so, irrespective of its physical strength. Thus, this is the first demonstration of a genuine awareness priming effect that is independent of stimulus strength. Notably, such influence was exerted by trials as far as 3 trials back. Second, we showed that while this awareness priming effect was large, it was not paralleled by any effect of previous visibility on response priming.

One may argue that the response priming measure was less sensitive than the prime visibility measure, which would explain why visibility on the previous trial appeared to affect only the latter but not the former. In order to test this possibility, we examined the effects of a variable known to affect both response priming and visibility on the current trial, namely, the SOA on the current trial (which determines masking strength). As expected, both visibility and response priming indeed increased with the SOA on the current trial, both ps < 0.0001 (Fig. 3B). Crucially, however, the comparison between Fig. 3A and B shows that response priming was not less sensitive than visibility. To illustrate, consider the increase in SOA on the current trial from 71 to 94 ms (Fig. 3B) and the increase in prime visibility on the previous trial from 2 to 3 (Fig. 3A). Both increases boosted prime visibility on the current trial *to the same extent* (from about 1.6 to 1.9), yet they produced markedly different effects on response priming: the increase in SOA on the current trial substantially increased response priming (Fig. 3B), while the increase in prime visibility on the previous trial tended to reduce it (Fig. 3A). We therefore conclude that the differential effect of prior conscious experience on prime visibility and response priming does not reflect a difference in sensitivity between the two measures.

4. Experiment 2

Experiment 2 was similar to Experiment 1 except that before reporting the visibility of the prime arrow observers judged its direction instead of the mask's direction. The mask arrow was bidirectional instead of pointing to either the right or left in order to prevent retroactive priming from the mask to the prime (e.g., Dark, 1988). To ensure that observers divided their attention between the prime and the mask, as they were required to do in Experiment 1, no-go trials were again included. On such trials, the mask arrow was truncated and observers had to press the spacebar instead of responding to the prime.

The objective of this procedure was three-fold. First, we sought to generalize our findings from a subjective to an objective measure of conscious perception. Specifically, we investigated whether prior conscious experience with the prime would improve conscious perception of similar primes on subsequent trials, when conscious perception is assessed using an objective measure (forced-choice discrimination of the prime direction), as reported by Lin and Murray (2014).

Second, we tested the possibility that the finding of Experiment 1 might indicate that prior experience induced a response bias towards higher visibility ratings rather than genuinely increasing observers' subjective awareness. To address this issue, we performed a Type-2 signal detection analysis (e.g., Galvin, Podd, Drga, & Whitmore, 2003; Kanai, Walsh & Tseng, 2010; Kunimoto,

[5] It is noteworthy that in this experiment as well as in Experiments 3 and 5, overall RTs increased as the visibility rating became higher. This finding was also reported by Lamy et al. (2015) and Peremen and Lamy (2014b). It raises the possibility that conscious perception of an object impairs the processing of a subsequent object appearing in close temporal proximity. We are currently investigating this "cost of awareness" (Ophir, Sherman, & Lamy, 2016).

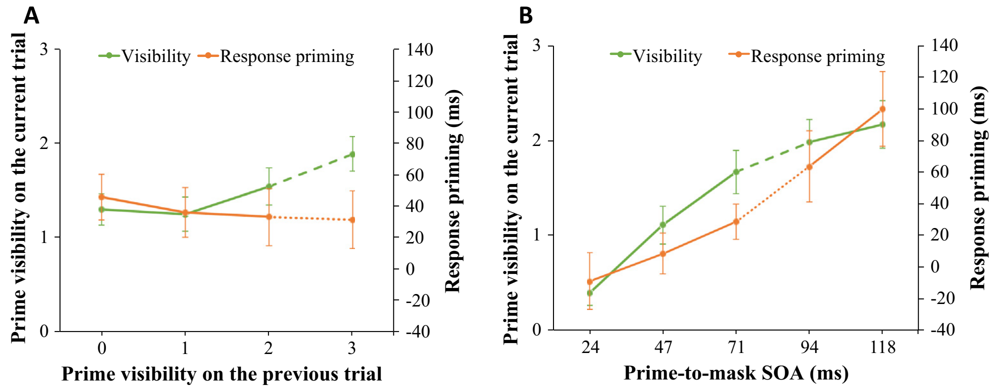

Fig. 3. Comparison of the effects of visibility on the previous trial and SOA on the current trial on response priming (in milliseconds) and on prime visibility in Experiment 1. Panel A: Mean response priming and mean prime visibility on the current trial as a function of prime visibility *on the previous trial*. Panel B: Mean response priming and mean visibility on the current trial as a function of prime-target SOA *on the current trial*. Error bars represent within-subject standard errors. The dashed lines single out portions of the graphs in which increases in visibility on the previous trial (panel A) and in current SOA (panel B) have a similar impact on visibility on the current trial (i.e., an increase from roughly 1.6 to 1.9). The dotted lines show the corresponding changes in response priming. The rationale for this comparison is explained in the discussion of Experiment 1.

Miller & Pashler, 2001; Lin & Murray, 2014) to measure the metacognitive sensitivity of the observers in discriminating between correct and incorrect responses. According to the Type 2 signal-detection analysis framework, metacognitive sensitivity measures the extent to which subjective reports are predictive of discrimination accuracy and is free of any response bias. Although Type-2 meta-cognitive sensitivity is typically calculated based on observers' confidence judgments about the correctness of their discrimination response of a stimulus property (e.g., Kolb & Braun, 1995; Kunimoto et al., 2001), Lin and Murray (2014) recently extended this procedure to PAS visibility ratings and measured the extent to which higher visibility ratings were associated with more correct discrimination responses than lower visibility ratings. They showed that metacognitive sensitivity for barely seen targets was higher when these were intermixed with clearly visible targets than when presented alone. They concluded that the higher awareness they observed in the intermixed condition did not result from a change in the response criterion. In Experiment 2, we used the same rationale and method as Lin and Murray's (2014) to determine whether prior conscious experience indeed increased Type-2 meta-cognitive sensitivity, which is uncontaminated by response biases.

Finally, we sought to determine whether the lowest rating on the PAS scale (denoting 'no experience' and labeled "1" in the scale's original form but '0' in our variant of it) is associated with chance objective performance on prime discrimination. Such a finding has been reported before (e.g., Lamy et al., 2015; Peremen & Lamy, 2014a; Ramsøy & Overgaard, 2004). Here, we sought to replicate it because in the present context, it would reinforce our conclusion that prior experience with a stimulus increases the probability that this stimulus achieves conscious access.

A corollary goal of Experiment 2 was to determine the extent to which the awareness priming effect observed in Experiment 1 was stimulus specific. Clearly seeing a left-pointing prime arrow might either increase only the visibility of a subsequent left-pointing prime arrow, or benefit both types of arrow because they are physically similar. In the latter case, the effect of prior experience would be to inform the observer of what specific instantiation of an arrow was used in the experiment, out of all the possible instantiations evoked by the instruction "the target will be preceded by a prime *arrow*". The reason why we did not assess shape-specific priming in Experiment 1 is that the target mask, which was also a directional arrow, intervened between the prime arrows on the previous and current trials and would therefore contaminate any direction-specific effect (e.g., Peremen & Lamy, 2014a, Experiment 1). As will become clear below, we could probe shape-specific priming in Experiment 2 because the mask was no longer directional.

4.1. Methods

4.1.1. Participants

Twelve undergraduate students from Tel Aviv University (12 right-handed, 9 women), age 18–35 years (M = 26.08 SD = 2.71) were tested in one session for course credit. All participants reported normal or corrected-to-normal vision.

4.1.2. Apparatus, stimuli, procedure and design

The apparatus, stimuli, procedure and design were similar to those of Experiment 1, except for the following changes. The mask arrow was bidirectional instead of pointing to either the left or right, and on *no-go* trials, both arrowheads were truncated. Observers again provided two responses but both pertained to the prime. They first produced a non-speeded discrimination response regarding the prime direction (left or right) by pressing designated keys on the numerical keypad with their right hands ('1' when the arrow pointed to the left and '3' when it pointed to the right) and then reported the prime visibility as in Experiment 1. The percentage of no-go trials was increased to 20%.

4.2. Results

The data from one participant were excluded from all analyses because his prime identification performance departed from the mean by more than 2 standard deviations (M = 0.35 vs. M = 0.70, SD = 0.16). Prime-absent (or catch) trials and no-go trials were also excluded. Preliminary analyses confirmed the reliability of participants' subjective reports: these rated 83.0% (range = [67.7%, 100%], SE = 6.6%) of all catch trials with a visibility rating of 0 and only 5.7% (range = [0%, 11.2%], SE = 2.9%) with a visibility rating of 3.

4.2.1. Prime visibility

We conducted a linear mixed model analysis with shape repetition, prime visibility on the previous trial and SOA on previous trial as within-subject factors and mean prime visibility on the current trial as the dependent measure. Prime visibility on the current trial again significantly increased as a function of prime visibility on the previous trial, $F(3,29) = 38.67$, $p < 0.0001$.This effect interacted with shape repetition, $F(3,28) = 4.19$, $p = 0.014$, indicating that shape priming increased as prime visibility on the previous trial increased. Crucially, however, prime visibility on the previous trial improved prime visibility on the current trial both when the prime shape repeated, $F(3,29) = 40.80$, $p < 0.0001$ and when it changed, $F(3,28) = 9.29$, $p < 0.0002$.[6] There was no other significant effect, all ps > 0.2. In particular, the main effect of SOA on the previous trial was not significant, $F(4,40) = 1.08$, $p > 0.37$, and did not interact with prime visibility on the previous trial, $F < 1$ (see Fig. 4).

