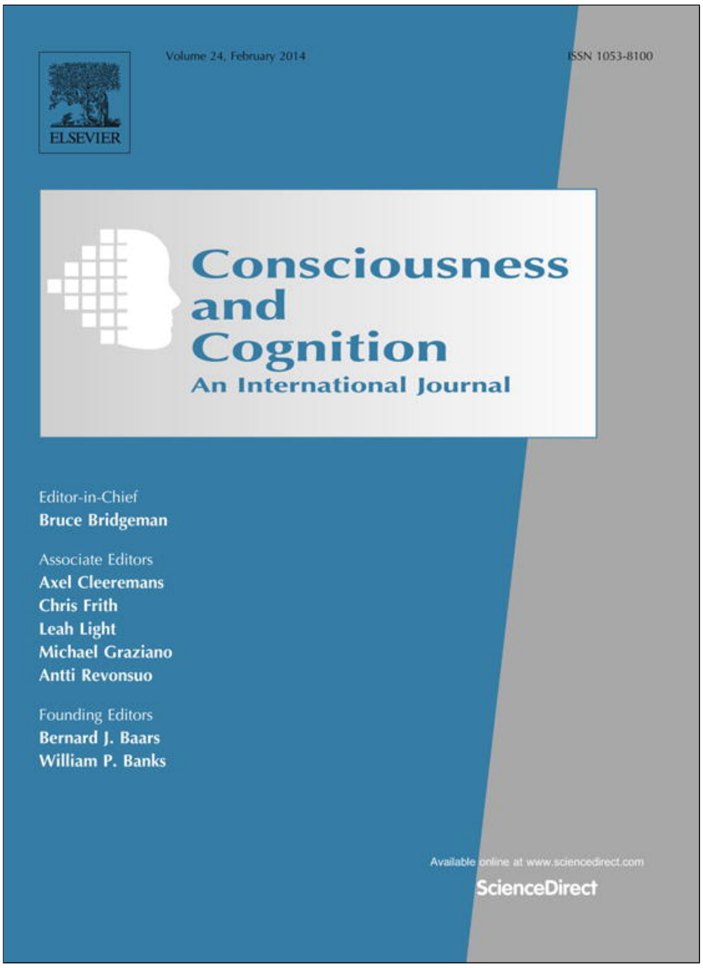
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Do conscious perception and unconscious processing rely on independent mechanisms? A meta-contrast study

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There is currently no consensus regarding what measures are most valid to demonstrate perceptual processing without awareness. Likewise, whether conscious perception and unconscious processing rely on independent mechanisms or lie on a continuum remains a matter of debate. Here, we addressed these issues by comparing the time courses of subjective reports, objective discrimination performance and response priming during meta-contrast masking, under similar attentional demands. We found these to be strikingly similar, suggesting that conscious perception and unconscious processing cannot be dissociated by their time course. Our results also demonstrate that unconscious processing, indexed by response priming, occurs, and that objective discrimination performance indexes the same conscious processes as subjective visibility reports. Finally, our results underscore the role of attention by showing that how much attention the stimulus receives relative to the mask, rather than whether processing is measured by conscious discrimination or by priming, determines the time course of meta-contrast masking.

1. Introduction

The recent surge of scientific interest in the phenomenon of conscious experience has led to the discovery that complex cognitive processes can unfold in the absence of consciousness (e.g., Dehaene & Naccache, 2001; Greenwald, Draine, & Abrams, 1996; Kunst-Wilson & Zajonc, 1980; Mudrik, Breska, Lamy, & Deouell, 2011; Sklar et al., 2012; van Opstal, Buc, Gevers, & Verguts, 2011) and to important progress in the search of the neural correlates of consciousness (NCC; e.g., Crick & Koch, 2003; Dehaene et al., 1998; Lamy, Salti, & Bar-Haim, 2009; Lau, 2011; Rees, 2011; Salti, Bar-Haim, & Lamy, 2012; Tononi & Koch, 2008). However, these breakthroughs still stand on shaky ground because the issue of what counts for conscious perception remains highly controversial (see Cardoso-Leite & Gorea, 2010; Holender & Duscherer, 2004; Marcel, 1983; Overgaard, Rote, Mouridsen, & Ramsøy, 2006; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010; Schmidt, 2013). Obviously, if the measure used to establish that a stimulus is not perceived consciously is to be doubted, so should the alleged feats of the unconscious and neural substrates of conscious vision.

The traditional way of establishing unconscious processing has been to demonstrate that a stimulus affects behavior even though conscious perception of this stimulus is absent (e.g., Marcel, 1983). Such dissociations between conscious perception and unconscious processing have been reported either between two direct measures of perception, typically a subjective measure and an objective measure (e.g., subjective visibility of the critical stimulus and performance on forced-choice discrimination of one of its properties); or between two objective measures of perceptual processing, one direct and the other indirect (e.g., priming). The clash between these operational definitions has generated recurrent waves of heated debate

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(Draine & Greenwald, 1998; Erdelyi, 1986, 2004; Greenwald, Klinger & Schuh, 1995; Merikle & Reingold, 1991, 1998; Reingold & Merikle, 1990). In particular, whether objective forced-choice performance should serve as a measure of unconscious processing, or be favored over subjective report as a measure of conscious processing remains open. Despite promising recent methodological developments (Lau & Passingham, 2006; Overgaard et al., 2006; Persaud, McLeod, & Cowey, 2007; Sandberg et al., 2010; Snodgrass, 2004), a consensus seems still far from reach.

