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Reexamining unconscious response priming: A liminal-prime paradigm

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ABSTRACT

Research on the limits of unconscious processing typically relies on the *subliminal-prime paradigm*. However, this paradigm is limited in the issues it can address. Here, we examined the implications of using the *liminal-prime paradigm,* which allows comparing unconscious and conscious priming with constant stimulation. We adapted an iconic demonstration of unconscious response priming to the liminal-prime paradigm. On the one hand, temporal attention allocated to the prime and its relevance to the task increased the magnitude of response priming. On the other hand, the longer RTs associated with the dual task inherent to the paradigm resulted in response priming being underestimated, because unconscious priming effects were shorter-lived than conscious-priming effects. Nevertheless, when the impact of long RTs was alleviated by considering the fastest trials or by imposing a response deadline, conscious response priming remained considerably larger than unconscious response priming. These findings suggest that conscious perception strongly modulates response priming.

1. Introduction

The notion that stimuli that are not consciously perceived can nevertheless undergo high-level processing is widely advocated (e.g., Dehaene & Changeux, 2011; Gibbons, 2009; Hassin, 2013; Jiménez-Ortega, Espuny, de Tejada, Vargas-Rivero, & Martín-Loeches, 2017; Kouider & Dehaene, 2007; Rohaut, Alario, Meadow, Cohen, & Naccache, 2016; Van Opstal, Gevers, Osman, & Verguts, 2010). Behavioral studies have shown that processes hitherto thought to fall in the exclusive realm of conscious abilities, such as semantic processing (e.g., Dehaene et al., 1998; Sklar et al., 2012), semantic integration (e.g., Mudrik, Breska, Lamy, & Deouell, 2011; Van Opstal, Calderon, Gevers, & Verguts, 2011; Van Opstal, de Lange, & Dehaene, 2011), high-level cognitive control (e.g., response inhibition: Hughes, Velmans, & DeFockert, 2009; Van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008), task-switching (e.g., Manly et al., 2014), conflict adaptation (e.g., Van Gaal, Lamme & Ridderinkhof, 2010), and context setting (e.g., Van Opstal et al., 2011) can occur in the absence of conscious perception. Likewise, growing evidence suggests that information that is not perceived consciously can be processed in a broad range of high-level brain regions including the prefrontal cortex (e.g., Lau & Passingham, 2006; Van Gaal & Lamme, 2012), which is traditionally associated with conscious control over behavior (e.g., Dehaene & Naccache, 2001). Although several methodological issues have been raised with regard to individual studies and failures to replicate have been reported (e.g., Desender & Van den Bussche, 2012; Hesselmann & Knops, 2014; Hesselmann & Moors, 2015; Moors, Boelens, van Overwalle, & Wagemans, 2016; Pratte & Rouder, 2009), these demonstrations raise the important question of what processes can unfold in the absence of conscious perception and conversely, for what processes consciousness is essential. More provocatively, they raise the possibility that unconscious processing may not have limits at all (e.g., Hassin, 2013).

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1.1. The subliminal-prime paradigm

The traditional way of establishing unconscious processing is to demonstrate that a stimulus affects behavior or brain activity even though conscious perception of this stimulus is absent (e.g., Marcel, 1983). Unconscious processing is most often probed in a paradigm, referred to here as the "subliminal-prime paradigm", that has become the gold standard for measuring unconscious priming (e.g., Almeida, Pajtas, Mahon, Nakayama, & Caramazza, 2013; Ansorge, Kiss, & Eimer, 2009; Dehaene et al., 1998; Frings & Wentura, 2008; Heinemann, Kunde, & Kiesel, 2009; Kiefer & Brendel, 2006; Kunde, Kiesel, & Hoffmann, 2003; Lau & Passingham, 2007; Manly et al., 2014; Naccache & Dehaene, 2001; Van Gaal, Lamme, & Ridderinkhof, 2010; Van Opstal et al., 2011; but see Rothkirch & Hesselmann, 2017 for an overview of alternative paradigms). This paradigm relies on the premise that conscious perception occurs whenever a stimulus can be classified with better accuracy than chance (e.g., Schmidt, 2015; see e.g., Peters, Ro, & Lau, 2016; Timmermans & Cleeremans, 2015 for a discussion of the relative advantages of objective and subjective measures of consciouness).

The subliminal-prime paradigm consists of two experimental phases: a priming phase and a prime-awareness phase. In the first (priming) phase, unconscious processing is assessed as the degree to which a subliminal prime influences the response to a visible target (in behavioral studies) or as the neural activity elicited by a subliminal prime (in brain studies). In the second (prime-awareness-test) phase, the observers' ability to discriminate some feature of the prime is assessed and chance performance on that task is held to attest to the subliminality of the prime. For example, Dehaene et al. (1998) required observers to classify a target digit as being smaller or larger than 5. Unbeknownst to the participants, a prime (also a number either smaller or larger than 5) was presented prior to the target. The prime was rendered subliminal by pre- and post-masks. Congruent trials (in which the prime and target were associated with the same response, e.g., > 5) were responded to faster than incongruent trials (in which they were associated with opposite responses). Yet, participants were at chance in post-experimental awareness tests, suggesting that they were objectively unaware of the prime. The authors concluded that a subliminal prime can be processed up to a semantic level (but see Abrams & Greenwald, 2000; Damian, 2001; Kunde et al., 2003 for alternative interpretations).

1.2. Caveats of the subliminal-prime paradigm

Despite its extensive use, the subliminal-prime paradigm can be criticized on several grounds. First, conscious perception of the prime during the post-experiment prime-awareness test may not provide an accurate estimate of conscious perception during the priming phase because it is not measured in the same context (e.g., Lamy, Carmel, & Peremen, 2017; Lin & Murray, 2014; Pratte & Rouder, 2009; see also 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 prime-awareness phase is underestimated (but see Finkbeiner, 2011, for contradictory evidence). Second, the prime-awareness phase typically does not include enough trials to allow rejecting the hypothesis of null sensitivity to the prime (e.g., Amihai, 2012).

Finally, and most relevant for the present purposes, the prime is selected so as to be subliminal on all trials and therefore, the role of conscious perception cannot be assessed because unconscious processing cannot be compared to conscious processing under the same stimulus conditions (e.g., Lamy, Alon, Carmel, & Shalev, 2015; van den Bussche et al., 2013).[1] This limitation is particularly important, because high-level unconscious processing is often inferred from very small priming effects (e.g., Almeida, Mahon, & Caramazza, 2010; Kunde et al., 2003; Van den Bussche, Notebaert, & Reynvoet, 2009) that may result from just a few trials in which the prime is consciously perceived. Finding that priming effects are substantially larger when the prime is consciously perceived than when it is not (all stimulus parameters being kept equal) would strongly mitigate the conclusion that high-level processing can be independent of conscious perception.

1.3. The liminal-prime paradigm

Recently, several authors have advocated the use of the *liminal-prime paradigm* as an alternative to the subliminal-prime paradigm (e.g., Lamy et al., 2015, 2017; van den Bussche et al., 2013). In this paradigm, subjective perception of the prime is measured on every trial using some variant of the *Perceptual Awareness Scale* (PAS, Ramsøy & Overgaard, 2004), while the impact of this prime on responses to the target (i.e., priming) is concomitantly assessed. With PAS, observers report on the quality of their subjective experience, using a 4-point scale of visibility: (1) 'No experience', (2) 'Brief glimpse', (3) 'Almost clear image', and (4) 'Absolutely clear image'. The underlying rationale is that when subjects experience partial awareness of the stimulus, they will use the intermediate levels of the scale, thereby increasing the probability that the lowest visibility rating indeed reflects total absence of conscious awareness of the stimulus. Accordingly, several authors have found that when observers report the lowest level of stimulus visibility using PAS, their performance on a concomitant objective forced-choice discrimination task on that stimulus is at chance (e.g., Lamy et al., 2015, 2017; Liu et al., 2016; Lähteenmäki, Hyönä, Koivisto, & Nummenmaa, 2015; Peremen & Lamy, 2014; Ramsøy &

[1] Several authors assessed the role of conscious perception by comparing priming on weak-stimulation (subliminal-prime) trials and on strong-stimulation (supraliminal) trials (e.g., Desender, Van Lierde, & Van den Bussche, 2013; Goller, Khalid, & Ansorge, 2017; Jiang, Bailey, Xiang, Zhang, & Zhang, 2016; Lin & Murray, 2015; Tapia, Breitmeyer, & Shooner, 2010; Van Gaal, Lamme, Fahrenfort, & Ridderinkhof, 2011; Van Gaal et al., 2014). In these studies, conscious information was found to have a much stronger impact on behavior and on brain activity than unconscious information but the effects of conscious perception were conflated with those of stimulation strength.

Overgaard, 2004; Tagliabue, Mazzi, Bagattini, & Savazzi, 2016). They suggested that such findings argue against the criticism that subjective measures of conscious perception such as PAS are less sensitive to the presence of conscious perception than objective measures.

The liminal-prime paradigm resolves several of the problems associated with the subliminal-prime paradigm. It allows measuring priming and conscious perception on the same trials and therefore in the same context and it does not suffer from intrinsic statistical power issues. Its main advantage, however, is to provide a means of evaluating the contribution of conscious perception, as priming can be compared when the prime is not consciously perceived (0-visibility trials) relative to when it is (above-0 visibility trials). Thus, different cognitive processes can be categorized according to the extent to which they depend on conscious processing. For instance, contingent attentional capture was found to be independent of conscious perception of the attention-grabbing stimulus (Lamy et al., 2015), whereas the same-location cost, which is thought to reflect processes related to working memory (e.g., Carmel & Lamy, 2014, 2015) was found to be entirely contingent on conscious perception of the critical stimulus (Lamy et al., 2015). Finally, trials in which the prime was judged to be invisible are not treated in isolation but instead the whole range of visibility judgments is considered (see Shanks, 2017 for detailed discussions of the problems associated with inferring unconscious processing from isolated post hoc analysis of trials - or participants - for which awareness of the prime is absent).