A linear mixed model analysis with visibility on the previous trial (0 vs. 3) and SOA on the previous trial as within-subject factors, and the proportion of 0-visibility ratings on the current trial as the dependent measure again confirmed that there were fewer 0-ratings following a high-relative to a low-visibility trial, 25.40% vs. 37.73%, respectively, $F(1,10) = 33.57$, $p < 0.0002$. The main effect of SOA on the previous trial was not significant, $F < 1$, yet the interaction between the two factors approached significance, $F(4,30) = 2.34$, $p = 0.077$. Paired comparisons showed that the effect of the prime's visibility on the previous trial was significant for SOAs on the previous trial up to 71 ms, all ps < 0.006 but did not reach significance for the 94 and 118 ms SOAs, $p = 0.072$ and $p = 0.149$, respectively, despite numerical trends in the expected direction. These findings indicate that awareness priming increased the probability that masked primes cross the limen of consciousness.

Again, we examined the influence of a trial further back than the previous trial. This effect was significant for trial *n-2*, $F(3,29) = 13.30$, $p < 0.0001$, and for trial *n-3*, $F(3,29) = 5.0$, $p = 0.006$ and was no longer significant for trial *n-4*, $F(3,27) = 1.79$, $p > 0.17$.

4.2.2. Prime-direction discrimination accuracy

We conducted a similar analysis with mean prime-direction discrimination accuracy on the current trial as the dependent measure. Only the main effect of prime visibility on the previous trial was significant, $F(3,29) = 3.83$, $p < 0.02$, indicating that accuracy on the current trial increased with prime visibility on the previous trial. There was no other significant effect, all Fs < 1. In particular, the effect of prime visibility on the previous trial interacted neither with shape repetition, nor with SOA on the previous trial. Prime visibility on trials earlier than the previous trial did not affect discrimination performance, ps > 0.28 for trials *n-2* and *n-3*.

Subjective visibility and prime discrimination performance followed the same time course (Fig. 5). An additional analysis showed that prime discrimination accuracy did not differ from chance (50%) when participants rated prime visibility to be 0, M = 52.7%, SD = 0.08, $t(10) = 1.17$ $p = 0.27$. In order to better assess the probability of chance performance (i.e., a null effect), we used Bayesian inference (Rouder, Speckman, Sun, Morey, & Iverson, 2009). The Bayesian inference provided weak support for the null hypothesis, Bayes Factor (BF01) = 1.92, p(H0|D) = 0.66.

4.2.3. Type-2. sensitivity

We assessed observers' metacognitive sensitivity to the correctness of their discrimination responses by calculating Type-2 sensitivity following the method reported by Lin and Murray (2014; see also Kunimoto et al., 2001).

$$\text{Type-2 sensitivity} = z(\text{Type-2 hit rate}) - z(\text{Type-2 false alarm rate})$$

where

Type-2 hit rate = p(high rating/correct response)
Type-2 false alarm rate = p(high rating/incorrect response)
High-rating trials corresponded to trials with a visibility rating >0 (Footnote 6)

This analysis showed that Type-2 sensitivity was larger following a trial in which the prime had been consciously perceived (i.e., with a visibility rating of 1, 2 or 3) than following a trial in which the prime had not been consciously perceived (i.e., with a visibility rating of 0), Type-2 $d' = 0.85$ (SD = 0.38) vs. 0.62 (SD = 0.34), respectively, $t(10) = 2.04$, $p = 0.03$.

4.3. Discussion

The results of Experiment 2 provided clear answers. First, we replicated the awareness priming effect observed in Experiment 1: the more clearly a stimulus was seen on a recent trial (irrespective of its physical strength) the more likely a similar stimulus was to gain conscious access on the current trial, both when visibility and when objective forced-choice discrimination performance were used to gauge conscious perception. Second, a Type-2 signal detection analysis showed that prior conscious experience improved metacognitive sensitivity, that is, the extent to which prime visibility ratings predicted prime discrimination accuracy. This result removes any concern that prior conscious experience affected only response biases. Third, we showed that the prime-visibility and discrimination-accuracy measures followed the same time course. Moreover, these measures were not differentially sensitive to conscious perception, as prime discrimination was no better than chance when prime visibility was rated to be null - although support for the null hypothesis was weak (but see Experiment 4). Finally, we found that awareness priming is not strictly stimulus specific. Indeed, while shape repetition significantly modulated awareness priming (albeit only on the subjective measure), awareness priming was observed even when the prime shapes on the current and previous trials were different.

5. Experiment 3

The purpose of Experiment 3 was two-fold. First, we attempted to replicate the main findings of Experiment 1 using a nominally different manipulation of prior experience. To do that, we contrasted the following prior-experience and no-prior-experience conditions. The prior-experience condition was similar to Experiment 1 and is henceforth referred to as the mixed-SOA condition. In this condition, clear exemplars of the stimuli were encountered recurrently across the experiment and from its beginning. In the no-prior-experience condition prime-mask SOAs were blocked and presented in ascending order (blocked-SOA condition): the most strongly masked trials occurred at the beginning of the experiment and the most weakly masked appeared at the end. Thus, primes became more likely to be visible as the experiment progressed. Note that exactly the same physical trials were presented in the two conditions and that these differed only in presentation order. We expected higher prime visibility in the mixed- than in the blocked-SOA condition (in line with previous reports, e.g., Lin & Murray, 2014; Pratte & Rouder, 2009) but a response-priming effect of the same magnitude in the two conditions.

[6] Lin and Murray (2014) grouped the lowest two visibility ratings in the "low-rating" category and the highest two in the "high-rating" category. In our experiment, only the lowest rating (0) was included in the low-rating category, whereas the remaining ratings (1, 2 and 3) were included in the high-rating category. We based this decision on the results of a preliminary test comparing the observed proportions of 1-ratings on prime-present and prime-present trials against the actual distribution of prime-present vs. absent-trials, which revealed that 1-ratings were predictive of the prime's presence. Note, however, that the improvement in Type 2 sensitivity when the prime had been consciously perceived on the previous trial relative to when it had not was also significant when 1-ratings were entered in the low-rating category, as in Lin and Murray's (2014) study.

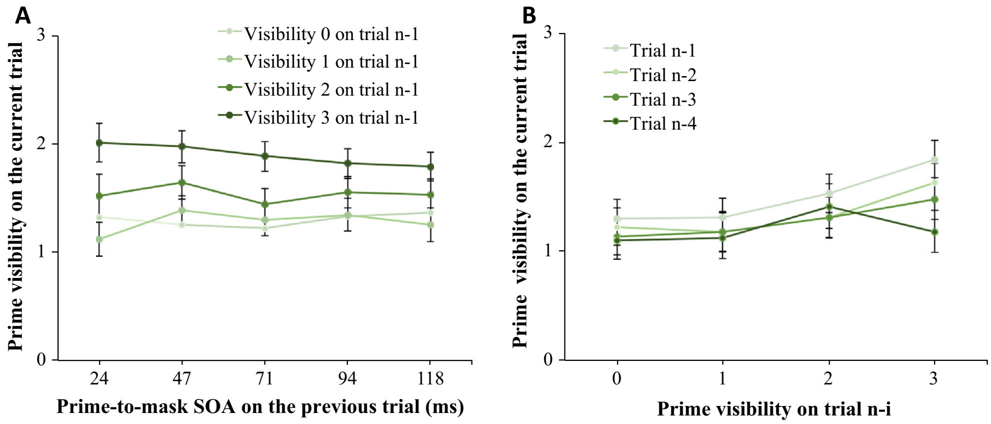

Fig. 4. Effects of awareness priming on prime visibility in Experiment 2. Panel A: Mean prime visibility on the current trial as a function of prime-target SOA on the previous trial for each condition of prime visibility on the previous trial. Panel B: Mean prime visibility on the current trial as function of prime visibility on trial *n-i* (with *i* varying from 1 to 4), when visibility had been null on all intermediate trials. Error bars represent within-subject standard errors.

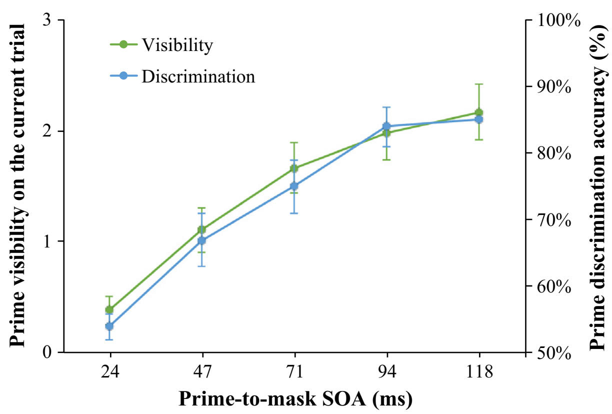

Fig. 5. Mean prime visibility and prime-discrimination performance on the current trial as a function of prime-target SOA on the current trial in Experiment 2. Error bars represent within-subject standard errors.

Second, we further examined awareness priming by looking at the effect from trials further back than in Experiments 1 and 2. In these experiments, we found the effect to be significant only from 1 to 3 trials back. However, as 0-visibility trials made up only 23% and 33% of all trials, respectively, the number of trials relevant for the analysis dropped dramatically as the number of trials back increased. Thus, power may have been insufficient to detect longer-term effects. Here, we increased the number of 0-visibility trials by using a larger proportion of short-SOA trials, thereby increasing the number of usable trials in the analysis of awareness priming from previous trials.