Several authors have rejected the classical dissociation procedure altogether and suggested alternative empirical strategies (Debner & Jacoby, 1994; Schmidt & Vorberg, 2006; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). They typically argued that simple dissociations provide inconclusive evidence for unconscious perceptual processing because the measure of consciousness used may not capture all aspects of conscious experience – a claim that has been referred to as the exhaustiveness problem (Reingold & Merikle, 1988, 1990; Vorberg et al., 2003). They suggested instead that if two processes are independent, then it should be possible to modulate them in qualitatively different ways. For instance, Vorberg et al. (2003) presented their participants with a brief arrow, the prime, followed after a variable stimulus-onset asynchrony (SOA) by a larger arrow that served as a type-B meta-contrast mask (see Breitmeyer (1984)). In one session, participants indicated whether the mask arrow pointed to the left or to the right, as fast as possible. The response times in this task served as an indirect measure of unconscious processing: response priming was calculated as the difference in response times when the mask followed a prime pointing in the same vs. in the opposite direction (e.g., Dehaene et al., 1998; Eimer & Schlaghecken, 1998; Klotz & Neumann, 1999; Mattler, 2003; Neumann & Klotz, 1994). In a different session, accuracy on non-speeded forced-choice discrimination of the prime arrow direction was assessed and served as a direct objective measure of conscious perception. The striking finding was that the direct measure followed the U-shape function that is characteristic of type-B meta-contrast masking, whereas response priming increased monotonically with prime-to-mask SOA. This is to date one of the most compelling demonstrations that separable mechanisms underlie conscious and unconscious information processing.

In the present study, we investigated whether conscious and unconscious vision indeed obey different temporal laws, with two important goals in mind. First, we used the temporal-dissociation rationale to compare the two competing measures of conscious perception (subjective report and forced-choice discrimination performance) in order to determine whether they index the same or different mechanisms. Second, we compared the time courses of conscious perception and unconscious processing measures *when these are sampled under the same experimental conditions*. This has not been done before. For instance, in Vorberg et al.'s (2003) study the dissociated reports were collected in different blocks of trials. It follows that while observers' attention was mainly allocated to the prime arrow in the direct task, it was mainly directed to the mask arrow in the indirect task. Differences in attention rather than in conscious perception may therefore account for the dissociated time courses.

2. Experiment 1

The stimuli were similar to Vorberg et al.'s (2003) except that both the prime and mask arrows pointed in one of four possible directions (upper right, upper left, lower right or lower left) instead of only two (left or right), as shown in Fig. 1. As a consequence, two of the 4 possible directions pointed to the left (upper left and lower left) and two pointed to the right (upper right and lower right). Likewise, classified in the vertical rather than on the horizontal axis, two of the 4 possible directions pointed upwards (upper left and upper right) and two pointed downwards (lower left and lower right). These conditions are illustrated in Fig. 1.

On each trial, participants performed a speeded forced-choice discrimination response to the direction of the mask arrow on one axis (e.g., horizontal, that is, left or right), followed by a non-speeded forced-choice discrimination response to the direction of the prime arrow on the other axis (e.g., vertical, that is, upwards or downwards). The purpose of using these arrows was to have the participants respond to the prime and mask arrows with different responses. Indeed, we suspected that responding to the same characteristics of the prime and mask (e.g., either left or right for both arrows) was most likely to create confusion and to induce contamination of the response to the prime by the response to the mask.

After the first two responses, participants reported the visibility of the prime using a sensitive scale ranging from 0 ("I saw nothing at all") to 3 ("I clearly saw the arrow"). This scale was similar to the Perceptual Awareness Scale (PAS; Ramsøy & Overgaard, 2004) except that report of "no experience" was labeled '0' instead of '1', in order to better convey total absence of perceptual experience. This procedure allowed us to extract the time courses of three indices of perceptual processing, simultaneously, using the same stimuli and under similar conditions: a sensitive index of subjective perception (visibility), a direct measure of objective performance (forced-choice discrimination of the prime arrow direction) and an indirect measure of visual processing (response priming, calculated from the responses to the masking arrow). We thereby sought to determine whether double-dissociations between the time courses of these measures could be observed when these are collected under similar conditions. We also examined the extent of prime processing when prime visibility was null, that is, whether simple dissociations could be observed: we probed whether objective discrimination of the prime arrow direction would be above chance and whether significant response priming could be observed, when subjects reported not seeing the prime at all.