1.4. Implications of the liminal-prime paradigm

Notwithstanding these advantages, it is important to consider that several features of the liminal-prime paradigm may alter the characteristics of the measured processes.

On the one hand, since participants are required to respond to the target (task 1) and then rate the prime's visibility (task 2), this paradigm entails a dual-task situation. As such, it is associated with slower responses relative to the subliminal-prime paradigm in which only responses to the target are required (e.g., Lamy et al., 2017; Pashler, 1994). It has been suggested that the impact of unconscious stimuli on behavior is short lived. Support for this claim comes from two types of findings: unconscious priming occurs (1) only with very short stimulus-onset asynchronies between the prime and target (e.g., Greenwald, Draine, & Abrams, 1996) and (2) only when response times are fast enough (e.g., Ansorge, Kiefer, Khalid, Grassl, & König, 2010; Dehaene et al., 1998, Fig. 2b; Kinoshita & Hunt, 2008). Thus, the liminal-prime paradigm may underestimate the magnitude of unconscious priming because it is associated with slow responses.

On the other hand, the fact that participants are required to rate the visibility of the prime entails that the prime is relevant to the task and benefits from temporal attention. Ivanoff and Klein (2003) showed that the requirement of rating prime awareness modulates the impact of the prime on behavior. In addition, Naccache, Blandin, and Dehaene (2002) showed that unconscious response priming is strongly enhanced by temporal attention. Thus, unconscious priming effects may be larger in the liminal- relative to the subliminal-prime paradigm because the prime is relevant to the task and benefits from temporal attention in the former but not in the latter paradigm.

Lamy et al. (2017) recently compared the magnitude of response priming in the two paradigms using the same stimuli. They found that although RTs were much slower in the liminal-than in the subliminal-prime paradigm, response priming was of similar magnitude. In light of the arguments presented above, this finding may result from the benefits of temporal attention and task relevance offsetting the cost of long RTs rather than indicating that response priming is unaffected by which of the two paradigms is used.

1.5. The present study

The main objective of the present study was to evaluate the implications of using the liminal-prime paradigm as a tool to investigate unconscious processing. To this end, we adapted Dehaene et al.'s (1998) iconic demonstration of unconscious response priming and used a liminal exposure duration for the prime, so as to ensure that its visibility would vary from trial to trial. We could thus compare response priming on unseen-prime trials (visibility 0) and on clearly perceived prime trials (visibility 3). In addition, we manipulated temporal attention to the prime and the prime's relevance to the task, as well as the number of reports required from the participants (single vs. dual task) in order to assess the impact of these factors on the magnitude of the response priming effect.

1.6. Statistical analyses

1.6.1. Outliers

In all experiments, trials with a reaction time below 150 ms were excluded from all RT analyses as anticipatory responses and for each participant, trials with an RT deviating from the median RT of each cell by more than 3 median absolute deviations (MAD) were also excluded as outliers (Leys, Ley, Klein, Bernard, & Licata, 2013).

1.6.2. Mixed-effects models

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. To overcome the resulting distortions and to avoid excluding participants based on considerations of balanced visibility rating distribution, we used mixed-effects models to analyze the data in all experiments. All statistical analyses including prime visibility as a factor were carried out using "R" statistical software (R Core Team, 2015). For reaction time (RT) analyses, we used a linear mixed-effects model (LMM), with response congruence (congruent vs. incongruent) and prime visibility (aware vs. unaware) as predictors and random subject-specific intercept and subject-specific slope (Barr, Levy, Scheepers, & Tily, 2013). We compared the basic model to a model with a random slope for each of the predictors (Bates, Kliegl, Vasishth, & Baayen, 2015). Following this procedure, the final model was expressed as: `Response Times ~Visibility + Congruence + Visibility: Congruence + (1 + Visibility| Subject)`. Effects in this final model were tested in a type III ANOVA, using the *lmer* function of the lme4 package (version 1.1-13; Bates, Maechler, Bolker, & Walker, 2015). The *p-value*s of the effects were determined using Satterthwaite approximations to degrees of freedom, as implemented in the *anova* function from the stats4 package (version 3.4.1). For accuracy analyses, a generalized linear mixed-effects model (GLMM) for binary data was fitted by using the *glme* function and a *logit* link function (Jaeger, 2008) with the same predictors and model selection procedure as for the RT analyses. The final model was expressed as: `Accuracy ~Visibility + Congruence + Visibility: Congruence + (1 + Visibility| Subject)`.

The summary output of the GLMM function of the lme4 package in R provides p-values based on asymptotic Wald tests, which is common practice for generalized linear models (Bolker et al., 2009). In contrast, the summary output of the *anova* function for LMM models provides F-values. We thus report z-values for error-rates and F-values for response times. For both RT and accuracy data, the p values for post hoc comparisons are reported with Tukey adjustments.

1.6.3. Bayesian analyses

Since our main interest was in the extent to which the response priming effect was modulated by conscious perception of the prime, we evaluated the evidence for an interaction between response congruence and prime visibility by computing the Bayes factor for this interaction in Bayesian ANOVA analyses (with subject as a random factor) using the JASP software package (version 0.8.1.2) and a Cauchy prior of 0.5. Following Dienes and McLatchie (2016) we consider a BF10 to provide evidence for H0 if it stands between 0 and 0.33, "inconclusive" evidence if it stands between 1/3 and 3 and evidence for H1 if it exceeds 3 (with a BF10 between 3 and 10, 10 and 30, 30 and 100 and > 100 providing substantial, strong, very strong and decisive evidence, respectively, for H10, Jeffreys, 1961). We applied the same criteria for BF01 and support for H1 vs. H0.

2. Experiment 1

In Experiment 1 we manipulated the extent to which the prime benefitted from temporal attention as well as the prime's relevance to the task at hand. On each trial, a frame with an aperture in one of its four sides surrounded either the prime or the target. Participants performed two tasks on each trial. The first task was to categorize the target as smaller or larger than 5. The second task was not speeded and varied across conditions. In the *attended-irrelevant* prime condition, the frame surrounded the prime and the second task was to report the side of its aperture. Thus, in this condition, the prime number benefitted from temporal attention because it appeared at the same time as the task-relevant frame, but it was irrelevant to the task. The *unattended-irrelevant* condition was similar except that the frame surrounded the target. Thus, the prime benefitted from less temporal attention because it appeared before the frame, and was again irrelevant to the task. In the *attended-relevant* prime condition (which corresponds to the liminal-prime paradigm), the second task was the prime-visibility task, and the prime thus benefitted from temporal attention and was task relevant. Response requirements were equated by assigning four possible responses to the second task in all conditions (up, down, left or right in the aperture-localization tasks, and 0, 1, 2 or 3 for the prime-visibility task).

We examined whether the unconscious response priming reported using the subliminal-prime paradigm (e.g., Dehaene et al., 1998; Kunde et al., 2003) could be observed using the liminal-prime paradigm (i.e., for trials in which the prime visibility was rated 0). In addition, to assess the impact of conscious perception on response priming, we compared response priming when the prime was consciously perceived (visibility 3) relative to when it was not (visibility 0). Finally, we predicted that if attention and/or task relevance[2] indeed increase response priming, this effect should be largest in the attended-relevant prime condition and smallest in the unattended-irrelevant prime condition.

Previous research using a number categorization task similar to the one employed here used a sample size of 12–18 participants (e.g., Dehaene et al., 1998; Kunde et al., 2003; Naccache & Dehaene, 2001) and previous studies using the liminal prime paradigm used 14 participants (Lamy et al., 2015). Here, in all experiments, the sample size was set to 16–18 participants.

2.1. Method

2.1.1. Participants

Eighteen undergraduate students (14 right handed, 16 women) from Tel-Aviv University, aged 19 to 26 years (M = 23.83, SD = 5.72) were tested in one session for course credit. All reported normal or corrected-to-normal vision.

2.1.2. Apparatus

Displays were presented in a dimly lit room on a 23-in. LED screen, using 1.920 × 1.280 resolution graphics mode and 120-Hz refresh rate. Responses were collected via the computer keyboard. Viewing distance was set at 50 cm from the monitor.

[2] Note that spatial attention may have been more widely spread out in the attended-irrelevant condition than in the attended-relevant condition: spatial attention was focused on the prime's location in the latter condition and distributed over a slightly larger region of space that included both the prime and the frame enclosing it, in the former condition. Thus, any effect of task relevance may be accounted for at least in part by small differences in the size of the attended area.

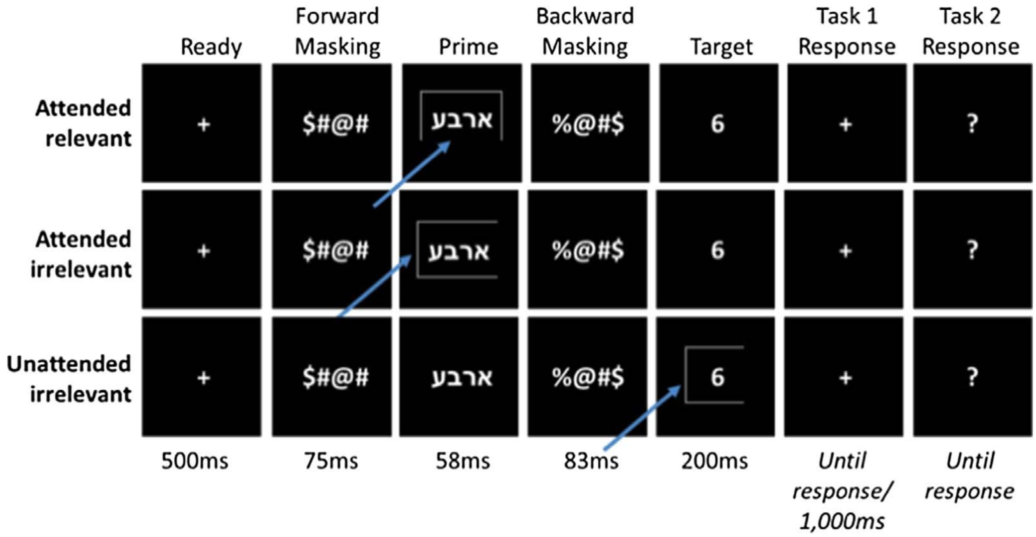

Fig. 1. Sequence of events in Experiment 1. This example depicts an incongruent trial: the prime and target numbers ("four" written in Hebrew and "6", respectively) were associated with different responses. For all conditions, the first task was to report whether the target was smaller or larger than 5. In the attended-relevant condition (*upper panel*) the second task was to indicate the prime visibility on a scale ranging from 0 to 3. In the attended-irrelevant condition (*middle panel*) the second task was to indicate the direction of the open frame, which surrounded the *prime*. In the unattended-irrelevant condition (*lower panel*) the second task was to indicate the direction of the open frame, which surrounded the *target*.