5.1. Method

5.1.1. Participants

Twenty-nine undergraduate students from Tel Aviv University (all right-handed, twenty-four women), age 20–30 years (M = 23.43, SD = 2.35) were tested in one session for course credit. All participants reported normal or corrected-to-normal vision.

5.1.2. Apparatus, stimuli, procedure and design

The apparatus, stimuli, procedure and design were similar to those of Experiment 1 except for the following changes. All stimuli were presented on an LCD monitor (SyncMaster) with 1920∗1080 resolution and 120 Hz refresh rate.[7] The prime appeared for 16.7 ms (instead of 24 ms) and was followed by the target-mask display with an SOA of 25, 33, 42, 50, or 125 ms (instead of 24, 47, 71, 94 or 118 ms). For half of the participants (mixed-SOA condition) SOAs were randomly mixed across trials as they were in Experiment 1. For the other half (blocked-SOA condition), trials with a given prime-target SOA were administered in two successive blocks of 50 trials each and the resulting five block pairs were presented in ascending order. Participants in this group did not undergo practice and were therefore not preexposed to long-duration sample prime and target displays prior to running on the experimental trials. These conditions are illustrated in Fig. 6.

5.2. Results

In all RT analyses, trials in which the response to the target direction was inaccurate were excluded (1.5% of all trials) and so were outlier-RT trials (fewer than 2% of all trials). Preliminary analyses confirmed the reliability of the participants' subjective reports: in the mixed-SOA and blocked-SOA conditions, the participants rated 87.2% (range: [72.2–100%], SE = 3.6%) and 82.0% (range: [68.4–100%], SE = 6.1%), respectively, of all catch trials with a visibility rating of 0 and 1.1% (range: [0–12.4%], SE = 0.6%) and 5.7% (range: [0–10.5%], SE = 2.7%), respectively, with a visibility rating of 3. The distribution of prime visibility ratings on prime-present trials as a function of the SOA on the current trial is presented in Fig. A1 of the Appendix A, separately for the mixed-SOA and for the blocked-SOA conditions.

This section includes two sets of analyses. In the first set, we examined the effects of awareness priming on visibility ratings and on response priming in the mixed-SOA condition in order to replicate the results from Experiments 1 and 2, while also looking at the impact of trials further back than 3 trials. In the second set, we examined the impact of prior experience by comparing mean prime visibility and response priming in the blocked- vs. mixed-SOA conditions.

[7] CRT and LCD monitors are based on very different technologies for visual stimulus presentation. Concerns have been raised with regard to possible differences in display persistence between the two technologies and to the suitability of LCD monitors for visual experiments in which presentations times are of the essence. However, recent psychophysical studies show that there is no longer any basis for such concerns with newer generations of LCD monitors (e.g., Lagroix, Yanko, & Spalek, 2012; Wang & Nikolic, 2011).

Fig. 6. Illustration of the prime-target SOA distribution across trials in the mixed- and in the blocked-SOA conditions (Experiment 3) as well as in the blocked-SOA condition with prior experience (Experiment 5). The shorter (and lighter) blue bars represent the shorter prime-target SOAs. The orange bars represent the highly above-threshold prime-target SOA used during practice. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5.2.1. Replication: Awareness priming in the mixed-SOA condition

5.2.1.1. Prime visibility. We conducted a linear mixed model analysis on trials from the mixed-SOA condition with prime visibility on the previous trial and SOA on previous trial as within-subject factors and mean prime visibility on the current trial as the dependent measure (Fig. 7A). The main effect of prime visibility on the previous trial was significant, $F(3,42) = 75.95$, $p < 0.0001$, indicating that prime visibility on the current trial increased with prime visibility on the previous trial. The main effect of SOA on the previous trial was not significant, $F(4,56) = 1.92$, $p > 0.1$ and the interaction between the two factors also failed to reach significance, $F(12,145) = 1.66$, $p = 0.09$. Again, the effect of prime visibility on the previous trial was significant for all SOAs, all ps < 0.05.

A linear mixed model analysis with visibility on the previous trial (0 vs. 3) and SOA on the previous trial as within-subject factors, and the proportion of 0-visibility ratings on the current trial as the dependent measure again confirmed that there were fewer 0-ratings following a high-relative to a low-visibility trial, 18.69% vs. 37.97%, respectively, $F(1,14) = 60.60$, $p < 0.0001$. This effect was significant for each condition of SOA on the previous trial, all ps < 0.01, and no effect involving the latter factor was significant, both Fs < 1. These findings indicate that awareness priming increased the masked primes' access to consciousness.

Analyses of the influence of a trial further back than the previous trial revealed a significant impact of all trials as far back as trial *n-5*, all ps < 0.0001 (Fig. 7B). The influence of trial *n-6* was non-significant, F < 1.

5.2.1.2. Response priming. We conducted a linear mixed model analysis with response congruency, prime visibility on the previous trial and prime-target SOA on previous trial as within-subject factors.

5.2.1.3. Reaction times. Only effects involving response congruency were of interest in this analysis. Only the main effect of response congruency was significant, $F(1,14) = 34.23$, $p < 0.0001$. Crucially, the interaction between response congruency and prime visibility on the previous trial was not significant, F < 1. In order to further examine the claim of a null interaction between response priming and visibility on the previous trial, we used Bayesian Model Averaging (BMA, Hoeting et al., 1999) and found the marginal posterior inclusion probability of the interaction to be 0.034. Unlike in Experiment 1, the interaction between response congruency and SOA on the previous trial reached significance, $F(4,56) = 2.74$, $p = 0.037$, yet follow-up comparisons did not show any significant effects. The 3-way interaction was non-significant, F < 1.

5.2.1.4. Accuracy. Only the main effect of response congruency was significant, with fewer errors when the prime and target arrows pointed in the same than in different directions, $F(1,14) = 8.29$, $p = 0.012$. There was no other significant effect, all ps > 0.15.

5.2.2. Comparison of the blocked -vs. mixed-SOA conditions

5.2.2.1. Prime visibility. Mean prime visibility scores as a function of prime-mask SOA are presented in Fig. 8. We conducted an ANOVA with design (mixed-SOA vs. blocked-SOA) as a between-subjects factor, SOA (25, 33, 42, 50 or 125 ms) as a within-subject factor and mean prime visibility as the dependent measure. The two main effects were significant: prime visibility was higher when the different SOAs were randomly mixed than when they were blocked (M = 1.24, SD = 0.58 vs. M = 0.95, SD = 0.87, respectively), $F(1,27) = 4.62$, $p < 0.05$, and increased with increasing SOAs, $F(4,108)$=231. 93, $p < 0.0001$. These factors interacted, $F(4,108) = 18.20$, $p < 0.0001$. Follow-up analyses revealed that for SOAs up to 50 ms, prime visibility was higher in the mixed-SOA than in the blocked-SOA condition, $F(3,81) = 27.35$, $p < 0.0001$, with this difference growing as the SOA increased, $F(3,81) = 8.25$, $p < 0.0001$. Specifically, while prime visibility increased with SOA in the mixed-SOA condition, $F(3,42) = 44.24$, $p < 0.0001$, it remained flat in the blocked-SOA condition, $F(3,39) = 1.78$, $p > 0.16$. For the 125 ms SOA, the effect was reversed, $F(1,27) = 6.65$, $p = 0.027$, with slightly higher prime visibility in the blocked-SOA than in the mixed-SOA condition.

Finally, to examine whether the present manipulation of prior conscious experience also increased the masked primes' access to consciousness we conducted a linear mixed model analysis with design (mixed-SOA vs. blocked-SOA) as a between-subjects factor and SOA on the current trial as a within-subject factor, and the proportion of 0-visibility ratings as the dependent measure. There were fewer 0-ratings in the mixed-relative to the blocked-SOA condition, 26.75% vs. 50.16%, respectively, $F(1, 27) = 9.45$, $p = 0.0048$. This effect interacted with SOA on the current trial, $F(4, 108) = 122.04$, $p < 0.0001$, indicating that the effect of prior experience was significant for all SOAs, ps < 0.01, except for the 125-ms SOA, F < 1.

As SOAs in the blocked-SOA condition were always presented in ascending order, while in the mixed-SOA condition they were presented in random order, these conditions also differed in the time within the experiment at which a given SOA occurred, and thus in the participants' practice with the task. For instance, a 25-ms SOA trial always occurred in the first 100 trials in the blocked-SOA condition, whereas it could occur at the end of the experiment in the mixed-SOA condition. In order to address this concern, we conducted additional analyses in which data from only the relevant block for a given SOA was entered into the analysis of the mixed-SOA condition. Thus, for instance, for the 33 ms-SOA condition, only the trials that occurred in the third and forth blocks of trials (as they did in the blocked-SOA condition) were included. As is clear from Fig. 8, this analysis yielded a similar pattern of results.