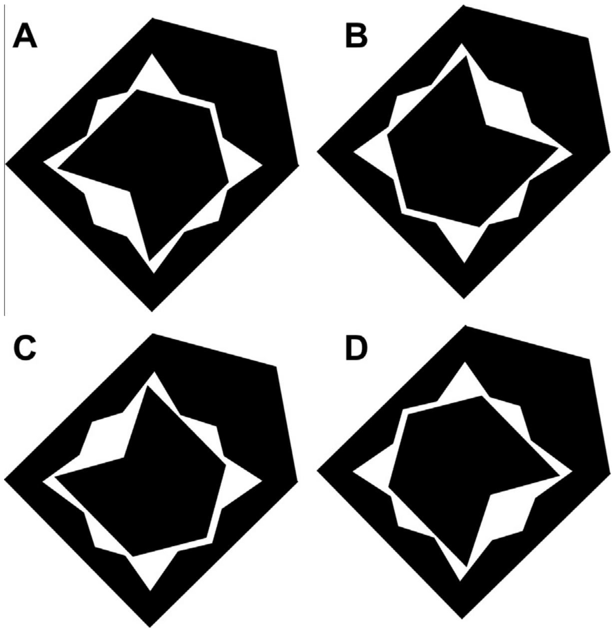

Fig. 1. Sample stimuli used in Experiment 1. The prime is the small arrow and the mask is the larger arrow enclosing it. Let us assume that in this example, participants were required to determine whether the mask pointed upwards or downwards (the mask-relevant axis being therefore the vertical axis) and whether the prime pointed to the left or to the right (the mask-irrelevant axis being therefore the horizontal axis). In stimulus C, for example, the correct response to the mask was "upwards" and the correct response to the prime was "right". In addition, the direction of the prime on the mask-relevant axis was incompatible (because the prime arrow pointed downwards) and direction of the prime on the mask-irrelevant dimension was compatible (because both arrows pointed to the right). Because responses to the mask were affected by the direction of the prime on both the relevant and the irrelevant axes, in all analyses, we compared the same-direction condition (in which the two arrows pointed in exactly the same direction, as in stimulus A) to the different-direction condition in which the arrows differed on at least one axis, as in stimuli B, C and D). The example corresponds to prime-to-mask SOA 0. Black-and-white polarity was reversed.

2.1. Materials and methods

2.1.1. Participants

Thirty-two undergraduate students (29 right handed, 23 women) from Tel Aviv University, age 18–29 years ($M = 23.1$, $SD = 2.1$) were tested in one session for course credit. All reported normal or corrected-to-normal vision.

2.1.2. Stimuli

Sample displays are presented in Fig. 1. The stimuli were presented on a 17-in. 85-Hz CRT monitor. The prime display consisted of a small arrow ($1.6^\circ \times 0.8^\circ$) and the mask display consisted of a larger arrow ($2.1^\circ \times 1.1^\circ$). Both arrows were gray (RGB 127, 127, 119) against a black background (RGB 0, 0, 0), were centered at fixation and pointed to secondary directions (45°, 135°, 225°, and 315°).

2.1.3. Procedure

The prime display appeared for 24 ms, followed after a variable SOA (0, 24, 47, 71, 94, or 118 ms) by a 96-ms mask display. On each trial, subjects had to provide three responses: they first made a speeded response to the *mask* arrow direction (e.g., left or right). Then they made a non-speeded two-alternative forced choice response to the *prime* arrow direction (e.g., upwards or downwards). Finally, 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"). Ten percent of the trials were catch trials: the mask was presented alone, without a prime. Each subject completed 400 trials divided into eight blocks and following two practice blocks of 50 trials each. Before practice, the observers viewed the sequence of events at a very slow pace that enabled them to clearly distinguish the prime and mask.

2.1.4. Design

Prime and mask arrow directions were equiprobable and randomly mixed. They were equally likely to be congruent or incongruent on the mask-relevant axis and on the prime-relevant axis. Prime- and mask-relevant axes (horizontal or vertical) were counterbalanced across subjects. Prime-to-mask SOAs were equiprobable and randomly mixed.

2.1.5. Statistical methods

In all experiments, all analyses were based on repeated-measures ANOVAs and p values were corrected for sphericity violations using Huynh–Feldt corrections, whenever relevant. We first examined the main effect of SOA on prime visibility and determined the weights corresponding to the obtained function to derive the quadratic component of the effect. We then applied the same weights to examine the SOA modulation of prime discrimination accuracy and prime–mask congruency effects. Several participants did not use all the possible visibility ratings. In order to overcome the resulting distortions in the analyses including prime visibility as a factor, we used a linear mixed-effects model in all analyses involving visibility as a factor. Prime-absent (or catch) trials as well as *no-go* trials were excluded from all analyses. In all RT analyses, trials in which response to the mask direction was inaccurate were excluded (5.8%). Trials in which the RT exceeded the mean of its cell (resulting from crossing the factors included in the relevant analysis) by more than 2.5 standard deviations were also excluded from all RT analyses (fewer than 1.8% of the trials).

2.2. Results

Preliminary analyses showed that response times to the mask arrow direction were modulated by its congruency with the prime's direction, not on only the mask-relevant axis, $F(1,28) = 19.65$, $p < .0001$ but also on the mask-irrelevant axis, $F(1,28) = 14.15$, $p < .0008$. To illustrate, if participants made a left/right response to a mask arrow pointing in the upper left direction, whether the prime pointed to the left or right (mask relevant axis) affected performance on mask direction discrimination, but also whether it pointed upwards on downwards (mask-irrelevant axis). The interaction between these effects was significant, $F(1,28) = 6.70$, $p < .02$: RTs were faster when the two arrows pointed exactly in the same direction, than when they differed on at least one axis (see Ansorge and Neumann (2005) for a conceptually similar finding), all *ps* < .0005, with no difference between the latter three conditions, all *ps* > .17. Therefore, we used this same-vs.-different direction effect, instead of response congruency on the mask-relevant dimension, as the measure of priming.

Prime visibility, prime discrimination performance and priming are shown as a function of SOA in Fig. 2. All three measures exhibited strikingly similar time courses: they followed the U-shaped function that is typical of type-B meta-contrast masking: Visibility was significantly modulated by SOA, $F(5,140) = 27.31$, $p < .0001$. It showed a significant quadratic component, $F(1,28) = 90.56$, $p < .0001$ with a minimum at 47 ms, as did the SOA effect on prime discrimination accuracy and on priming, $F(1,28) = 51.20$, $p < .0001$ and $F(1,28) = 7.70$, $p < .01$, respectively.