2.1.3. Stimuli and procedure

The sequence of events is presented in Fig. 1. The fixation was a 0.4 × 0.4° plus sign (+). The target was either a digit or a number word written in Hebrew and drawn from eight possible numbers (1–9 excluding 5). The prime was similar to the target, except that the number was drawn from only four possible numbers (1, 4, 6, and 9). On each trial, either the prime or the target was enclosed in a 4.2 × 1.4 cm 1-pixel thick gray frame with one of its four sides open. The pre- and post-mask were identical and consisted of a random string of 5 symbols ($, %, @, #). Each stimulus was gray (RGB: 127, 127, 119, with a luminance of about 33 cd/m^2) and centered at fixation. Each letter, digit and symbol was drawn in a 28-point Arial font (~1.15° of visual angle). The sequence of events consisted of the successive presentation of the fixation (500 ms), pre-mask (75 ms), prime (58 ms), post-mask (83 ms) and target (200 ms) displays. Following the target, the fixation display was again presented for 1000 ms or until the first response was given, and was immediately followed by a question mark, which remained on the screen until the second response was given.

On each trial, participants were instructed to perform two tasks. In all conditions, they first determined whether the target was smaller or larger than 5 and responded by pressing designated keys on the computer keyboard with their right hands, as fast and accurately as possible. Then, they provided a second response, which was not speeded. In the *unattended-irrelevant* condition, the frame enclosed the target and participants were required to report which of its sides was missing, by pressing one of four designated keys on the computer keyboard with their left hands. The *attended-irrelevant* condition was similar, except that the frame enclosed the prime. In the *attended-relevant* condition, the frame enclosed the prime, but participants were not asked to respond to it: instead they had to rate the visibility of the prime using a scale ranging from 0 ("I saw nothing at all") to 3 ("I saw the number clearly"). Thus, in all conditions, the non-speeded task required a 4-alternative forced-choice response. Note that the frame appeared for 58 ms when it enclosed the prime and for 200 ms when it enclosed the target.

Eye movements were not monitored, but subjects were explicitly requested to set their eyes on the center of the screen throughout each trial. Erroneous responses or failures to respond during the presentation of the response display were followed by a 150-ms 1000 Hz beep.

2.1.4. Design

The three dual-task conditions were presented in separate blocks of 320 trials each, divided into 2 blocks and separated by a self-paced break. The first block of each dual-task condition was preceded by two practice blocks of 20 trials each. During the first practice block, participants provided only the speeded response to the target. During the second practice block, subjects provided the two responses, just as on the experimental trials. Dual-task condition order was counterbalanced across subjects. Twenty percent of the trials were prime-absent (or catch) trials. In each experimental block, prime and target numbers and formats were randomly mixed and equally likely to be congruent or incongruent.[3]

[3] In this and the following experiments, the primes and targets could be either digits or number words. We adopted this design in order to remain as close as possible to previous experiments (e.g., Dehaene et al., 1998). However, our objective was not to determine the extent to which response priming reflected semantic processes but to evaluate the effects of using liminal primes and adding a second task (subjective visibility rating) to the main target number categorization task (for a discussion

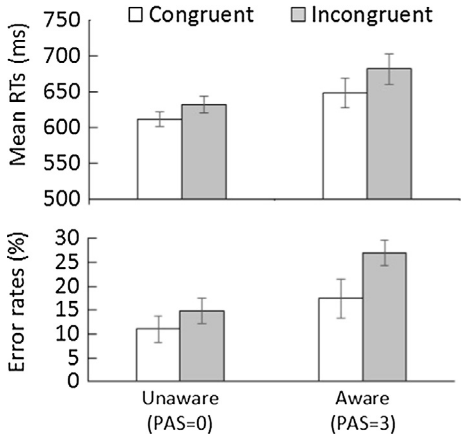

Fig. 2. Mean RTs and error rates in the attended-relevant condition from Experiment 1 for congruent and incongruent trials by prime-visibility rating (0 vs. 3). Error bars indicate within-subject standard errors (Morey, 2008).

Table 1
Model output for the fixed and random factors in Experiment 1.

Fixed effects	Coefficient	Std. err	Z-value	*P-value*
(Intercept)	0.99	0.156	6.36	< .001
Visibility = 0 visibility	0.75	0.251	2.98	0.003
Congruence = congruent	0.58	0.168	3.44	< .001
Interaction	−0.23	0.231	−1.02	0.31
Random effects	Variance	Std. dev		
Subject (intercept)	0.13	0.35		
Visibility	0.50	0.71		

2.2. Results

Prime-absent trials were excluded from all RT and accuracy analyses. In all RT analyses, trials in which responses to the target were inaccurate were excluded (13.2%). Preliminary analyses showed that dual-task condition order interacted with none of the variables of interest (all Fs $<$ 1). Therefore, the data were collapsed across orders of dual-task condition in all analyses.

2.2.1. Effects of conscious perception of the prime on response priming

The following analyses were conducted only on the data from the attended-relevant prime condition. The data from two participants were excluded from these analyses because they reported visibility ratings of 2 or 3 on more than 50% of prime-absent (catch) trials (relative to an average of 3% for the group). The participants rated prime visibility to be 0, 1, 2 and 3 on 33%, 28%, 17%, and 22% of the trials, respectively, on prime-present trials and on 58%, 27%, 12% and 3%, respectively, on prime-absent trials. We adopted the most conservative criterion for conscious perception: the unaware condition included only trials on which visibility was rated 0, and the aware condition included only trials on which visibility was rated 3. Mean response times and error rates are presented in Fig. 2.

2.2.1.1. Reaction times. Anticipatory responses as well as outlier RT trials (0.6%) were excluded from this analysis. The main effects of prime visibility and response congruence were significant, with slower RTs on aware- than on unaware-prime trials, $F(1, 10) = 7.01$, $p = .023$ and on incongruent than on congruent trials, $F(1, 1925) = 23.77$, $p < .001$. The interaction between the two factors was not significant, $F(1, 1923) = 1.21$, $p = .27$. Post-hoc comparisons revealed that the effect of response congruence was significant for both aware-prime trials, $t(1921) = 3.82$, $p < .001$ and unaware-prime trials, $t(1920) = 3.03$, $p = 0.013$. A Bayes factor analysis revealed that the evidence for an interaction between prime visibility and response congruence, was inconclusive, $BF_{10} = 1.28$.

(*footnote continued*)
of the semantic interpretation of these response priming effects see e.g., Damian 2001; Kiesel, Kunde, Pohl, & Hoffmann, 2006; Kunde et al., 2003; Reynvoet, Gevers, & Caessens, 2005). Therefore, in order to simplify the description of the results, the prime and target format variables were not entered as factors in the analyses reported in the results section. Note however that none of the effects involving an interaction between prime format (digit vs. word) × target format (digit vs. word) and response priming was significant.

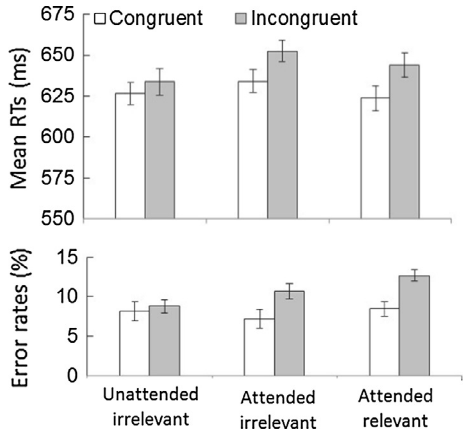

Fig. 3. Mean RTs and error rates in Experiment 1 for congruent- and incongruent-response trials by conditions of temporal attention and prime's relevance. Error bars indicate within-subject standard errors (Morey, 2008).

2.2.1.2. Accuracy. The model output for the fixed and random factors is presented in Table 1. The main effects of prime visibility and response congruence were significant, with poorer accuracy on aware-than on unaware-prime trials, and on incongruent than on congruent trials. The interaction between the two factors was not significant. Post-hoc comparisons revealed that response congruence was significant on aware-prime trials, $z = -3.44$, $p = .003$, and failed to reach significance on unaware-prime trials, $z = -2.22$, $p = 0.12$.

2.2.2. Frame aperture localization accuracy

Accuracy at localizing the frame aperture was lower in the attended-irrelevant than in the unattended-irrelevant prime condition, M = 50.4%, SD = 21.4% vs. M = 85.3%, SD = 22.5%, $F(1, 17) = 46.07$, $p < 0.0001$. This finding reflects the facts that the frame was presented for 58 ms in the former condition and for 200 ms in the latter, and that the critical stimuli for the two tasks coincided in time in the latter but not in the former. Crucially however, frame identification accuracy was clearly above chance (25%) in both conditions, both ps $< .001$, confirming that participants allocated their attention to the frame as instructed to.