5.2.2.2. Response priming. Having demonstrated that mixing short- and long-SOA trials increased prime visibility on short-SOA trials (up to 50 ms), we set out to assess the impact of this manipulation

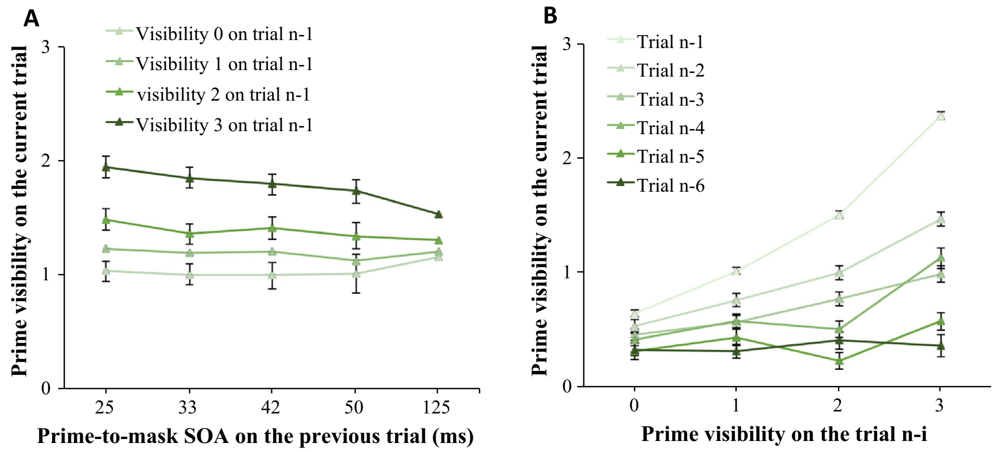

Fig. 7. Effects of awareness priming on prime visibility in the mixed-SOA condition of Experiment 3. Panel A: Mean prime visibility on the current trial as a function of prime-target SOA on the previous trial for each condition of prime visibility on the previous trial. Panel B: Mean prime visibility on the current trial as function of prime visibility on trial *n-i* (with *i* varying from 1 to 6), when visibility had been null on all intermediate trials. Error bars represent within-subject standard errors.

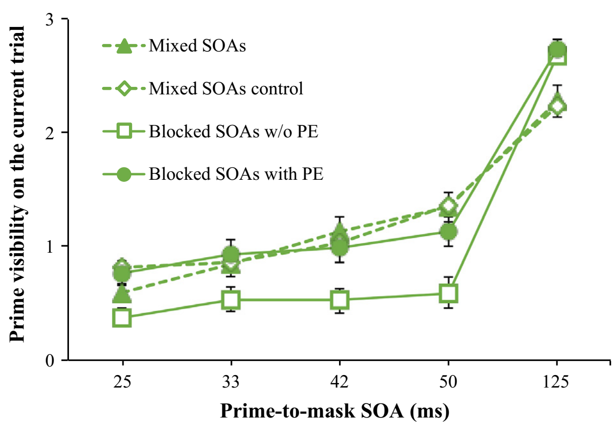

Fig. 8. Mean prime visibility on the current trial as a function of prime-target SOA on the current trial in the mixed-SOA and blocked-SOA conditions as well as for mixed-SOA trials in which block number for a given prime-target SOA was matched between the mixed- and blocked-SOA conditions (Experiment 3), and in the blocked-SOA condition with prior experience (Experiment 5). Error bars represent within-subject standard errors.

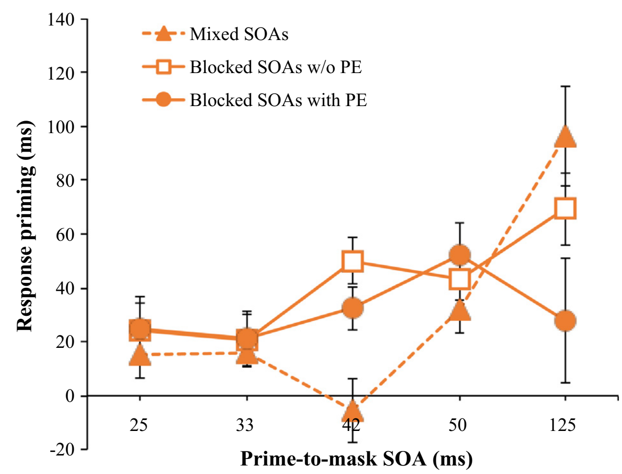

Fig. 9. Mean response priming (in milliseconds) as a function of prime-target SOA on the current trial in the mixed- and in the blocked-SOA conditions (Experiment 3) as well as in the blocked-SOA condition with prior experience (Experiment 5). Error bars represent within-subject standard errors.

on response priming in an ANOVA with design (mixed-SOA vs. blocked-SOA) as a between-subjects factor, and SOA (25, 33, 42, 50 or 125 ms) and response congruency (congruent vs. incongruent) as within-subject factors. Mean RTs and accuracy are reported in Table A1 of the Appendix A.

5.2.2.2.1. Reaction times. Response priming effects are presented in Fig. 9. The main effect of response congruency was significant, $F(1,27) = 97.93$, $p < 0.0001$, with faster RTs on congruent than on incongruent trials in both the mixed-SOA condition, M = 491 ms, SD = 159 vs. M = 524 ms, SD = 165, $F(1,14) = 30.84$, $p < 0.0001$ and the blocked-SOA condition, M = 357 ms, SD = 94 vs. M = 401 ms, SD = 88, $F(1,13) = 80.67$, $p < 0.0001$. Reaction times were also slower when the different SOAs were randomly mixed than when they were blocked, $F(1,27) = 8.02$, $p = 0.0086$ and increased as the SOA became longer, $F(4,108) = 19.31$, $p < 0.0001$. The 2-way interaction between SOA and response congruency was also significant, $F(4,108) = 16.68$, $p < 0.0001$, indicating that response priming increased with SOA. Response priming tended to be smaller across SOAs in the mixed-relative to the blocked-SOA condition, but this effect did not reach significance, $F(1,27) = 1.85$, $p = 0.18$. It was modulated by a 3-way interaction with design, $F(4,108) = 5.34$, $p < 0.0006$, which was further explored by conducting a separate ANOVA with design and response congruency as factors for each SOA. These revealed that the interactions between the two factors were non-significant for the 25- and 33-ms SOAs, Fs < 1, as well as for the 125-ms SOA, $F(1,27) = 2.27$, $p = 0.14$. However, for the 42- and 50-ms SOAs, response priming was actually smaller when SOAs when randomly mixed than when they were blocked, $F(1,27) = 18.30$, $p = 0.0002$ and $F(1,27) = 3.93$, $p = 0.058$, respectively.

5.2.2.2.2. Accuracy. A similar ANOVA on the accuracy data revealed a significant main effect of design, $F(1,27) = 13.71$, $p = 0.001$, with higher accuracy in the mixed-SOA than in the blocked-SOA condition. Thus, there was a speed-accuracy trade-off by which observers responded slower but more accurately in the mixed-SOA condition. The significant main effect of response congruency, $F(1,27) = 11.55$, $p = 0.008$, mirrored the RT data. The interactions between design and SOA, $F(4,108) = 3.66$, $p = 0.002$, and between design and response congruency, $F(4,108) = 3.64$, $p = 0.067$ were modulated by a 3-way interaction that approached significance, $F(4,108) = 2.15$, $p = 0.08$. Follow-up analyses showed that as was observed with RT data, response priming was similar in the mixed- and in the blocked-SOA conditions, all ps > 0.25, except for the 50 ms SOA $F(1,27) = 8.19$, $p < 0.001$, for which it was again smaller in the former condition.

5.3. Discussion

In this experiment we examined the effects of prior experience by assessing awareness priming (as in Experiment 1) and by comparing the mixed-SOA condition, in which clear exemplars of the prime were seen from the beginning of the experiment, with the blocked-SOA condition, in which clear exemplars were presented only at the end of the experiment.

The findings of Experiment 1 were thoroughly replicated: prior conscious experience of the prime on a given trial affected prime visibility on subsequent trials (awareness priming) but not its indirect impact on behavior: response priming was similar irrespective of how clearly the prime had been seen on the previous trial. In addition, increasing the number of 0-visibility trials by using a larger proportion of short-SOA trials than in Experiment 1 indeed allowed us to detect a substantial influence of awareness priming from trials as far back as trial *n-5*.

A conceptual replication of these findings was achieved with a different manipulation of prior experience. For the same liminal prime-target SOAs (up to 50 ms), prime visibility was higher when SOAs were mixed than when they were blocked and presented in ascending order. This finding reflected enhanced conscious access rather than higher visibility of consciously perceived primes, as the proportion of 0-visibility trials was substantially smaller in the mixed-relative to the blocked-SOA conditions. Crucially, however, this effect was not paralleled by increased response priming: if anything, response priming tended to be smaller in the mixed- than in the blocked-SOA condition. This difference appeared to stem from an unexpected drop in response priming for the 42-ms SOA.

In the next two experiments, we addressed two open questions. First, in Experiment 3 we only examined conscious access using visibility reports. The distinctive pattern in that experiment was that, instead of growing as the SOA increased, as was the case in the mixed-SOA condition, prime visibility remained flat in the blocked-SOA condition for SOAs ranging from 25 to 50 ms. Although we already demonstrated in Experiment 2, in which SOAs were randomly mixed, that both visibility and objective discrimination performance were enhanced by prior experience and followed the same time course, it would be reassuring to show that not only visibility reports but also objective discrimination performance shows the characteristic pattern observed in the blocked-SOA condition of Experiment 3. This was the objective of Experiment 4. We also again investigated whether the two measures are equally sensitive to conscious experience by examining whether prime discrimination performance was at chance level when prime visibility was null.