In addition, visibility significantly modulated prime discrimination accuracy, with both effects exhibiting strong linear components, $F(1,83) = 834.73$, $p < .0001$ and $F(1,81) = 5.21$, $p < .03$, respectively (see Fig. 3). The more visible the prime was, the more accurate observers were in discriminating its direction and the more strongly its direction primed response to the mask arrow direction. Crucially, however, priming was significant when observers reported prime visibility to be null, 42 ms, $F(1,28) = 5.73$, $p < .03$. Prime arrow discrimination accuracy was above chance, 54.52%, $t(28) = 3.73$, $p < .0009$, but further analyses revealed that responses to the prime were contaminated by perception of the mask arrow: when participants did not see the prime they seemed to respond to the mask direction instead: prime discrimination accuracy was above

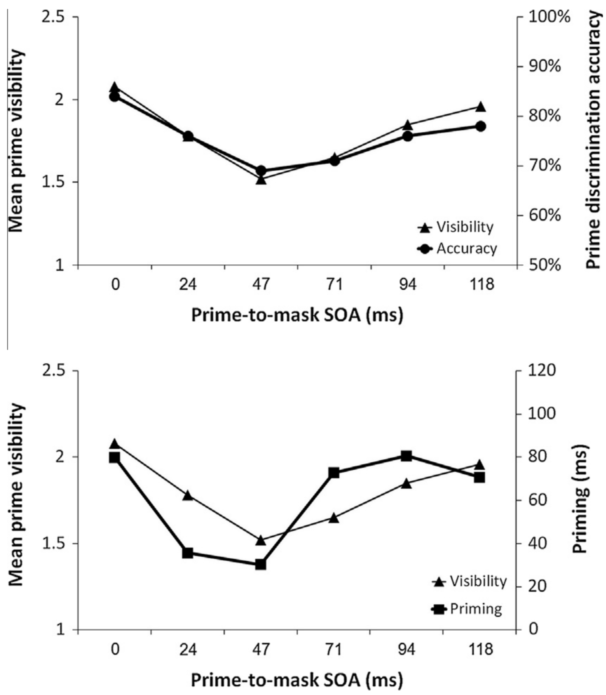

Fig. 2. Upper panel: Mean prime visibility rating (left *Y*-axis) and priming effect in milliseconds (right *Y*-axis) – calculated as the difference between RTs when the prime and mask pointed in the same vs. in different directions – in Experiment 1, as a function of prime-to-mask SOA. Lower panel: Mean prime visibility rating (left *Y*-axis) and mean percentage (%) of correct responses to the prime-arrow direction (right *Y*-axis) in Experiment 1 as a function of prime-to-mask SOA.

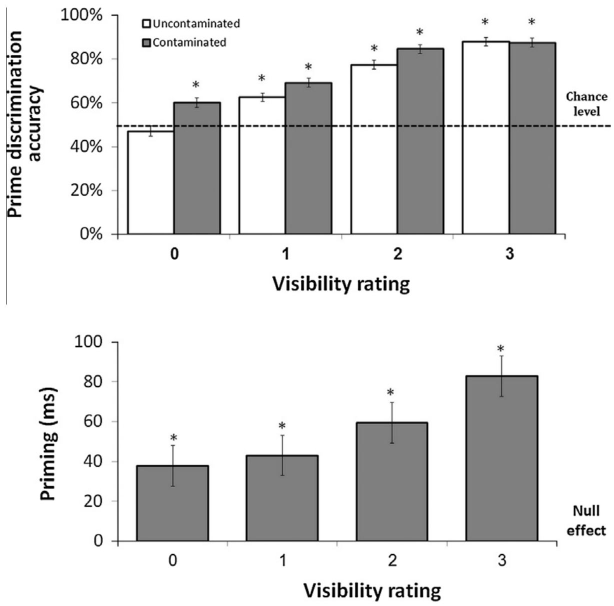

Fig. 3. Upper panel. Percentage (%) of correct responses to the prime-arrow direction in Experiment 1 as a function of visibility rating when the mask arrow pointed in the same direction as prime arrow on the prime-relevant dimension (contaminated trials) and when it pointed in a different direction (uncontaminated trials). Accuracy on uncontaminated trials was at chance for visibility 0. Lower panel. Mean response-priming effect in milliseconds in Experiment 1 as a function of visibility rating. Priming was significant for visibility 0. Error bars represent standard errors.

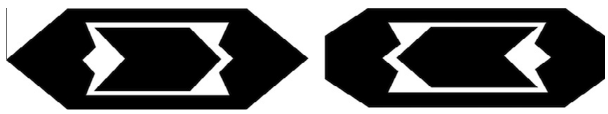

Fig. 4. Sample stimuli in Experiment 2. The mask arrow was bi-directional. On *go* trials, it was intact (left-hand panel), whereas on *no-go* trials, its heads were truncated (right-hand panel). Black and white polarity was reversed.

chance only when the mask and prime had the same direction on the prime-relevant direction, 61.15%, $t(28) = 3.93$, $p < .0005$ but not when they had different directions, 48.23%, $t < 1$. As could be expected, this contamination was larger the less visible the prime was, $F(3,82) = 11.63$, $p < .0001$, with a significant linear component, $F(1,82) = 25.65$, $p < .0001$. We conclude that priming was significant when visibility was null, but forced-choice discrimination of the prime direction was at chance.