2.2.3. Response priming as a function of temporal attention and prime relevance

The following analyses, which do not include prime visibility as a factor, were carried out using Statistical Analysis Software (SAS 9.3). A repeated measures analysis of variance (ANOVA) with prime-target response congruence (congruent vs. incongruent) and dual-task condition (unattended-irrelevant, attended-irrelevant, attended-relevant) was conducted on RT and accuracy data for the target number classification task of all 18 participants. In this analysis, all the trials of the attended-relevant condition were included, irrespective of awareness ratings.[4]

2.2.3.1. Reaction times. Anticipatory responses and outlier RT trials (0.2%) were excluded from this analysis. Planned comparisons revealed that although the congruence effect increased numerically with both attention and prime relevance (see Fig. 3), only the cumulative effects of attention and relevance reached significance (unattended-irrelevant vs. attended-relevant), $F(1, 17) = 4.69$, $p = .045$, while the separate effects of attention (attended-irrelevant vs. unattended irrelevant) and relevance (attended-relevant vs. attended-irrelevant) did not, $F < 1$ and $F(1, 17) = 2.48$, $p = .13$, respectively. Post-hoc comparisons revealed that the congruence effect was significant in both the attended-relevant and attended-irrelevant conditions, $F(1, 17) = 15.27$, $p = .001$ and $F(1, 17) = 8.22$, $p = .01$ ($p = .003$ and $p = .03$ after Bonferroni correction), respectively, but not in the unattended-irrelevant condition, $F(1, 17) = 1.94$, $p = .18$.

2.2.3.2. Accuracy. The accuracy results paralleled the RT results. Planned comparisons revealed that relative to the unattended-irrelevant condition, response priming was larger in the attended-relevant and attended-irrelevant conditions, $F(1, 17) = 6.22$, $p = .023$ and $F(1, 17) = 5.96$, $p = .026$, respectively, with no significant difference between the latter two conditions, $F < 1$. Post-hoc comparisons further revealed that the response congruence effect was significant for both the attended-relevant and attended-irrelevant conditions, $F(1, 17) = 10.62$, $p = .0046$ and $F(1, 17) = 10.90$, $p = .0042$ ($p = .014$ and $p = .013$ after Bonferroni correction), respectively, but not in the unattended-irrelevant condition, $F < 1$.

[4] The results followed the same pattern on both RT and accuracy data when trials with incorrect responses to the frame aperture were also excluded from the analyses in the unattended and attended irrelevant conditions (recall that the attended-relevant condition required a prime-visibility response).

2.3. Discussion

The results of Experiment 1 yielded two main findings. First, we observed unconscious response priming in a task similar to Dehaene et al.'s (1998); see also, Kunde et al. (2003) using the liminal- instead of the subliminal-prime paradigm. Although unconscious response priming was numerically smaller than response priming for clearly seen primes, the difference between the two effects was not significant and a Bayes Factor analysis indicated that the evidence for this null interaction was inconclusive. Second, response priming was observed only when the prime benefitted from temporal attention, that is, in the attended-relevant and –irrelevant prime conditions, but not when the prime was unattended and irrelevant.

The latter finding is consistent with previous claims that stimuli that remain outside of conscious awareness require attentional amplification in order to elicit measurable semantic priming effects (e.g., Kiefer & Brendel, 2006; Naccache et al., 2002; Xiao & Yamauchi, 2017). For instance, Naccache et al. (2002) noted that most masked-priming paradigms use a fixed temporal onset of primes and targets, thereby allowing participants to focus their temporal attention on a narrow time window. They further suggested that the occurrence of unconscious priming is contingent on the allocation of temporal attention to the time window during which the prime-target pair is presented. In the unattended-irrelevant prime condition of Experiment 1, no response priming was observed when the prime display was not associated with any task although the prime and target appeared in a fixed time window as they did in previous studies that reported unconscious response priming (e.g., Dehaene et al., 1998). This finding is especially surprising in light of the fact that here, primes were not subliminal: they were probably not consciously perceived on a portion of the trials but not on all trials.

Two possible accounts for this discrepancy between our findings and previous reports come to mind. One is that the use of a dual task in our experiment lengthened RTs, leaving enough time for the prime-related activation to dissipate (e.g., Ansorge et al., 2010; Kinoshita & Hunt, 2008). The second is that requiring observers to perform a difficult task (respond to both the target number and the aperture of the frame enclosing it) induced them to further narrow the focus of their attention around the time the target was expected to appear, leaving the prime outside the temporal focus of attention.

We took two steps to evaluate these accounts. First, we conducted a control experiment with sixteen new participants (all right handed, 9 women). It was similar to Experiment 1 except that (a) participants were not informed of the presence of the prime and performed only the target number classification task and (b) the experiment was longer (640 trials). Thus, the prime was again unattended and irrelevant, as it was in the unattended-irrelevant condition of Experiment 1 but in the context of a single task. We expected to replicate previous findings (e.g., Dehaene et al., 1998; Kunde et al., 2003) and observe a significant response priming effect. This prediction was confirmed: the response priming effect was highly significant both for RTs, $M = 543$ ms, $SD = 51$ ms vs. $M = 557$ ms, $SD = 51$ ms on congruent vs. incongruent trials, respectively, $F(1, 15) = 8.70$, $p = .001$, and for accuracy, $M = 96.0\%$, $SD = 2.1\%$ vs. $M = 93.2\%$, $SD = 3.7\%$, on congruent vs. incongruent trials, respectively, $F(1, 15) = 15.13$, $p = .0015$. Thus, although the prime was unattended and irrelevant in both the single- and dual-task conditions, the congruence effect was significant in the former but not in the latter condition.

Second, we evaluated whether this difference could be accounted for by longer RTs in the dual-relative to the single-task condition. We first conducted a between-experiment comparison which confirmed that participants were indeed slower on the dual than on the single task, $F(1, 31) = 12.58$, $p = .0013$. We then examined the response-priming effect across the RT distribution in both the dual task (unattended-irrelevant condition of Experiment 1) and the single task (control experiment). To do that, we used a vincentization procedure (Ratcliff, 1979): quantiles of RT distributions were computed for each participant, each summarizing 10% of the cumulative RT distribution, and were then averaged to produce the group distribution (Rouder & Speckman, 2004). This nonparametric procedure was applied separately for congruent and incongruent trials in the single- and dual-task conditions, thus yielding estimates of the congruence effect for each bin and condition.

As Fig. 4 shows, the response priming effect was present in both conditions in the early part of the RT distribution and entirely vanished in the later part. Because there were not enough trials per condition to conduct a meaningful statistical analysis of the vincentized data with 10 bins, we aggregated the data in just two bins (50% fastest and 50% slowest trials, see Fig. 5). An ANOVA with response congruence (congruent vs. incongruent) and RT-distribution half (fast vs. slow trials) as within-subject factors revealed a significant interaction between the two factors, for both the dual task, $F(1, 17) = 5.63$, $p = .03$ and the single task, $F(1, 15) = 40.28$, $p = .0001$, respectively, indicating that the congruence effect was larger for fast than for slow trials.[5]

Taken together, these results indicate that on the one hand, temporal attention and task relevance magnify response priming in the liminal-prime paradigm relative to the standard single-task paradigm. On the other hand, the slower RT and high task difficulty associated with the dual task inherent to the liminal-prime paradigm reduce the congruence effect relative to the standard single task.

3. Experiment 2

The foregoing analyses show that at least with liminal primes, response priming decreases as RTs increase and entirely dissipates for the slowest RTs. These results underscore the potential impact of overall RTs on the detection of unconscious priming effects. In Experiment 1, there were not enough trials in the attended-relevant prime condition (which corresponds to the liminal-prime

[5] Complementary analyses indicated that the response congruence effect was smaller in the dual- than in the single-task even for the fastest trials. If confirmed by further research, this observation would suggest that just as the focus of spatial attention is adjusted like a zoom lens as a function of task difficulty (e.g., Eriksen & Eriksen, 1974), so is the focus of temporal attention.

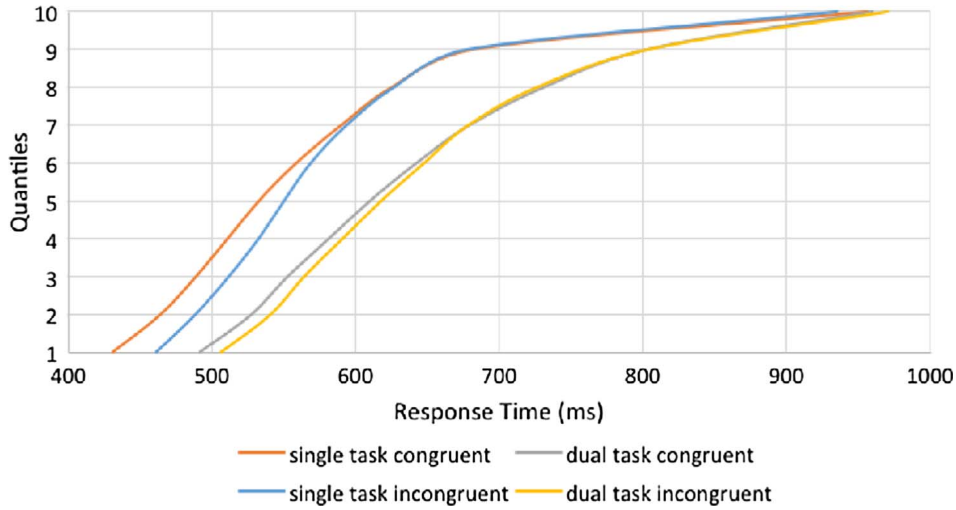

Fig. 4. Vincentized reaction time distributions on congruent- and incongruent-response trials for unattended-irrelevant primes in Experiment 1 (dual-task) and in the control experiment (single-task).