Second, the finding that prime visibility of trials as far as 5 trials back influenced prime visibility on the current trial raises the possibility that awareness priming may be akin to a Eureka effect (Hochstein & Ahissar, 2002), by which pre-exposure to high-visibility exemplars at the beginning of the experiment yields a conscious percept that improves perception throughout the experiment. Although the number of 0-visibility trials was increased in Experiment 3 relative to Experiment 1, our failure to detect awareness priming from trials earlier than 5 trials back may still result from an insufficient number of trials: the further back the trial the influence of which is tested, the fewer the trials available for analysis because all intervening trials must be rated with a visibility of 0. The objective of Experiment 5 was to test the existence of longer-term awareness priming.

6. Experiment 4

This experiment was similar to the blocked-SOA condition of Experiment 3, except that before reporting the visibility of the prime arrow, observers judged its direction instead of the mask target's direction. To ensure that observers divided their attention between the prime and the mask, no-go trials were again included.

6.1. Method

6.1.1. Participants

Twelve undergraduate students from Tel Aviv University (12 right-handed, 8 women,), age 18–35 years (M = 22.58 SD = 3.2) were tested in one session for course credit. All participants reported normal or corrected-to-normal vision.

6.1.2. Apparatus, stimuli, procedure and design

The apparatus, stimuli, procedure and design were similar to those of the blocked-SOA condition of Experiment 3 except that the same changes as introduced from Experiment 1 to Experiment 2 were also introduced here. Thus, both responses pertained to the prime and participants pressed the spacebar on no-go trials.

6.2. Results and discussion

Preliminary analyses confirmed the reliability of participants' subjective reports: these rated 76.2% (range = [44.4–100%], SE = 10.2%) of all catch trials with a visibility rating of 0 and only 1.9% (range = [0–5.6%], SE = 1.4%) with a visibility rating of 3.

6.2.1. Prime visibility

An ANOVA with SOA (25, 33, 42, 50 or 125 ms) as a within-subject factor and mean prime visibility as the dependent measure revealed a significant main effect of SOA, $F(4,44)=55.42$, $p = 0.0001$. Further comparisons revealed that mean visibility remained constant across SOAs up to 50 ms, $F(3,33)=1.37$, $p > 0.26$, and was significantly larger for the 125 ms SOA than for all shorter SOAs, all ps < 0.0001 (see Fig. 10).

6.2.2. Prime-discrimination accuracy

A similar analysis with mean accuracy on the prime-discrimination task as the dependent measure revealed a significant main effect of SOA, $F(4,44)=17.42$, $p = 0.0001$, that followed the same pattern as visibility reports, as is clear from Fig. 10: mean

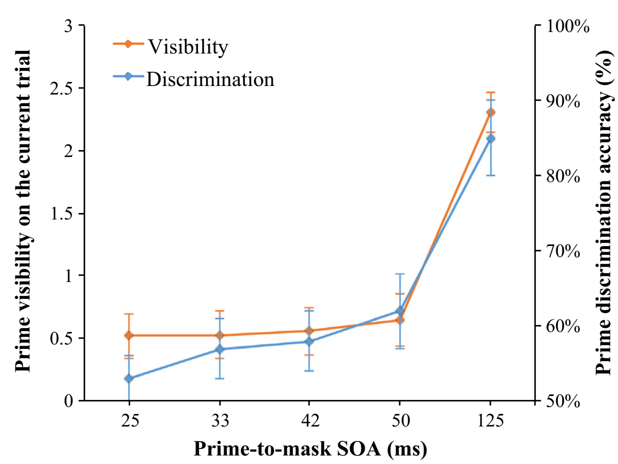

Fig. 10. Mean prime visibility and prime-discrimination performance on the current trial as a function of prime-target SOA on the current trial in Experiment 4. Error bars represent within-subject standard errors.

prime discrimination accuracy did not grow significantly across SOAs up to 50 ms, $F(3,33)$=1.90, $p > 0.14$ and was significantly larger for the 125 ms SOA than for all shorter SOAs, all ps < 0.001. Further analyses showed that prime discrimination accuracy again did not differ from chance (50%) when prime visibility was rated 0, M = 53.6%, SD = 10%, t(11) = 1.21, p = 0.25. In order to better assess the probability of chance performance (i.e., a null effect), we used Bayesian inference (Rouder et al., 2009). The Bayesian inference provided positive support for the null hypothesis, Bayes Factor (BF01) = 3.16, p(H0|D) = 0.76. Note that such support was stronger when the results from Experiments 2 and 4 were combined, Bayes Factor (BF01) = 4.40, p(H0|D) = 0.81.

The results of Experiment 4 show that the visibility-rating pattern observed in the blocked-SOA condition of Experiment 3 was closely replicated. Crucially, the same pattern was observed for discrimination performance.

7. Experiment 5

In Experiment 5, we explored the possibility that prior exposure to a consciously perceived exemplar of the prime may have longer-term effects than we detected in Experiments 1–3 of the present study. To test this possibility we compared the blocked-SOA condition of Experiment 3 to a new prior-experience condition that differed from it only in the fact that during training, participants were shown clear exemplars of the prime arrows (henceforth, blocked-SOA condition with prior experience). We expected prime visibility to be higher in the blocked-SOA condition with than without prior experience and response priming to be again unaffected by this manipulation of prior experience.

7.1. Method

7.1.1. Participants

Fourteen undergraduate students from Tel Aviv University (14 right-handed, 10 women), aged 20–30 years (M = 23.14, SD = 1.70) were tested in one session for course credit. All participants reported normal or corrected-to-normal vision.

7.1.2. Apparatus, stimuli, procedure and design

The apparatus, stimuli, procedure and design were similar to those of the blocked-SOA condition of Experiment 3 except that prior to the experiment, participants were pre-exposed to the prime and target (blocked-SOA condition with prior-experience), as described for Experiment 1. In addition, the participants underwent 10 practice trials with long-duration sample prime and target displays (200 and 300 ms, respectively) and for which the prime and target shapes clearly visible.

7.2. Results

In all RT analyses, error trials were excluded (1.2%) and so were outlier-RT trials (fewer than 1.5% of the trials). Preliminary analyses confirmed the reliability of participants' subjective reports: these rated 84.3% (range = [60.9–100%], SE = 2.8%) of all catch trials with a visibility rating of 0 and only 2.1% (range = [0–10.0%], SE = 0.9%) with a visibility rating of 3. In all the foregoing analyses, the data from the present experiment (henceforth, prior-experience condition) were compared to the blocked-SOA condition of Experiment 3 (henceforth, no-prior-experience condition). The distribution of prime visibility ratings on prime-present trials as a function of the SOA on the current trial is presented in Fig. A1 of the Appendix A.

7.2.1. Prime visibility

Mean prime visibility was significantly higher in the prior-experience than in the no-prior-experience condition, $F(1,26) = 8.93$, $p = 0.006$, (M = 1.31, SD = 0.72. M = 0.95, SD = 0.87, respectively), as well as when the SOA increased $F(4,104) = 230.88$, $p < 0.0001$. The interaction between the two factors approached significance, $F(4,108) = 2.42$, $p = 0.052$. Follow-up analyses revealed that while for SOAs up to 50 ms, visibility was higher in the prior-experience than in the no-prior-experience condition, all ps <. 03, the effect was absent for the 125 ms SOA, F < 1 (see Fig. 8).

A linear mixed model analysis with design (prior experience vs. no prior experience) as a between-subjects factor and SOA on the current trial as a within-subject factor, and the proportion of 0-visibility ratings as the dependent measure showed that there were fewer 0-ratings in in the prior-experience than in the no-prior-experience condition, 26.75% vs. 50.17%, respectively, F (1,26) = 9.30, p = 0.0052. Again, the significant interaction between the two factors, F(4,104) = 72.75, p < 0.0001, indicated that the effect of prior experience was significant for all SOAs, ps < 0.001, except for the 125-ms SOAs, F < 1.

It is noteworthy that even when looking only at the 25 ms SOA (i.e., the first two blocks), visibility was higher in the prior-experience than in the no-prior-experience condition, t(27) = 2.83, $p < 0.009$. As the 25 ms block followed practice by two minutes or so, the latter effect indicates that prior conscious perception of the prime had a longer-term effect than the 10–20 s or so that correspond to 5 trials (which is how far back awareness priming was found to be generated in Experiment 3).

7.2.2. Response priming

We conducted an ANOVA with design (prior experience vs. no prior experience) as a between-subjects factor, and SOA (25, 33, 42, 50 or 125 ms) and response congruency (congruent vs. incongruent) as within-subject factors. Mean RTs and accuracy are reported in Table 1 of the Appendix A.

7.2.2.1. Reaction times. The main effect of response congruency was significant, $F(1,26) = 118.75$, $p < 0.0001$, with faster RTs on congruent than on incongruent trials in both the blocked-SOA condition (no prior experience), M = 491 ms, SD = 159 vs. M = 524 ms, SD = 165, F(1,14) = 30.84, p < 0.0001 and the blocked-SOA condition with preexposure (prior experience), M = 423 ms, SD = 90 vs. M = 459 ms, SD = 82, F(1,13) = 37.96, p < 0.0001. The main effects of prior experience and prime-target SOA were also significant, $F(1,26) = 5.82$, $p = 0.023$ and $F(4,104) = 6.19$, $p < 0.0002$, respectively. Response congruency interacted with SOA, indicating that response priming increased with longer SOAs, $F(4,104) = 2.86$, $p < 0.027$. Crucially, the interaction between prior experience and response priming showed a trend towards *larger* response priming in the no-prior experience than in the prior-experience condition (see Fig. 9), which did not reach significance, F(1,26) = 2.29, p = 0.14. There was no other significant effect.