2.3. Discussion

Experiment 1 showed that when the different measures of perceptual processing (subjective reports, forced-choice discrimination performance and priming) are collected under the same conditions they cannot be dissociated by their time courses. In addition, when meta-contrast rendered the prime completely invisible, there was substantial priming but discrimination of the prime direction was at chance. In that experiment, however, the irrelevant dimension of the mask contaminated prime direction judgments. Thus, only the results pertaining to the uncontaminated condition were informative and our endeavor to use all three measures in the same experiment was therefore not entirely successful. We therefore attempted to replicate the main findings of Experiment 1 by comparing the measures in pairs: subjective report and forced-choice discrimination of the prime direction in Experiment 2; and subjective report and response priming in Experiment 3. Thus, the prime visibility time course served as an anchor for between-experiment comparison.

3. Experiments 2 and 3

The stimuli used in Experiments 2 and 3 were similar to those used by Vorberg et al. (2003) and are shown in Figs. 4 and 5, respectively. Notably, in Experiment 2, the mask arrow was bi-directional, such that prime discrimination responses could no longer be contaminated by the direction of the mask arrow. In addition, in both Experiments 2 and 3, in order to ensure that observers divided their attention between the prime and mask a minority of trials were *no-go* trials, in which the heads of the mask arrow were truncated. Observers were required to terminate the trial by pressing the spacebar whenever this happened, which ensured that they allocated some attention to the mask.

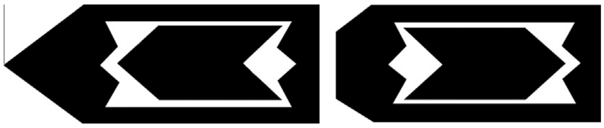

Fig. 5. Sample stimuli in Experiment 3. The mask arrow pointed either in the same direction as the prime arrow (congruent trials, left-hand stimulus) or in the opposite direction (incongruent trials, right-hand stimulus). On *go* trials, it was intact (left-hand panel), whereas on *no-go* trials, its head was truncated (right-hand panel). Black and white polarity was reversed.

3.1. Materials and methods

3.1.1. Participants

Twenty-two new undergraduate students from Tel Aviv University (all right-handed, 13 women), age 22–28 years ($M = 25$, SD = 1.8) in Experiment 2 and 16 in Experiment 3 (10 right handed, 12 women), age 20–27 years ($M = 23.2$, SD = 1.9) were tested in one session for course credit. All subjects reported normal or corrected-to-normal vision.

3.1.2. Stimuli, procedure and design

Experiment 2 was similar to Experiment 1 except for the following changes. All arrows were horizontally oriented (Fig. 4). The prime, 1.6° in width and 0.8° in height, pointed to either the left or right. The mask was a neutral, bidirectional arrow, 2.8° in width and 1.1° in height. Observers provided only two responses: the non-speeded forced-choice response to the direction of *prime* arrow and the prime visibility report. In order to ensure that observers divided their attention between the prime and the mask, 20% of the trials were *no-go* trials. On *no-go* trials, the mask arrow was truncated and observers had to press the spacebar instead of providing the two responses pertaining to the prime. The importance of responding accurately to the truncated arrows was emphasized. Ten percent of the trials were catch trials. Each subject completed 600 trials, divided into 12 blocks.

Experiment 3 was similar to Experiment 2, except for the following changes. The mask arrow, 2.1° in width and 1.1° in height, was no longer bidirectional and was equally likely to point to the left or right (Fig. 5). The prime arrow was equally likely to point in the same direction as the mask arrow (congruent trials) as in the opposite direction (incongruent trials). Observers provided two responses: the speeded response to the direction of the *mask* arrow and the report of prime visibility. Five percent of the trials were catch trials and 10% were *no-go* trials.

3.2. Results and discussion

In Experiment 3, trials in which response to the mask direction was inaccurate were excluded (2.2%), and so were outlier RTs (fewer than 0.5% of the trials). The results from Experiment 1 were fully replicated: in both Experiments 2 and 3, prime visibility was modulated by SOA, $F(5,75) = 2.69$, $p < .09$ (this interaction thus only approaching significance after Huynh–Feldt correction) and $F(5,95) = 8.14$, $p < .0001$, respectively, and showed a significant quadratic component with a minimum at the 47-ms SOA, $F(1,15) = 12.90$, $p < .003$ and $F(1,19) = 38.43$, $p < .0001$, respectively. Prime discrimination accuracy and response priming followed the same pattern, as confirmed by significant quadratic components, $F(1,15) = 25.89$, $p < .0001$, $F(1,19) = 6.48$, $p < .02$, respectively (Fig. 6). Both prime discrimination accuracy and response priming were correlated with prime visibility, $F(3,36) = 38.21$, $p < .0001$ and $F(3,53) = 3.70$, $p < .02$, respectively, and showed strong linear components, $F(1,12) = 169.37$, $p < .0001$ and $F(1,53) = 6.66$, $p < .02$. Crucially, response priming was again significant when visibility was null, 49.44 ms $F(1,18) = 15.29$, $p < .001$, whereas prime discrimination accuracy was again at chance, 51.7%, $t(15) = 1.31$, $p > .2$ (Fig. 7).