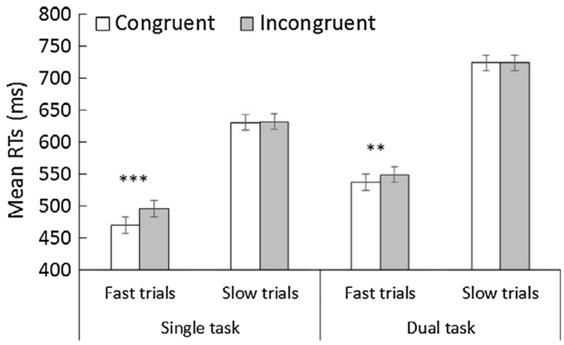

Fig. 5. Mean reaction times (in milliseconds) as a function of task, prime-target congruence and fast vs. slow trials in Experiment 1 (dual-task) and in the control experiment (single-task). Numbers in parentheses represent the standard errors. ** < .01; *** < .001.

paradigm) to examine how the size of the response congruence effect varied across the RT distribution in the aware and in the unaware-prime conditions. In addition, the critical comparison for determining the extent to which response priming depended on conscious perception of the priming event yielded inconclusive results. We therefore conducted a replication of the attended-relevant prime condition in a full experiment. Participants first performed the speeded number classification task and then rated the prime visibility.

We inquired whether the findings of Experiment 1 would be replicated in this condition, namely, whether response priming would be significant when the prime was rated to be invisible, and whether it would be similar to the response priming effect elicited by a clearly seen prime. Of particular interest was whether (1) unconscious priming would vanish with increasing RTs, (2) response priming from consciously perceived primes would be more resistant to the passage of time and (3) for the fastest responses, unconscious response priming would be smaller than conscious response priming.

3.1. Method

3.1.1. Participants

Seventeen undergraduate students (12 right handed, 12 women) from Tel-Aviv University, age 21–33 years (M = 25.28, SD = 3.31) were tested in one session for course credit. All reported normal or corrected-to-normal vision.

3.1.2. Apparatus, stimuli, procedure and design

The apparatus, stimuli, procedure and design were similar to those of the attended-relevant prime condition of Experiment 1 except that each participant completed 576 experimental trials in the experimental phase. These were divided into 4 blocks, separated by a self-paced break.

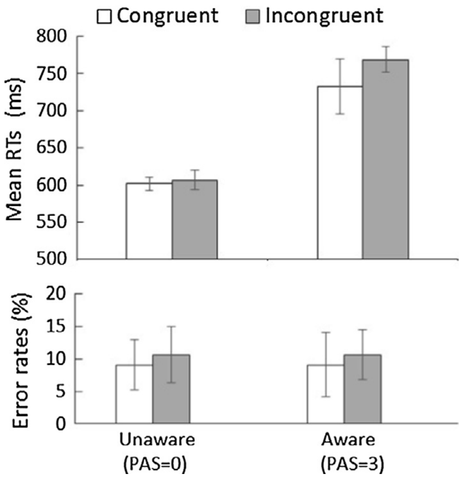

Fig. 6. Mean RTs and error rates in Experiment 2 for congruent- and incongruent-response trials as a function of prime visibility rating (0 vs. 3). Error bars indicate within-subject standard errors (Morey, 2008).

3.2. Results and discussion

In all RT analyses, trials in which responses to the target were inaccurate were excluded (11.4%) and so were anticipatory responses and outlier trials (2.3%). The data from three participants were excluded from analysis: one of them was at chance at responding to the target (M = 52.3% vs. M = 88.6%, SD = 6.1% for the group) and the remaining two participants reported a visibility rating of 3 on more than 50% of prime-absent (catch) trials (relative to an average of 2% for the group). The participants rated prime visibility to be 0, 1, 2 and 3 on 46%, 18%, 15%, and 21% of the trials, respectively, on prime-present trials and on 72%, 20%, 6% and 2%, respectively, on prime-absent trials.

3.2.1. Reaction times

The main effects of prime visibility and response congruence were significant, with slower RTs on aware than on unaware-prime trials, $F(1, 11) = 41.64$, $p < .001$ and on incongruent relative to congruent trials, $F(1, 3644) = 17.3$, $p < .001$ (see Fig. 6). The interaction between the two factors was significant, $F(1, 3643) = 10.08$, $p = .001$. Post-hoc comparisons revealed that the congruence effect was significant on aware-prime trials, $t(3645) = -4.40$, $p = .001$ and non-significant on unaware-prime trials, $t(3641) = -0.89$, $p = .81$. A Bayesian Factor analysis provided substantial evidence for the interaction between prime visibility and response congruence, $BF_{10} = 5.25$.

3.2.2. Accuracy

The model output for the fixed and random factors is presented in Table 2. The main effects of prime visibility and response congruence were significant, with poorer accuracy on aware-than on unaware-prime trials, and on incongruent-than on congruent trials. The interaction between the two factors was not significant. Nevertheless, in line with the RT data, the congruence effect approached significance on aware-prime trials, $z = 2.47$, $p = .06$ and was non-significant on unaware-prime trials, $z = 1.56$, $p = .39$.

3.2.3. RT quantile analysis

To examine how the size of the congruence effect varied across the RT distribution in the aware and in the unaware-prime conditions, we used the same vincentization procedure as in Experiment 1. Fig. 7 shows the mean RT separately for aware- and unaware-prime trials on congruent and incongruent trials, for each decile of the cumulative RT distribution. Because there were not

Table 2
Model output for the fixed and random factors in Experiment 2.

Fixed effects	Coefficient	Std. err	Z-value	*P-value*
(Intercept)	1.89	0.254	7.43	< .001
Visibility = 0 visibility	0.42	0.213	1.96	0.0505
Congruence = incongruent	-0.39	0.159	−2.47	0.013
Interaction	0.21	0.197	1.08	0.28
Random effects	Variance	Std. dev		
Subject (intercept)	0.62	0.79		
Visibility	0.16	0.40		

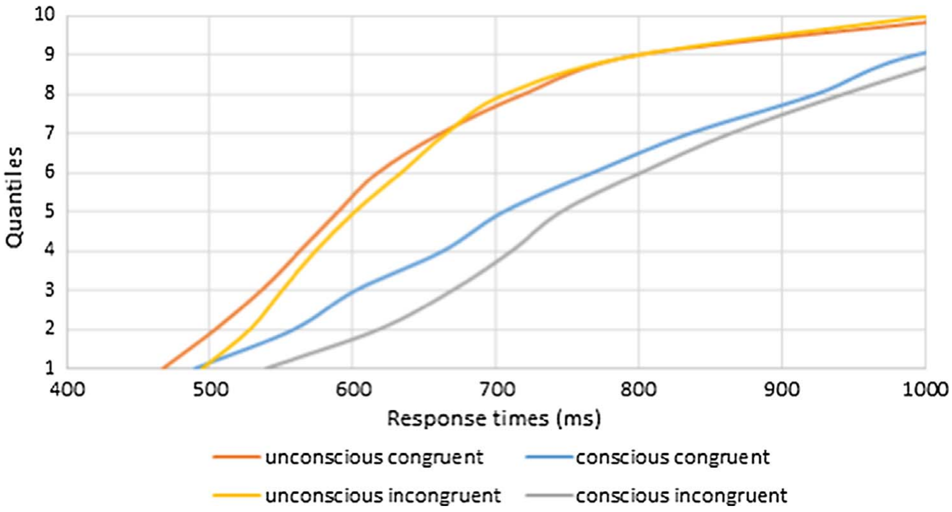

Fig. 7. Vincentized reaction time distributions on congruent- and incongruent-response trials for aware-prime (PAS = 3) and unaware-prime (PAS = 0) trials in Experiment 2. The data for 0-rating (unaware) trials include all participants. Two participants were excluded from the data for 3-rating (aware) trials because they never used this rating.

enough trials per condition to conduct a meaningful statistical analysis of the vincentized data with 10 bins, we aggregated the data in just two bins (50% fastest and 50% slowest trials, see Fig. 8). We conducted a separate LMM analysis for fast and slow trials. For fast trials, the interaction between response congruence and prime visibility was significant $F(1, 1827) = 18.96$, $p < .001$, indicating that response priming was larger for aware-than for unaware-prime trials. Post-hoc comparisons revealed that the response congruence effect was significant for both unaware-and aware-prime trials, $t(617) = -4.5$, $p < .001$ and $t(617) = -8.23$, $p < .001$, respectively. For slow trials, the interaction was also significant, $F(1, 1790) = 10.1$, $p = .001$, indicating that response priming was again larger for aware-than for unaware-prime trials. However, post hoc comparisons revealed that the congruence effect was significant on aware-prime trials, $t(605) = -2.98$, $p = .011$, but not on unaware-prime trials, $t(605) = 1.24$, $p = .55$. Complementary analyses indicated that while for undetected primes, response priming was significantly smaller for slow than for fast trials, $F(1, 2522) = 14.6$, $p < .001$, this difference was not significant for clearly seen primes, $F(1, 1117) = 1.61$, $p = .20$, despite a numerical trend in the same direction.

The results of Experiment 2 sharpened the findings of the attended-relevant condition of Experiment 1. First, in this experiment, there was positive evidence showing that congruence effects were larger for consciously perceived primes than for primes reported to be invisible. This finding is in line with the numerical trend reported in the attended-relevant condition of Experiment 1. Further analyses of the RT distribution (Fig. 7) revealed that unconscious response priming waned quickly, whereas conscious response priming remained significant across the RT distribution. Nevertheless, even for the fastest trials, the congruence effect remained smaller for undetected than for consciously perceived primes.