7.2.2.2. Accuracy. The accuracy data showed a similar pattern, with significant effects of prior experience, $F(1,26) = 5.46$, $p = 0.027$ and congruency, $F(1,26) = 10.95$, $p = 0.0027$. These effects were modulated by a significant 3-way interaction with SOA, $F(4,104) = 3.97$, $p = 0.005$, showing that the congruency effect was similar with and without prior experience for all SOAs, ps > 0.13, except for the 50 ms SOA, in which the congruency effect was larger in the prior-experience than in the no-prior-experience condition, $F(1,26) = 10.9$, $p = 0.003$. All other effects were non significant, all Fs < 1.

7.3. Discussion

Pre-exposing observers to just a few high-visibility exemplars of the prime during practice (blocked-SOA condition with prior experience) had the same influence as interspersing high-visibility exemplars across the experiment (mixed-SOA condition of Experiment 3): in both cases, prime visibility was higher with than without prior experience, while response priming was not (in fact, it showed a numerical trend in the opposite direction: response priming tended to be smaller with than without prior experience). It is noteworthy that while the results from the blocked-SOA condition with prior experience in the present experiment were very similar to those of the mixed-SOA condition in Experiment 3 in most respects (see Figs. 8 and 9), the drop in response priming for the 42-ms observed in the latter experiment did not occur here. Also note that this drop did not occur either with a similar SOA (47 ms) in Experiment 1, which also involved a mixed-SOA design. Taken together, these findings reinforce the notion that the unexpected drop in Experiment 3 was spurious.

8. General discussion

8.1. Summary of the results

The main finding of the present study is that prior conscious visual experience of an object fosters conscious access by a similar object, yet does not modulate this object's indirect impact on behavior. In all experiments, a briefly presented arrow (the prime) was masked after a variable time interval. Conscious perception of the prime was measured by collecting the observers' subjective reports on the prime's visibility on a 4-point scale or their forced-choice response on the prime's direction, and was found to be strongly modulated by three manipulations of prior conscious visual experience. First, we reported a robust awareness priming effect: how clearly a prime was subjectively perceived on a recent trial, irrespective of its physical strength, strongly affected conscious perception of the prime on the current trial. Second, primes masked to exactly the same extent were associated with increased conscious access when weakly masked exemplars were intermixed across the experiment relative to when they were presented only at the end of the experiment. Third, conscious perception in the latter condition was strongly enhanced when observers were pre-exposed to just a few high-visibility exemplars of the prime during practice, which occurred about 2 min before the experimental phase began. In sharp contrast, none of these manipulations of prior experience increased response priming, that is, the impact of the congruence between the prime's and target-mask arrow's directions on performance.

This study yielded two additional findings that are more directly relevant to research on unconscious processing: our subjective and objective measures of conscious perception followed the same time course and were equally sensitive to the presence of conscious perception, as prime discrimination performance was at chance for 0-visibility ratings.

8.2. Awareness priming

The idea that prior experience affects conscious access has already been strongly established (e.g., Chang et al., 2015; Dolan et al., 1997; Gaillard et al., 2006; Lin & Murray, 2014; Melloni et al., 2011; Pinto et al., 2015; Schwiedrzik et al., 2009; Schwiedrzik et al., 2014). The main contribution of the present findings in this respect is that we showed the determinant factor in the effect of prior experience on conscious access to be prior *conscious perception* of the critical stimulus rather than *pre-exposure to a physically salient exemplar* of this stimulus, whereas in previous experiments, the two factors were confounded.

How long does awareness priming last? On the one hand, the effect appears to be time sensitive: it was strongest the closer back in time conscious perception of the prime had occurred (see Figs. 2, 4 and 7). On the other hand, as is clear from the comparison between the blocked-SOA conditions with and without prior experience (Fig. 8), just a few exposures to highly salient exemplars of the prime sufficed to boost conscious perception of subsequent liminal primes over several blocks of trials, which indicates that the effect is rather impervious to the passage of time.

One possible resolution of this apparent inconsistency is that longer-term effects of awareness priming may result from a chain effect. Conscious perception of the prime during practice may have enhanced conscious perception on early trials of the experiment, and then conscious perception on these early trials may have facilitated conscious perception on subsequent trials and so on. Experimental trials followed practice by at least 150 s, which exceeds the time over which we found awareness priming to last (5 trials, which span over no >30 s), yet five trials may be an underestimation of the longevity of awareness priming, due to lack of power: to assess the effect of conscious perception on trial *n-5*, for instance, we looked only at sequences in which above-0 visibility of the prime on trial *n-5* was followed by four consecutive 0-visibility trials. Note also that the exemplars shown during practice were more salient than the primes shown during the experiment because their exposure duration was longer. These observations raise the possibility that more salient stimuli might generate awareness priming that wanes slower than less salient stimuli. We tested this hypothesis on the present data.

As Fig. 11 shows, in Experiment 1 awareness priming was significantly reduced from trial *n-1* to trial *n-2* when the prime on the corresponding trials involved a short-exposure consciously perceived prime (25 or 47 ms), $F(1,11) = 16.15$, $p = 0.0002$, but did not when it involved a long-exposure consciously perceived prime (94 or 118 ms), $F < 1$. Experiments 2 and 3 yielded similar results.[8]

These findings are consistent with previous demonstrations of the effects of prior experience (e.g., Dolan et al., 1997; Gaillard et al., 2006), in which just a few exposures (and sometimes only one exposure) to a clear exemplar of one stimulus improved conscious perception of an ambiguous version of that stimulus much later in the experimental session. A novel aspect of our findings is that with weak stimuli, awareness priming is shorter lived and therefore does not neatly overlap with the notion of a Eureka effect (e.g., Ahissar & Hochstein, 1997) or abrupt learning (Rubin et al., 1997).

8.3. Potential alternative accounts

Our main finding was that prior experience with a stimulus increased this stimulus' visibility but did not affect its indirect impact on behavior. We interpreted this finding as a dissociation between conscious access and response priming. Yet, several confounding factors may challenge this interpretation.

8.3.1. Response biases

One may argue that consciously perceiving the prime on a previous occasion may merely induce a response bias rather than genuinely improving conscious access. If so, the reported dissociation between conscious perception and response priming would be hardly surprising or informative. This argument mainly applies to

[8] Note that while conscious perception of a previous prime and not its prime-target SOA determines awareness priming, prime-target SOA for *a consciously perceived prime* determines how long the awareness priming it generates lasts.

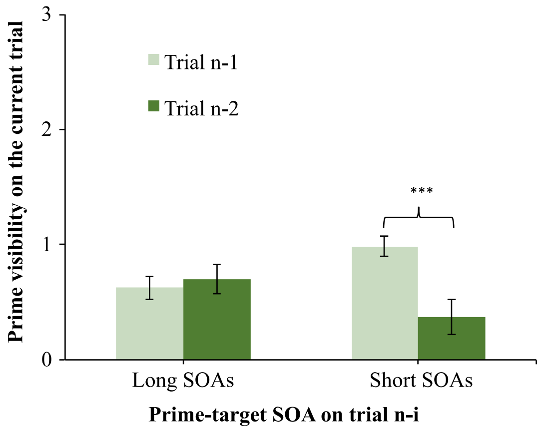

Fig. 11. Awareness priming from trial *n-1* and from trial *n-2* in Experiment 1 when prime-target SOA on those trials had been short (24 or 47 ms) vs. long (94 or 118 ms). Awareness priming is calculated as the visibility on the current trial when visibility on trial *n-i* had been 3 minus the visibility on the current trial when visibility on trial *n-i* had been 0 (with *i* = 1 or 2). Error bars represent within-subject standard errors.

the subjective visibility measure, as prior conscious experience might simply induce a response bias towards higher visibility ratings. However, our finding that prior conscious experience also improved performance on forced-choice discrimination of the prime does not suffice to overrule the response-bias argument. Indeed, recent research (e.g., Jones, Moore, Shub, & Amitay, 2015) has shown that even in the absence of a systematic bias towards one of the possible responses, a factor that improves forced-choice discrimination performance can do so by reducing non-stationary biases (e.g., the influence of the response on a recent trial on the response on the current trial). We thus directly addressed the response-bias issue by using a Type-2 signal detection analysis, which provides an estimate of metacognitive sensitivity that is free from response bias (e.g., Kunimoto et al., 2004; Lin & Murray, 2014). This analysis showed that prior conscious experience enhanced participants' metacognitive sensitivity to the correctness of their discrimination responses.

8.3.2. Long RTs associated with our dual task

The generalizability of our findings may be limited by the fact that in order to measure response priming and subjective visibility simultaneously and under the same conditions, we had to use a dual task: participants first responded to the target direction and then reported their subjective perception of the prime. As a consequence, RTs to the target were substantially slower (on the order of 100 to 150 ms) than in similar single-task response priming experiments (e.g., Vorberg et al., 2003). Based on this observation, one may argue that visibility ratings and response priming may not have the same characteristics in our study as in single-task response priming studies.

We took two steps to address this issue. First, we conducted a single-task control experiment that was similar to the mixed-SOA condition of Experiment 3 in all respects except that 15 new participants were required to respond only to the mask arrow: no visibility ratings were collected nor were participants informed of the presence of the prime. The results of this experiment showed that although, as expected, mean RTs were substantially faster in the single-than in the dual-task conditions (M = 324 ms, SD = 53 ms vs. M = 507 ms, SD = 155 ms, respectively), the magnitude and time course of response priming as a function of prime-target SOA was highly similar in the two conditions (see Fig. A2 of the Appendix A), except for the unexpected drop for the 42-ms in the dual task, which as we explained earlier, was likely to be spurious.