The results of Experiments 1–3 are clear and reliable. They strongly suggest that subjective reports of prime visibility and forced-choice discrimination of the prime arrow measured the same mechanism: not only did the two measures follow almost exactly the same time course, but discrimination accuracy fell to chance when visibility was null. With regard to the indirect measure of processing, priming was substantial even when observers reported not seeing the priming at all, yet also followed the same U-shape function as the two other measures. The latter finding, however, may simply result from the fact that priming increased with visibility, which could explain why priming was yoked to fluctuations in visibility as a function of SOA. Thus, our priming results are open to two different interpretations: the time course of meta-contrast masking may influence levels of visual processing that are common to conscious processes (indexed by visibility and prime discrimination performance) and unconscious processing (indexed by response priming). Alternatively, part of the response priming effect may be independent of visibility and follow a different time course. In order to test these interpretations against each other we examined the time course of response priming separately for each level of visibility. According to the former interpretation, the same U-shaped pattern should remain apparent at all levels of visibility, whereas the latter account predicts that this pattern should break down when we factor out the influence of visibility. As is clear from Fig. 8, the time course of priming consistently conformed to the U-shaped pattern at all visibility levels.

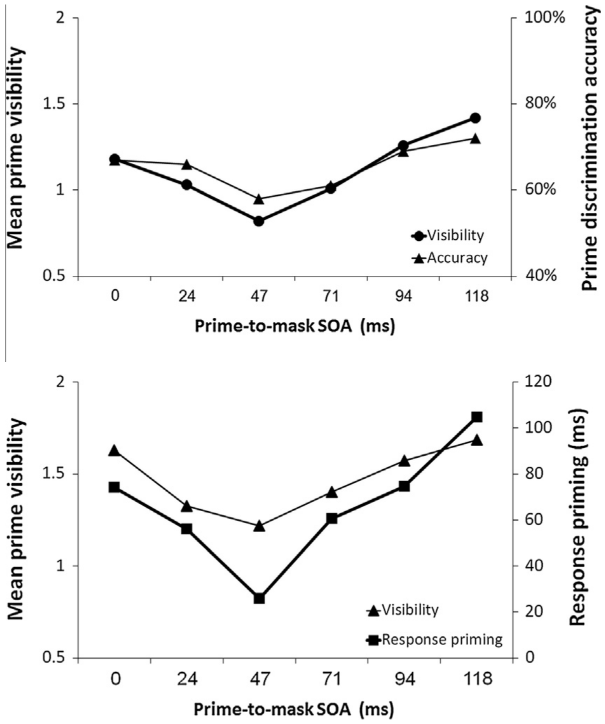

Fig. 6. Upper panel: Mean prime visibility rating (left *Y*-axis) and mean percentage (%) of correct responses to the prime-arrow direction (right *Y*-axis) as a function of prime-to-mask SOA in Experiment 2. Lower panel: Mean prime visibility rating (left *Y*-axis) and response priming effect in milliseconds (right *Y*-axis) – calculated as the difference between RTs when the prime and mask arrow directions were congruent vs. incongruent – as a function of prime-to-mask SOA in Experiment 3.

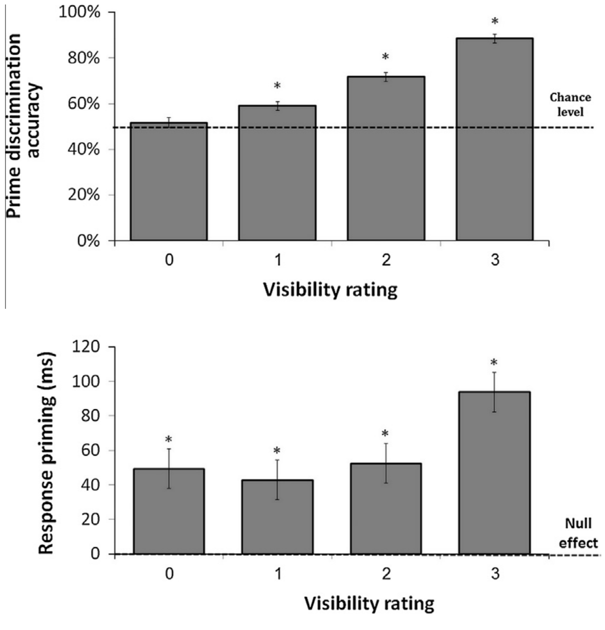

Fig. 7. Upper panel: Percentage (%) of correct responses to the prime-arrow direction in Experiment 2 as a function of visibility rating. Accuracy was at chance for visibility 0. Error bars represent standard errors. Lower panel: Mean response-priming effect in milliseconds in Experiment 3, as a function of visibility rating. Priming was significant for visibility 0. Error bars represent standard errors.

4. Experiment 4

Taken together, the results suggest that previous dissociation of visual perception and response priming by their time course (Schmidt & Vorberg, 2006; Vorberg et al., 2003) reflected differences in the conditions in which these measures were collected, most probably differences in the amount of attention allocated to the prime. If this conclusion is correct, then we should observe a different time course of the priming effect with identical stimuli when the only task is to respond to the mask arrow (and the prime arrow is therefore unattended). This prediction was confirmed by the results of Experiment 4.

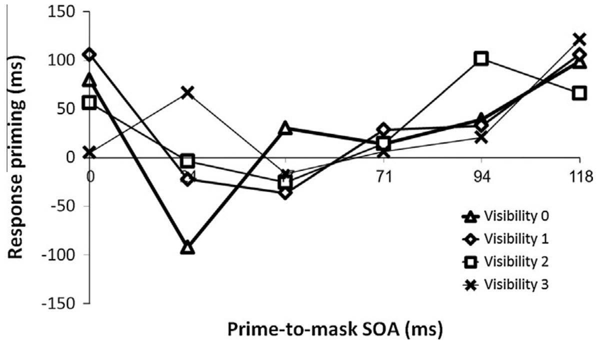

Fig. 8. Mean response-priming effect in milliseconds in Experiment 3 as a function of prime-to-mask SOA, separately for each visibility rating.