4. Experiment 3

The objective of Experiments 3 was to provide converging evidence for the findings of Experiments 1 and 2. We used an adaptation of the response-window procedure pioneered by Draine and Greenwald (1998), who designed it in order to overcome the possible dilution of priming effects across latency and accuracy measures. These authors suggested that imposing a stringent deadline

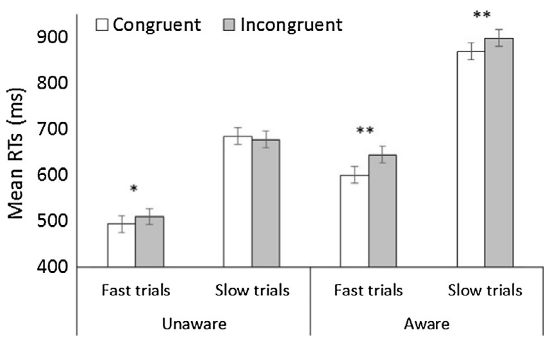

Fig. 8. Mean reaction times (in milliseconds) as a function of prime visibility, prime-target congruence and fast or slow trials in Experiment 2. Numbers in parentheses represent the standard errors. * < .05; ** < .01.

on responses should increase mean error rates and confine the priming effect to the accuracy measure. Here, our objective was simply to encourage participants to respond before unconscious response priming dissipated and thereby to alleviate the impact of the long RTs associated with our dual task on unconscious response priming. Based on the results of Experiment 2, we limited response latencies to 600 ms.

4.1. Method

4.1.1. Participants

Eighteen undergraduate students (15 right handed, 14 women) from Tel-Aviv University, age 22–34 years (M = 24.6, SD = 3.04) were tested in one session for course credit or for 40 NIS (roughly 10 USD). All 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 2 except that we imposed a response deadline of 600 ms. Participants were instructed to respond as fast as possible and when their RT exceeded 600 ms, a beep was sounded and a new trial began. Each participant completed 640 experimental trials in the experimental phase. These were divided into 4 blocks, separated by a self-paced break.

4.2. Results and discussion

The data from one participant were excluded from analysis because she was below chance level at categorizing the target (37.2% relative to M = 77.0%, SD = 7.7% for the group). The participants rated prime visibility to be 0, 1, 2 and 3 on 43%, 20%, 16%, and 21% of the trials, respectively, on prime-present trials and on 71%, 19%, 6% and 4%, respectively, on prime-absent trials. Mean RTs and accuracy data are presented in Fig. 9.

4.2.1. Reaction times

The main effect of response congruence was significant, $F(1, 4008) = 191.1$, $p < .001$ and interacted with prime visibility, $F(1, 4008) = 39.45$, $p < 0.001$, indicating that response congruence was significantly larger when subjects were aware of the prime, $t(4007) = 12.14$, $p < .0001$ than when they were unaware of it, $t(4003) = 6.72$, $p < .0001$. There was no main effect of prime visibility, $F(1, 12) = 1.71$, $p > .21$. A Bayesian Factor analysis provided decisive evidence for the interaction between response congruence and prime visibility, $BF_{10} > 100$.

4.2.2. Accuracy

The main effect of response congruence was significant and interacted with prime visibility, indicating that response priming was significantly larger when subjects were aware of the prime, $z = -9.05$, $p < .0001$, than when they were unaware of it, $z = -4.1$, $p = .0002$. The main effect of prime visibility was not significant (see Table 3).

4.2.3. Quantile analysis

We used the same vincentization procedure as in the previous experiments to examine how the size of the response priming effect varied across the RT distribution in the aware and in the unaware-prime conditions. Fig. 10 shows the mean RT separately for aware- and unaware-prime trials on congruent and incongruent trials, for each decile of the cumulative RT distribution. A separate LMM analysis for fast and for slow trials revealed that the interaction between response congruence and prime visibility was significant for both, $F(1, 2015) = 63.42$, $p < .001$, and $F(1, 1961) = 48.46$, $p < .001$, respectively, indicating that response priming was larger for

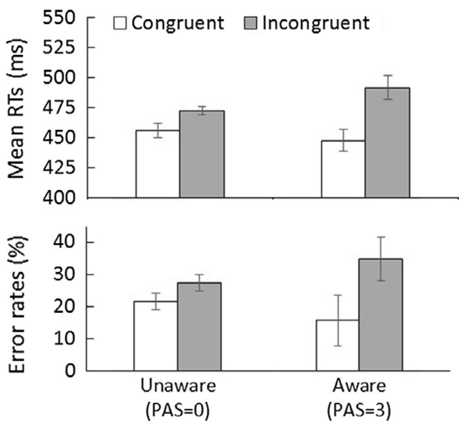

Fig. 9. Mean RTs and error rates in Experiment 3 for congruent- and incongruent-response trials as a function of prime visibility rating (0 vs. 3). Error bars indicate within-subject standard errors (Morey, 2008).

Table 3
Model output for the fixed and random factors in Experiment 3.

Fixed effects	Coefficient	Std. err	Z-value	*P-value*
(Intercept)	0.98	0.120	8.13	< .001
Visibility = 3 visibility	−0.35	0.271	−1.30	0.193
Congruence = congruent	0.32	0.076	4.13	< .001
Interaction	0.74	0.139	5.31	< .001
Random effects	Variance	Std. dev		
Subject (intercept)	0.19	0.43		
Visibility	1.01	1.01		

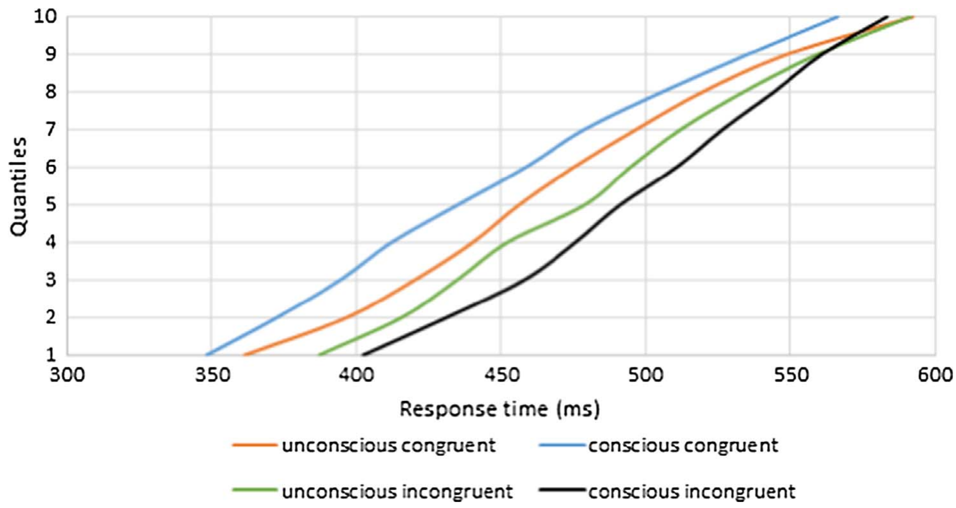

Fig. 10. Vincentized reaction time distributions on congruent- and incongruent-response trials for aware-prime (PAS = 3) and unaware-prime (PAS = 0) trials in Experiment 3. In the data for 0-rating (unaware) trials include all participants. One participant was excluded from the data for 3-rating (aware) trials because she never used this rating.

aware-than for unaware-prime trials across the RT distribution. Post-hoc comparisons revealed that the response congruence effect was significant for both fast and slow aware-prime trials, $t(683) = 16.92$, $p < .001$ and $t(666) = 11.88$, $p < .001$, respectively, and for both fast and slow unaware-prime trials, $t(683) = 10.75$, $p < .001$ and $t(666) = 5.16$, $p < .001$. Complementary analyses revealed that for both undetected and clearly seen primes, response priming was significantly smaller for slow than for fast trials, $F(1, 2740) = 18.0$, $p < .001$ and $F(1, 1250) = 18.61$, $p < .001$, respectively.

Taken together, these results replicate the main findings of Experiment 2: for trials with an RT faster than 600 ms, unconscious response priming was significant, yet smaller than conscious response priming. In addition, these effects were reduced as RTs increased.

4.3. General discussion

The objective of the present study was to reevaluate mounting claims in the current literature relying on objective measures of conscious perception, according to which conscious perception is not required for high-level processing (e.g., Gibbons, 2009; Jiménez-Ortega et al., 2017; Rohaut et al., 2016; Van Opstal et al., 2010). We compared unconscious and conscious response priming with identical primes using the liminal-prime paradigm. We found evidence for unconscious priming in all three experiments, yet overall, this effect was considerably smaller than response priming from consciously perceived primes. Unconscious response priming was short lived and vanished as response times to the target increased, whereas conscious response priming remained significant across the RT distribution. We also assessed the impact of using the liminal-prime paradigm, which involves a dual task, on the magnitude of the observed response priming. On the one hand, relative to the standard single-task paradigm, the slower RTs and higher task difficulty in the liminal-prime paradigm reduced response priming. On the other hand, the increased temporal attention and task relevance accruing to the prime in the liminal-prime paradigm boosted response priming.[6]

[6] A corollary finding emerged in all three experiments: high prime-visibility reports were associated with slower RTs and/or poorer accuracy at responding to the target than null prime-visibility reports. We refer to this effect as the “cost of awareness” and suggest that it reflects a phenomenon akin to the attentional blink (e.g., Raymond, Shapiro, & Arnell, 1992): being conscious of an event (irrespective of how much spatial attention accrues to this event) impairs the perception of a

The present findings put previous reports of high-level unconscious processing into perspective. The liminal-prime paradigm used here maximized the chances of detecting unconscious processing in several respects. First, our stimuli were calibrated so as to elicit liminal perception and were thus likely to generate stronger sensory stimulation than stimuli designed to remain subliminal on all trials (e.g., Dehaene et al., 1998; Kiesel et al., 2006; Kunde et al., 2003; Reynvoet et al., 2005). Second, unlike in previous subliminal priming studies, our primes were temporally attended and relevant to the task, which we showed to increase response priming. Third, in our study all the stimuli in the prime set could serve as targets. It was suggested that under such conditions, "acquired mappings between targets and response keys are also applied to subliminally presented primes" (Damian, 2001, p. 158). As a result, unconscious response priming may not reflect only unconscious semantic processing, if at all, but also unconscious shape processing and should therefore be larger. Finally, we assessed unconscious response priming before it waned, that is, for the fastest trials when responses were moderately speeded (Experiments 1 and 2) and with a stringent response window of 600 ms (Experiment 3). Nevertheless, we reported small unconscious priming effects that were much smaller than conscious response priming effects. Thus, our findings invite for caution and suggest that the "power of the unconscious" may be seriously overrated in the current literature (e.g., Hassin, 2013).