The second step we took addressed the potential impact of protracted response latencies on visibility ratings (which could not be examined in the single-task control, since by necessity, this control did not include visibility ratings). We compared the mean distribution of visibility ratings for the 50% fastest trials and for the 50% slowest trials in Experiments 1, 3 and 5. The distributions for fast and for slow trials were virtually identical (see Table A2 of the Appendix A). Taken together, these findings show that the generality of our findings is not limited to the dual-task situation that prevailed in our study.

8.3.3. Fluctuations in general performance

We reported a short-term effect of consciously perceiving the prime on a prior encounter, which manifested in a stronger effect, the more recent the trial in which conscious perception of the prime had been experienced (see Fig. 2B). One could argue that this short-term effect resulted from spontaneously occurring fluctuations in general performance (reflecting peaks and troughs of attention and/or arousal). According to this argument, a series of high-awareness ratings in a row (also associated with high objective performance) may have conveyed the impression that one high-visibility trial caused the next trial to garner a high visibility rating, when in fact both high-visibility ratings were caused by a common underlying factor.

Two observations make this alternative account unlikely, however. First, if higher visibility ratings and objective performance resulted from periods of heightened attention, it is difficult to explain why paying more attention to the stimuli and task did not also increase response priming – an effect that is known to benefit from both spatial attention (e.g., Kentridge et al., 2008) and temporal attention (e.g., Naccache, Blandin, & Dehaene, 2002). Second, we reported that the longevity of awareness priming depended on the stimulus-driven salience of the consciously perceived prime that elicited the priming effect. Such dependency should not be observed if random fluctuations of overall performance were the critical underlying factor. We thus conclude that fluctuations in general performance are unlikely to account for the short-term awareness priming reported here.

8.4. Methodological implications for the study of unconscious processing

Although it was not our primary objective to investigate unconscious processing, the present findings have methodological implications for that field of research. The gold-standard paradigm in that field consists of two experimental phases. In the first (response-priming) phase, unconscious processing is assessed as the degree to which a subliminal prime influences response to a visible target. In the second (prime-awareness test) phase, observers' ability to discriminate some feature of the prime is assessed and chance performance is held to attest to the subliminality of the prime (e.g., Dehaene et al., 1998; D'Ostilio & Garraux, 2012; Hughes, Velmans, & De Fockert, 2009; Kentridge et al. 2008; Kunde, Kiesel, & Hoffmann, 2003).

Three aspects of this methodology are worth noting. One is its reliance on an objective measure for guarantying total absence of conscious processing, mainly because it is thought to be more conservative than a subjective measure. Here, we provided further support against this argument, by replicating previous demonstrations showing that a 4-point scale subjective measure is as sensitive to the presence of conscious perception as an objective forced-choice discrimination measure of perception (e.g., Peremen & Lamy, 2014a; Ramsøy & Overgaard, 2004): across

Experiments 2 and 4, 0-visibility trials were associated with chance-level discrimination performance.

The second notable aspect is that the critical object is (assumed to be) subliminal on all trials. As a consequence, the role of conscious perception cannot be assessed because unconscious processing cannot be compared to conscious processing under the same stimulus conditions (instead, the comparison typically involves a subliminal vs. supraliminal stimulus, e.g., van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009). By contrast, subjective measures allow monitoring conscious perception of a liminal prime trial by trial, such that unconscious and conscious processing of the same stimulus can be compared (e.g., Lamy et al., 2015; Peremen & Lamy, 2014a; Van den Bussche et al., 2013). A potential criticism against this approach is that assessing both response priming and conscious perception on each trial entails a difficult, slow dual task that may alter the characteristics of the measured processes. Here, we refuted this argument by showing that at least with pattern backward masking – which is the most widely used method in the study of unconscious processing (e.g., Van den Bussche, Van den Noortgate, & Reynvoet, 2009) – response priming was very similar whether it was measured in the context of a single or of a dual task and the distribution of visibility ratings was unaffected by response latency.

Finally, the third aspect concerns the measurement of response priming and prime awareness in different phases. This aspect has been criticized because it can generate different contexts or conditions (e.g., Reingold & Merikle, 1988). For instance, Pratte and Rouder (2009) suggested that it is easier to maintain attention and motivation in the response-priming phase than in the prime-awareness phase, with the consequence that conscious processing during the response-priming phase is underestimated. Moreover, Lin and Murray (2014) demonstrated that such underestimation also occurs when the response-priming phase includes both weakly and strongly masked trials, whereas the prime-awareness phase includes only strongly-masked trials (as is the case in many studies, see Lin & Murray, 2014 for review): they showed that intermixing weakly-masked primes boosts strongly-masked primes into consciousness – a finding that was replicated here.

This finding also entails that it should be easier to detect unconscious processing when the prime is never consciously perceived: this should occur because prime salience enhances response priming and a prime can remain invisible with higher stimulus salience when it has not been seen previously relative to when it has. As Fig. A3 of the Appendix A shows, our findings illustrate this point: unconscious priming – measured as response priming when visibility was rated 0 – was larger when observers had had prior conscious experience of the prime (mixed-SOA and blocked-SOA with preexposure conditions) than when they had not (blocked-SOA condition without preexposure). This observation may be of practical interest for imaging studies aimed at uncovering the neural correlates of unconscious processing, in which signal-to-noise ratio is an important issue.

8.5. How do models of conscious perception account for the present findings?

8.5.1. The dual-stream model

Our findings are fully consistent with the distinction between vision for perception and vision for action suggested by Goodale and Milner (1992); see also Milner & Goodale, 2008). We reported that a variable (prior experience) that boosts vision for (conscious) perception does not affect vision for action (indexed by response priming). We thereby generalize previously reported dissociations (see Goodale, 2014 for review) from conscious content to conscious access and from motor actions involving direct and online interaction with the critical object (e.g., grasping or reaching) to motor behaviors in which the association between a stimulus and a motor response is arbitrary.

The implications of our findings should be drawn with caution. First, they do not entail that prior experience never affects vision for action. Buckingham and Goodale (2013) pointed out that there might be independent sets of priors for motor control and vision for perception. They bring the following example to bear in order to illustrate this point. When a small cube and a similar but larger cube are adjusted to have identical weights, people expect the larger cube to be heavier: as a result, when lifting the cubes for the first time, they apply excessive force to lift the large cube and too little to lift the small one. However, after just a few trials, participants adjust their behavior and apply the same force to the two cubes (Flanagan & Beltzner, 2000). Thus, prior experience affects their motor actions. However, such prior experience does not affect the size-weight perceptual illusion that has been reported with this set-up (Murray, Ellis, Bandomir, & Ross, 1999): when lifting the cubes, participants report that the small one feels substantially heavier than the (equally-weighted) larger one, and the magnitude of this illusion is unaffected by how many times the cubes are lifted. Taken together with our results, these findings suggest that prior motor experience might affect vision for action, while prior conscious perceptual experience might affect vision for perception, with no cross-talk. Further research is needed to examine this possibility.

Second, we showed that prior conscious experience modulates conscious perception but does not affect response priming, yet response priming is just one of the indirect measures used to probe visual processing – often in order to demonstrate unconscious processing. Other measures, such as semantic priming (e.g., Marcel, 1983) are also used - although they have been less successful at generating robust unconscious effects (see Kouider & Dehaene, 2007, for review). Thus, further research is needed in order to determine whether our findings can be generalized to indirect measures other than response priming.

In this respect, it is important to underscore that qualitative dissociations between conscious access and an indirect measure of visual processing (here, response priming) cannot necessarily be interpreted as qualitative dissociations between conscious and unconscious processing. Indeed, while response priming in the absence of conscious perception can be taken to index unconscious processing, response priming (from trials in which the prime may or may not be consciously perceived) is not a measure of unconscious processing in and of itself.

8.5.2. Predictive coding

Our findings are also generally consistent with the predictive-coding framework, according to which moment-to-moment conscious perception is shaped by matching incoming sensory information with an internal predictive model that relies on previous experience and context. When sensory evidence is strong (e.g., prime-mask SOA > 100 ms in the present study), even a weak and general model ("the prime is a small arrow") suffices and prior information has little impact on conscious perception. However, when sensory evidence is weak and ambiguous (e.g., prime-mask SOA < 50 ms), prior knowledge of how the stimulus looks like provides a more specific model, thereby reducing the number of iterations necessary for matching sensory information from lower-level brain regions with more abstract representations from higher-level regions (e.g., Ahissar, Nahum, Nelken, & Hochstein, 2009; Di Lollo et al., 2000; Mumford, 1992).

As we mentioned in the introduction, several studies have showed that neural activity is weaker in lower ventral areas for expected or previously perceived stimuli than for unexpected ones (e.g. Alink et al., 2010; Egner et al., 2010; Kok et al., 2013; Todorovic & de Lange, 2012), in line with predictive-coding models.

As response priming is strongly dependent on stimulus strength, this measure could be used as a proxy of representation strength in sensory areas. Our findings show that prior experience does not reduce response priming (despite weak numerical trends in the predicted direction). Yet, they do not provide direct evidence against predictive-coding models because these make no explicit prediction with regard to the impact of priors on motor action. Buckingham and Goodale (2013) noted such under-specification of the behavioral impact of priors in predictive-coding models, going so far as to claim that "the term "prior" seems to serve only as a convenient placeholder in lieu of any tangible mechanism linking expectations to the perceptual or motor effects they appear to entail" (p. 209).