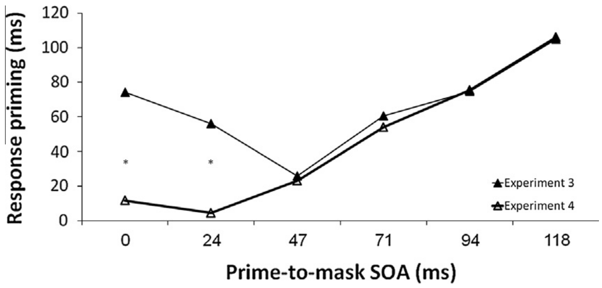

Fig. 9. Mean response-priming effect in milliseconds in Experiments 3 and 4 as a function of prime-to-mask SOA. The time course of meta-contrast masking was different when the prime was attended (Experiment 3) than when it was unattended (Experiment 4).

4.1. Materials and methods

4.1.1. Participants

Nine new undergraduate students (6 right handed, 7 women) from Tel Aviv University, age 22–28 years ($M = 24.4$, $SD = 1.7$) were tested in one session for course credit. All subjects reported normal or corrected-to-normal vision.

4.1.2. Stimuli, procedure and design

This experiment was similar to Experiment 3 except that participants provided only one response, the speeded discrimination of the mask arrow direction. There were no truncated arrows (i.e., no *no-go* trials). Ten percent of the trials were prime-absent trials. Each subject completed 500 trials, divided into 10 equal blocks.

4.2. Results and discussion

Trials in which response to the mask direction was inaccurate were excluded (2.0%), and so were outlier RTs (fewer than 1.8% of the trials). The main effect of response priming was highly significant on both RT and accuracy, $F(1,8) = 69.79$, $p < .0001$ and $F(1,8) = 10.49$, $p < .02$, respectively, and interacted with SOA, $F(5,40) = 39.23$, $p < .0001$ and $F(5,40) = 7.01$, $p < .0001$, respectively. Priming increased monotonically with prime-to-mask SOA, as reflected by significant linear components of the SOA effect on both RT and accuracy, $F(1,8) = 72.34$, $p < .0001$ and $F(1,8) = 8.61$, $p < .02$, respectively. A between-experiment analysis confirmed that the time course of priming differed when observers were required to allocate some attention to the prime (Experiment 3), relative to when they completely ignored it (Experiment 4), as reflected by the significant 3-way interaction between SOA, priming and experiment, $F(5,135) = 8.38$, $p < .0001$ (Fig. 9). These results show that Vorberg et al.'s (2003) findings are fully replicated when participants are not required to pay attention to the prime arrow. Taken together, the results from Experiments 2–4 strongly support the conclusion that differences in attention rather than in conscious perception account for the dissociation between the time courses of forced-choice discrimination performance and response priming during meta-contrast masking.

5. General discussion

Our experiments show that the time courses of subjective reports, objective discrimination performance and response priming during meta-contrast masking do not reveal qualitative dissociations. Instead, they suggest that meta-contrast masking modulates processes that are common to the mechanisms underlying these measures. A crucial aspect of our study is that we assessed all measures under similar conditions, both in terms of the stimuli we used and in terms of how observers distributed their attention between the prime and mask (Experiments 1–3). When attention was removed from the prime (Experiment 4), we replicated earlier findings (Schmidt & Vorberg, 2006; Vorberg et al., 2003) and priming showed a qualitatively different time course. Our findings therefore demonstrate that previous qualitative dissociations resulted from differences in the amount of attention allocated to the prime rather than from differences between the processes underlying conscious perception and response priming. Thus, if conscious perception and unconscious processing rely on independent mechanisms, a variable that modulates them in qualitatively different ways remains to be identified.

In addition, we found evidence for perceptual processing without awareness only when using an indirect measure: response priming was substantial when observers reported visibility of the prime to be null, but their performance at overtly discriminating the direction of the prime was at chance. These findings suggest that subjective reports of conscious perception and objective discrimination performance reflect the same underlying mechanisms with equal sensitivity, provided that the subjective measure employed is sensitive enough.

The latter finding seems to be at odds with several previous reports (e.g., Del Cul, Baillet, & Dehaene, 2007; Railo & Koivisto, 2012, but see Boyer, Harrison, & Ro, 2005; Wyart & Tallon-Baudry, 2008). With healthy observers, how subjective perception is measured is likely be a crucial factor in these differences: above-chance discrimination performance without awareness was mostly reported when less sensitive yes/no subjective reports were used (Koivisto & Revonsuo, 2003; Lamy et al., 2009) and when low yet above-zero reports of visibility were included in the "unaware" condition (Boyer et al., 2005; Del Cul et al., 2007). The most striking dissociations between subjective reports and objective discrimination performance, however, come from studies of patients with damage to the primary visual cortex (V1), who exhibit blindsight. These patients report total absence of subjective consciousness, while showing very high forced-choice performance levels (Cowey, 2005; Weiskrantz, Barbur, & Sahraie, 1995), in sharp contrast with our findings. However, it is important to reflect on what above-chance discrimination performance actually represents: some information allows the participant to discriminate between different states of the critical stimulus. There is little reason to assume that this information should be the same in healthy individuals and in patients in whom the primary source of visual information has been damaged, especially considering the fact that blindsight performance is thought to be heavily dependent on extensive practice (Cowey, 2010). Therefore, objective performance may reflect markedly different mechanisms in healthy observers and in blindsight patients.