4.3.1. Alternative liminal-prime paradigms

Different procedures for comparing conscious and unconscious processing under constant stimulation have been suggested. For instance, van den Bussche et al. (2013) used a variant of the liminal-prime paradigm with a different measure of conscious perception of the prime that combined prime visibility and prime identification reports (see also, Faivre & Kouider, 2011; Gelbard-Sagiv, Faivre, Mudrik, & Koch, 2016; Haase & Fisk, 2015).

Targets were colored strings (red or blue) and primes were color words ("RED" or "BLUE"). Instead of rating the visibility of the prime, observers were required to report their confidence in the identity of the prime (1 = I am certain I saw RED; 2 = I am uncertain I saw RED; 3 = I did not see the color word; 4 = I am uncertain I saw BLUE; 5 = I am certain I saw BLUE). The color congruence effect (or Stroop effect, Stroop, 1935) was 33 ms when participants reported not seeing the prime and 140 ms when they reported being confident about the prime color. These findings are theoretically consistent with ours, yet two remarks are in order. On the one hand, the Stroop effect was contaminated by prime awareness responses: response priming could occur on certain- and uncertain-response trials, in which a color response was selected for the prime, but not on unconscious-prime trials in which no color response was selected. Thus, this variant of the liminal-prime paradigm spuriously inflates the difference between unconscious and conscious semantic priming. On the other hand, the awareness report in that study included only 3 levels, which may be less sensitive than 4-level awareness reports. As a result, unconscious semantic priming may have been overestimated in that study. We therefore suggest that the liminal-prime paradigm with a traditional 4-level PAS scale is a better method to compare conscious and unconscious priming.

Francken, van Gaal, and de Lange (2011) manipulated prime discriminability by using meta-contrast masks and pseudo-masks, while keeping the prime strength equal. Both the prime and target were arrows and could point either to the same or to opposite directions. The mask manipulation resulted in large differences in discriminability of the primes. However, response priming was of the same magnitude for the poorly discriminable and well discriminable primes. This finding suggests that shape processing is independent of conscious perception. Alternatively, however, as discriminability was quite high in the poor-discriminability condition ($d' = .89$), it may indicate that response priming was no longer sensitive to stimulus visibility above a certain level of discriminability. Further research is needed to resolve this issue.

4.3.2. Reevaluation of the liminal-prime paradigm

In light of the present findings, how useful is the liminal-prime paradigm as a tool for studying unconscious processing? Despite potential caveats, we suggest that it is the best available paradigm to determine the extent to which a given mental operation depends on conscious perception.

4.3.2.1. Suitability of the liminal-prime paradigm for the study of unintentional unconscious priming. In the liminal-prime paradigm, participants are necessarily informed of the presence and basic characteristics of the prime, since they are required to report its visibility. Thus, it is possible to claim that this paradigm is unsuitable for the study of automatic unconscious priming, which constitutes an important area of research. Note however, that this weakness of the paradigm can only result in overestimating unconscious processing: indeed, intentional processing of a prime affects behavior more strongly than unintentional processing of this prime (as shown in Experiment 1, for instance). Thus, while this criticism may pose a challenge when a process is found to be independent of conscious perception, it does not apply when a process is found to depend on conscious perception (e.g., response priming in the present study), because the liminal-prime paradigm actually underestimates the role of conscious perception.

4.3.2.2. Long RTs associated with the liminal-prime paradigm. We found the dual-task structure inherent to the liminal-prime paradigm to lengthen RTs, and unconscious response priming to wane with longer RTs. Thus, with the liminal-prime paradigm, unconscious response priming is underestimated, which may undermine the conclusion that high-level processing is stronger for consciously

(*footnote continued*)
temporally close subsequent event. This finding is outside the scope of the present paper and is not further discussed here (see Ophir, Sherman, & Lamy, 2017 for details).

perceived than for missed primes. However, we showed that this problem could be alleviated by examining unconscious priming across the whole RT distribution (Experiment 2) as well as by imposing a stringent response deadline (Experiment 3). In both cases, it was clear that unconscious priming was smaller than conscious priming for the fastest trials, that is, even before the effect started to decrease.

Moreover, although the response activation that is triggered by an invisible prime and underlies unconscious response priming vanishes quickly, this is not true of all indirect measures of unconscious processing. Kinoshita and Hunt (2008) showed that the effect of primes for which a stimulus-response mapping has been established (i.e., which could also serve as targets) is strongly reduced in the later bins of the RT distribution. Our results are consistent with this finding, since following Dehaene et al. (1998) we used primes that could serve as targets, and found response priming to wane with slower RTs. However, Kinoshita and Hunt (2008) further reported that the effect of primes with no pre-established stimulus-response mapping remained stable across the RT distribution. Thus, priming that is genuinely semantic and does not result from pre-established response associations may be impervious to the passage of time. Note however that conscious perception of the primes in Kinoshita et al.'s study was not assessed. Therefore, further evidence is required to establish that *unconscious* semantic priming can be observed across the RT distribution for novel primes. We are currently examining this issue.

In a different vein, Lamy et al. (2015) reported a spatial cueing effect of the same magnitude for consciously perceived and missed cues using the liminal-prime paradigm. They concluded that attentional capture is independent of conscious perception. In that study, RTs were overall longer than in the present study, so why did spatial cueing effects not wane in time? It has been suggested that spatial attention remains focused at the location at which it has been shifted until a new event occurs (e.g., Carmel & Lamy, 2014; see also Gaspelin, Ruthruff, & Lien, 2016). Thus, the difference between the effects of spatial attention (which last for several hundreds of ms) and the response congruence effects (which are short-lived) can explain why the spatial cueing effects associated with invisible cues remained stable over time.

Taken together, these findings suggest that the impact on behavior of a liminal object when it is consciously perceived vs. entirely missed can be reliably compared using the liminal-prime paradigm despite the relatively long RTs characteristic of dual tasks.

Note however, that for the specific purpose of demonstrating the presence of unconscious processing rather than of evaluating the role of conscious perception, it should be useful to add an awareness block to the liminal-prime paradigm. In such a block, visibility ratings and forced-choice discrimination responses are collected on each trial and performance is expected to improve with higher visibility ratings and to be at chance on 0-visibility trials. Although such a relationship between PAS ratings and objective performance has been reported many times (e.g., Lamy et al., 2015, 2017; Liu et al., 2016; Lähteenmäki et al., 2015; Peremen & Lamy, 2014; Ramsøy & Overgaard, 2004; Tagliabue et al., 2016), it would be important to reestablish it whenever evidence for unconscious processing is reported using PAS.

4.3.2.3. Regression to the mean. Shanks (2017) recently warned against the problems associated with inferring unconscious processing from post hoc analysis of trials in which awareness of the critical stimulus is absent. Specifically, he posited that because of regression to the mean, "it is a statistical certainty that applying an extreme cutoff on one dimension (such as a measure of awareness) will yield a less extreme cutoff for the expected value of the other variable (such as a measure of performance)". Applied to the present study, regression to the mean entails that response priming was overestimated on 0-visibility trials and underestimated on 3-visibility trials. While this observation weakens the claim that we demonstrated unconscious response priming here, it does not challenge our main conclusion, namely, that response priming is weaker for unconscious than for conscious primes. If anything, regression to the mean entails that we underestimated the difference in the impact of conscious vs. unconscious primes on behavior.

4.3.2.4. Isolating conscious perception?. The thrust of the liminal-prime paradigm is to assess the role of conscious perception in a given process by allowing a comparison between conscious and unconscious priming with invariant stimulation. However, it is important to keep in mind that measuring the impact of conscious perception "all other things being equal" is not possible. By definition, if all external and internal parameters are kept constant on two given trials, subjective visibility of the critical stimulus should be identical on those trials. Variable visibility under identical stimulation conditions therefore results from stochastic fluctuations of attention, expectations or neural noise.

It follows that the stronger impact of the same prime when it is consciously perceived relative to when it is not, as reported here, is likely to reflect the role of these factors rather than the role of conscious perception (see Schmidt, 2015, footnote 6, for a similar argument). It may also reflect consequences of conscious processing, such as encoding in working memory, which is successful when visibility is rated to be 3 and fails on 0-visibility trials.

A similar issue has been raised with regard the difficulty of disentangling the neural correlates of consciousness from the neural correlates of its prerequisites and consequences (Aru, Bachmann, Singer, & Melloni, 2012; De Graaf, Hsieh, & Sack, 2012). However, if one considers conscious perception as the transition from its prerequisites to its consequences rather than as a stage of processing in and of itself (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Deouell, 2015), then the liminal-prime paradigm gets as close as is possible to comparing an unconscious and a conscious state under the same objective conditions.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2017.12.006.