Awareness priming as demonstrated in the present study is just of one the sources of prior knowledge that have been shown to affect conscious perception. It will therefore be important to determine whether the dissociation reported here between vision for perception and vision for action holds with other manipulations of prior knowledge.

8.5.3. Global workspace

A central tenet of the Global Workspace model (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006) is that conscious perception critically depends on neural activation strength. This model therefore predicts that factors that enhance a stimulus' conscious access should also increase its impact on behavior. Our findings do not support this hypothesis: prior experience facilitated conscious access, yet did not enhance response priming.

In recent developments of the model, Dehaene and colleagues (e.g., Dehaene et al., 2014; King & Dehaene, 2014) incorporated effects of priors on conscious perception by formalizing perception as a statistical inference problem. Thus, for a constant level of activation in sensory areas (resulting from sensory evidence and attention), conscious perception is allowed to vary as a function of prior knowledge. At first sight, this prediction is consistent with our findings: we showed that prior experience affects conscious perception, yet does not affect response priming which presumably indexes the activation associated with the critical stimulus.

However, further scrutiny into the mechanisms suggested to account for the effects of priors on perceptual decisions reveals that the Global Workspace model in its present formulation does not account for our findings. Specifically, King and Dehaene (2014) suggested that "...in order to perform optimally, given a sensory input and prior knowledge, subjects should attempt to compute the posterior probability of each of the classes in order to select the class with the maximum a posteriori (MAP) choice, which is the one most likely to be correct "(King & Dehaene, 2014, p.2). For subjective perceptual decisions, prior knowledge refers to the probability that a stimulus (rather than none) is presented and therefore modulates the criterion for deciding that a stimulus was present. For forced-choice discrimination decisions ("does the stimulus belong to class X or Y?"), prior knowledge refers to the probability that the stimulus belonged to one category vs. the other and therefore modulates the likelihood of an X vs. a Y response. In our study, we showed that prior experience with a prime arrow improved perception of a subsequent prime both when it instructed the same decision (i.e., response) and when it instructed a different decision. Thus, it is not clear within the framework suggested by the Global Workspace model, what criterion prior experience with the prime might have influenced. Our findings are therefore more consistent with the notion that prior experience provides a model against which sensory evidence is matched (e.g., Hochstein & Ahissar, 2002) and which can boost conscious access irrespective of response-related task requirements.

9. Conclusions

The present research fills an important gap in the literature, which has focused on the effects of expectations and prior experience on conscious perception without assessing their indirect effects on behavior. We provide the first demonstration that prior conscious experience enhances conscious access, while having no indirect impact on behavior. We suggest that further research investigating this issue has the potential of providing a strong test between the current theoretical models of conscious vision, which have typically been able to account for much of the current experimental literature, each in its own way, with only few decisive tests directly confronting them one against the other.

Author's note

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Appendix A

See Figs. A1–A3 and Tables A1–A3.

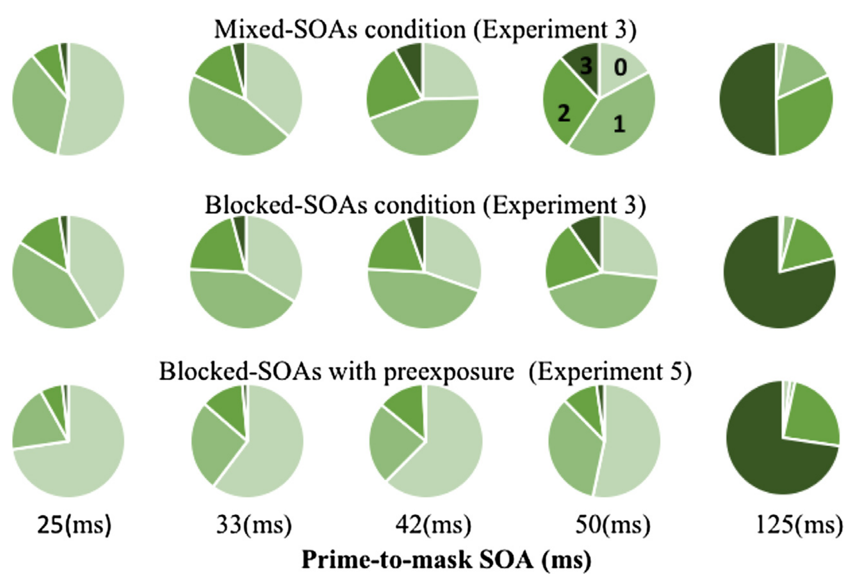

Fig. A1. Distribution of visibility ratings as a function of prime-target SOA for each design condition of Experiments 3 and 5.

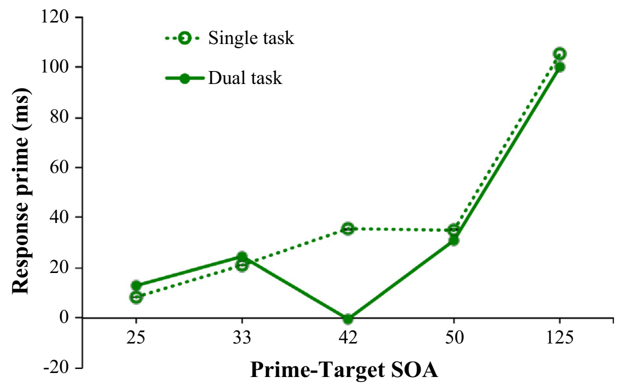

Fig. A2. Mean response priming (in milliseconds) in the mixed-SOAs condition of Experiment 3 (which involved a dual task, since participants responded both to the target arrow direction and to the prime visibility) and in the control experiment (which involved a single task, since participants responded only to the target arrow direction).

Fig. A3. Mean reaction times (in milliseconds) in the congruent and in the incongruent prime-target conditions, for 0-visibility trials only, in the mixed- and in the blocked-SOA conditions (Experiment 3) as well as in the blocked-SOA condition with prior experience (Experiment 5). Error bars represent within-subject standard errors.

Table A2
Mean reaction times (RTs) and distribution of visibility ratings of the participants' 50% fastest trials and 50% slowest trials in Experiments 1, Experiment 3 (mixed-SOAs and blocked-SOAs conditions) and Experiment 5 (blocked-SOAs condition with preexposure).

		Mean RT (ms)	Visibility rating			
			0	1	2	3
Experiment 1	Fast	449	23.23%	31.89%	25.15%	19.73%
	Slow	699	23.32%	30.88%	24.00%	21.80%
Mixed-SOA condition	Fast	400	27.32%	37.07%	21.18%	14.43%
	Slow	631	27.03%	37.43%	20.52%	15.01%
Blocked-SOAs condition	Fast	305	51.23%	20.60%	12.72%	15.45%
	Slow	468	49.82%	21.03%	13.13%	16.01%
Blocked-SOAs with preexposure	Fast	349	26.80%	36.02%	17.62%	19.56%
	Slow	554	26.76%	35.29%	17.66%	20.28%

Table A3
Distribution of the SOAs (stimulus-onset asynchrony) on the current trial as a function of the visibility rating on the previous trial in Experiment 1. In this table, the relevant comparison is within each column. It shows that SOAs on the current trials were evenly distributed across conditions of visibility ratings on the previous trial. This was true in all the experiments, since all SOAs were equiprobable and randomly mixed.

SOA on the current trial	Visibility rating on the previous trial			
	0	1	2	3
24	317	322	268	204
47	296	335	249	213
71	304	334	237	215
94	312	306	245	220
118	298	313	257	206

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.12.009.

Table A1
Mean reaction times and accuracy on congruent and on incongruent trials in Experiments 1, 3 and 5. SE = standard error.

Visibility	Congruent		Incongruent		Congruent		Incongruent	
	Mean RT	*SE*	*Mean RT*	*SE*	*% accuracy*	*SE*	*% accuracy*	*SE*
Experiment 1								
0	517.4	44.3	532.3	44.3	98.9	0.7	99.0	0.7
1	554.9	44.1	570.2	44.2	98.4	0.7	98.4	0.7
2	552.6	44.3	600.1	44.3	99.3	0.7	98.4	0.7
3	559.9	44.5	631.1	44.3	98.7	0.8	97.4	0.7
Experiment 3 (Mixed SOAs condition)								
0	460.4	39.4	477.4	39.5	99.7	0.4	99.3	0.5
1	489.2	39.4	503.6	39.4	99.7	0.4	99.3	0.4
2	505.7	39.6	543.0	39.5	99.3	0.5	99.0	0.5
3	537.8	39.8	601.0	39.7	98.6	0.6	98.1	0.5
Experiment 3 (Blocked SOAs without pre-exposure)								
0	332.1	18.3	364.2	18.4	98.2	0.4	96.1	0.4
1	366.4	18.9	400.3	18.8	99.2	0.5	97.9	0.5
2	415.3	19.4	478.2	19.1	98.2	0.7	96.5	0.6
3	379.4	19.1	434.8	19.1	98.4	0.6	98.2	0.6
Experiment 5 (Blocked SOAs with pre-exposure)								
0	398.9	17.2	420.7	17.5	99	0	98.6	0.5
1	421.9	17.1	455.4	17.1	99	0	99.1	0.4
2	451.4	17.9	485.5	17.7	100	1	98.2	0.5
3	445.5	17.7	474.5	17.6	99	1	98.5	0.5

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