The idea that unconscious processing and conscious perception can be strictly dissociated is a cornerstone of leading neural theories of consciousness (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2010). For instance, Global Workspace theory (Dehaene et al., 2006) postulates that conscious access is characterized by a dynamic non-linear transition from localized to global neural activity. While the present findings invalidate previous demonstrations of a qualitative dissociation between unconscious processing and conscious perception, they are not necessarily incompatible with such accounts. For one, the fact that conscious and unconscious processing follow the same time course during meta-contrast masking does not entail that they cannot be dissociated on a different variable. More crucially, one should keep in mind that different procedures for impairing consciousness are likely to interfere with processing at different levels. Here, we used metacontrast masking, yet by impeding processing at later stages of perceptual processes (arguably, continuous flash suppression, Tsuchiya & Koch, 2005, or the attentional blink, Raymond, Shapiro, & Arnell, 1992), one might be able to demonstrate that conscious perception relies on the same processes as unconscious processing up to a certain point, after which it takes on unique properties, as the Global Workspace theory would suggest. It will therefore be important to use the present approach using additional procedures to limit conscious perception in further research.

The results from our study have two further implications. First, by showing that subjective reports can be as sensitive as objective measures, our findings foster subjective measures as the preferred index of visual consciousness. For one, consciousness is, by essence, subjective. Subjective experience lies at the heart of the mystery of consciousness and by banning it from consciousness research, we run the risk of throwing the baby with the bathwater. Subjective measures are also superior from a methodological viewpoint. With subjective measures it is possible to assess conscious perception on every trial. In contrast, direct objective measures do not allow trial-by-trial assessment of conscious perception: participants are thought to be unaware of a certain stimulus property if their accuracy at discriminating this property is at chance *across the experiment*. Therefore, unlike subjective measures, accuracy measures are not sensitive to momentary fluctuations in the ability of a stimulus to thrust to consciousness.

The second implication of our findings pertains to the role of attention in meta-contrast masking. Our results suggest that attention to the prime determines whether type-A or type-B meta-contrast masking is observed. When the prime was unattended (as was the case here in Experiment 4 and in the condition of Vorberg et al.'s (2003) study used to measure priming), priming followed the same temporal pattern as typically observed during type A masking. Under exactly the same stimulus and exposure conditions, the temporal signature of priming during meta-contrast masking conformed to a type-B pattern when the prime became task relevant and therefore received some attention (as was the case here in Experiments 1–3 for all three measures and in the condition of Vorberg et al.'s (2003) study used to measure conscious perception). Previous research suggested that the type of the masking function (A or B) depends on the relative strength or energy of the prime and mask (Breitmeyer, 1978; Breitmeyer & et al., 2006; Di Lollo, von Mühlenen, Enns, & Bridgeman, 2004) and on the mask spatial lay-out (Duangudom, Francis, & Herzog, 2007). Here, we showed that the relative attention allocated to the prime and mask, rather than their physical characteristics alone, may also determine the type of the meta-contrast masking function.

Two arguments may challenge this conclusion. First, several studies showed that the meta-contrast masking function becomes flatter when less attention is allocated to the prime, that is, attention does not affect the earliest SOAs – as we found

– but instead improves visibility at intermediate SOAs (e.g., Enns, 2004; Tata, 2002). However, two potentially critical differences between our attention manipulation and previous ones may explain this difference. One is that in previous studies the prime received either full attention or only some, whereas in our study it received either no attention at all or some. It is therefore possible that type A masking might be observed only with total absence of attention. The other is that in previous studies attention was manipulated by varying either set size or spatial uncertainty in the prime display, whereas here, the prime always appeared on its own and at a known location: the prime's attentional salience was determined by whether or not it was relevant to the task. Shelley-Tremblay and Mack (1999) showed that attentional salience of a centrally presented prime does indeed alter the shape of the metacontrast function, in a way that is consistent with our findings. They showed that a prime better resisted metacontrast masking when it was a meaningful stimulus known to capture attention and crucially, that attention improved performance not only for intermediate but also for early SOAs.

The second argument is that when no attention at all is allocated to the prime and priming follows a monotonic function (Experiment 4), target visibility might nonetheless follow a U-shape function. Let us note upfront that this question cannot be resolved empirically. Inattentional blindness experiments (e.g., Mack & Rock, 1998) have demonstrated the dramatic effects of attention defined as "intention". Specifically, when subjects do not know that they have to refer to an object (even when this object is physically intact – and presumably all the more so if this object is degraded by masking), they do not see it at all. Yet, when they expect to be asked about that same object, they clearly see it, even if their attention is severely overloaded by a difficult central task. Thus, as visibility is always tied to a direct measure of perception, it is not possible to measure visibility without attention (or intention) and therefore, there is no empirical way to resolve the question of whether visibility without attention indeed would follow the same monotonically increasing function as priming.

Yet, as all our experiments showed that priming and visibility (whether measured with a subjective measure or with a forced-choice objective measure) followed the same time course when attention was divided between the target and mask, it is more parsimonious to suggest that it was also the case in the last experiment, in which no attention was allotted to the target.

6. Conclusions

We found no evidence that conscious perception and unconscious processing rely on independent mechanisms. We showed that subjective reports and objective discrimination performance reflect the same conscious perception mechanism, and that unconscious processing can be demonstrated using response priming. The rationale used in our study could usefully be extended to procedures other than meta-contrast masking for preventing conscious perception in order to determine at what stage of perceptual processing, if any, unconscious processing and conscious perception diverge in separate processing paths.

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