References

Abrams, R. L., & Greenwald, A. G. (2000). Parts outweigh the whole (word) in unconscious analysis of meaning. *Psychological Science, 11*(2), 118–124.
Almeida, J., Mahon, B. Z., & Caramazza, A. (2010). The role of the dorsal visual processing stream in tool identification. *Psychological Science, 21*(6), 772–778.
Almeida, J., Pajtas, P. E., Mahon, B. Z., Nakayama, K., & Caramazza, A. (2013). Affect of the unconscious: Visually suppressed angry faces modulate our decisions. *Cognitive, Affective, & Behavioral Neuroscience, 13*(1), 94–101.
Amihai, I. (2012). Problems in using d' measures to assess subjective awareness. *i-Perception, 3*(10), 783–785.
Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the theory of embodied cognition with subliminal words. *Cognition, 116*(3), 303–320.
Ansorge, U., Kiss, M., & Eimer, M. (2009). Goal-driven attentional capture by invisible colors: Evidence from event-related potentials. *Psychonomic Bulletin & Review, 16*(4), 648–653.
Aru, J., Bachmann, T., Singer, W., & Melloni, L. (2012). Distilling the neural correlates of consciousness. *Neuroscience & Biobehavioral Reviews, 36*(2), 737–746.
Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278.
Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. arXiv preprint arXiv:1506.04967.
Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48.
Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., & White, J. S. S. (2009). Generalized linear mixed models: A practical guide for ecology and evolution. *Trends in Ecology & Evolution, 24*(3), 127–135.
Carmel, T., & Lamy, D. (2014). The same-location cost is unrelated to attentional settings: An object-updating account. *Journal of Experimental Psychology: Human Perception and Performance, 40*(4), 1465.
Carmel, T., & Lamy, D. (2015). Towards a resolution of the attentional-capture debate. *Journal of Experimental Psychology: Human Perception and Performance, 41*(6), 1772.
Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27*(1), 154.
De Graaf, T. A., Hsieh, P. J., & Sack, A. T. (2012). The 'correlates' in neural correlates of consciousness. *Neuroscience & Biobehavioral Reviews, 36*(1), 191–197.
Dehaene, S., & Changeux, J. P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron*. http://dx.doi.org/10.1016/j.neuron.2011.03.018.
Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences, 10*(5), 204–211.
Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition, 79*, 1–37.
Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*(6702), 597–600.
Deouell, L. (2015). Chasing a mirage – The quest for the genuine neural correlate of consciousness. *Poster presented at the 19th meeting of the ASSC, Paris*.
Desender, K., & Van den Bussche, E. (2012). Is consciousness necessary for conflict adaptation? A state of the art. *Frontiers in Human Neuroscience, 6*.
Desender, K., Van Lierde, E., & Van den Bussche, E. (2013). Comparing conscious and unconscious conflict adaptation. *PLoS One, 8*(2), e55976.
Dienes, Z., & McLatchie, N. (2016). Four reasons to prefer Bayesian over orthodox statistical analyses. *Psychonomic Bulletin and Review*. http://dx.doi.org/10.3758/s13423-017-1266-z.
Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General, 127*(3), 286.
Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Attention, Perception, & Psychophysics, 16*(1), 143–149.
Faivre, N., & Kouider, S. (2011). Increased sensory evidence reverses nonconscious priming during crowding. *Journal of Visualized Experiments, 11*, 1–13. http://dx.doi.org/10.1167/11.13.16.
Finkbeiner, M. (2011). Subliminal priming with nearly perfect performance in the prime-classification task. *Attention, Perception, & Psychophysics, 73*(4), 1255–1265.
Francken, J. C., van Gaal, S., & de Lange, F. P. (2011). Immediate and long-term priming effects are independent of prime awareness. *Consciousness & Cognition, 20*(4), 1793–1800.
Frings, C., & Wentura, D. (2008). Trial-by-trial effects in the affective priming paradigm. *Acta Psychologica, 128*(2), 318–323.
Gaspelin, N., Ruthruff, E., & Lien, M. C. (2016). The problem of latent attentional capture: Easy visual search conceals capture by task-irrelevant abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 42*(8), 1104.
Gelbard-Sagiv, H., Faivre, N., Mudrik, L., & Koch, C. (2016). Low-level awareness accompanies "unconscious" high-level processing during continuous flash suppression. *Journal of Vision, 16*(1), 3 1–16.
Gibbons, H. (2009). Evaluative priming from subliminal emotional words: Insights from event-related potentials and individual differences related to anxiety. *Consciousness and Cognition, 18*(2), 383–400.
Goller, F., Khalid, S., & Ansorge, U. (2017). A double dissociation between conscious and non-conscious priming of responses and affect: Evidence for a contribution of misattributions to the priming of affect. *Frontiers in Psychology, 8*.
Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science-New York then Washington,* 1699–1701.
Haase, S. J., & Fisk, G. D. (2015). Awareness of "invisible" arrows in a metacontrast masking paradigm. *The American Journal of Psychology, 128*(1), 15–30.
Hassin, R. R. (2013). Yes it can: On the functional abilities of the human unconscious. *Perspectives on Psychological Science, 8*(2), 195–207.
Heinemann, A., Kunde, W., & Kiesel, A. (2009). Context-specific prime-congruence effects: On the role of conscious stimulus representations for cognitive control. *Consciousness and Cognition, 18*(4), 966–976.
Hesselmann, G., & Knops, A. (2014). No conclusive evidence for numerical priming under interocular suppression. *Psychological Science, 25*(11), 2116–2119.
Hesselmann, G., & Moors, P. (2015). Definitely maybe: Can unconscious processes perform the same functions as conscious processes? *Frontiers in Psychology, 6*.
Hughes, G., Velmans, M., & DeFockert, J. (2009). Unconscious priming of a no-go response. *Psychophysiology, 46*, 1258–1269. http://dx.doi.org/10.1111/j.1469-8986.2009.00873.x.
Ivanoff, J., & Klein, R. M. (2003). Orienting of attention without awareness is affected by measurement-induced attentional control settings. *Journal of Vision, 3*(1) 4-4.
Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*(4), 434–446.
Jeffreys, H. (1961). *The theory of probability*. OUP Oxford.
Jiang, J., Bailey, K., Xiang, L., Zhang, L., & Zhang, Q. (2016). Comparing the neural correlates of conscious and unconscious conflict control in a masked Stroop priming task. *Frontiers in Human Neuroscience, 10*.
Jiménez-Ortega, L., Espuny, J., de Tejada, P. H., Vargas-Rivero, C., & Martín-Loeches, M. (2017). Subliminal emotional words impact syntactic processing: Evidence from performance and event-related brain potentials. *Frontiers in Human Neuroscience, 11*.
Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious "automatic" processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience, 18*(2), 184–198.
Kiesel, A., Kunde, W., Pohl, C., & Hoffmann, J. (2006). Priming from novel masked stimuli depends on target set size. *Advances in Cognitive Psychology, 2*(1), 37–45.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition, 36*(7), 1324–1334.
Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society B, 362*, 857–875.
Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition, 88*(2), 223–242.
Lähteenmäki, M., Hyönä, J., Koivisto, M., & Nummenmaa, L. (2015). Affective processing requires awareness. *Journal of Experimental Psychology: General, 144*(2), 339.
Lamy, D., Alon, L., Carmel, T., & Shalev, N. (2015). The role of conscious perception in attentional capture and object-file updating. *Psychological Science, 26*(1), 48–57.
Lamy, D., Carmel, T., & Peremen, Z. (2017). Prior conscious experience enhances conscious perception but does not affect response priming. *Cognition, 160*, 62–81.
Lau, H. C., & Passingham, R. E. (2006). Relative blindsight in normal observers and the neural correlate of visual consciousness. *Proceedings of the National Academy of Sciences, 103*(49), 18763–18768.
Lau, H. C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *Journal of Neuroscience, 27*(21), 5805–5811.
Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology, 49*(4), 764–766.
Lin, Z., & Murray, S. O. (2014). Priming of awareness or how not to measure visual awareness. *Journal of Vision, 14*(1), 27. http://dx.doi.org/10.1167/14.1.27.
Lin, Z., & Murray, S. O. (2015). More power to the unconscious: Conscious, but not unconscious, exogenous attention requires location variation. *Psychological Science, 26*(2), 221–230.
Liu, C., Sun, Z., Jou, J., Cui, Q., Zhao, G., Qiu, J., & Tu, S. (2016). Unconscious processing of facial emotional valence relation: Behavioral evidence of integration between subliminally perceived stimuli. *PloS one, 11*(9), e0162689.
Manly, T., Fish, J. E., Griffiths, S., Molenveld, M., Zhou, F. A., & Davis, G. J. (2014). Unconscious priming of task-switching generalizes to an untrained task. *PloS one, 9*(2), e88416.
Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15*, 197–237.
Moors, P., Boelens, D., van Overwalle, J., & Wagemans, J. (2016). Scene integration without awareness: No conclusive evidence for processing scene congruence during continuous flash suppression. *Psychological Science, 27*(7), 945–956.
Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Reason, 4*(2), 61–64.
Mudrik, L., Breska, A., Lamy, D., & Deouell, L. Y. (2011). Integration without awareness expanding the limits of unconscious processing. *Psychological Science*.
Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science, 13*(5), 416–424.
Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition, 80*(3), 215–229.
Ophir, E., Sherman, E., & Lamy, D. (2017). Consciousness at a price: The Attentional Blink is a Cost of Awareness. *The 4th meeting of the Israeli Society for Cognitive Psychology (ISCOP), Akko*.
Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220.
Peremen, Z., & Lamy, D. (2014). Do conscious perception and unconscious processing rely on independent mechanisms? A meta-contrast study. *Consciousness and Cognition, 24*, 22–32.
Peters, M. A., Ro, T., & Lau, H. (2016). Who's afraid of response bias? *Neuroscience of Consciousness*.
Pratte, M. S., & Rouder, J. N. (2009). A task-difficulty artifact in subliminal priming. *Attention, Perception, & Psychophysics, 71*(6), 1276–1283.
R Core Team (2015). *R: A Language and Environment for Statistical Computing [Computer Software]*. Vienna: R Foundation for Statistical Computing.
Ramsøy, T. Z., & Overgaard, M. (2004). Introspection and subliminal perception. *Phenomenology and the Cognitive Sciences, 3*, 1–23.
Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin, 86*, 446–461.
Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*(3), 849.
Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics, 44*(6), 563–575.
Reynvoet, B., Gevers, W., & Caessens, B. (2005). Unconscious primes activate motor codes through semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(5), 991.
Rohaut, B., Alario, F., Meadow, J., Cohen, L., & Naccache, L. (2016). Unconscious semantic processing of polysemous words is not automatic. *Neuroscience of Consciousness, 2016*(1).
Rothkirch, M., & Hesselmann, G. (2017). What we talk about when we talk about unconscious processing – A plea for best practices. *Frontiers in Psychology, 8*.
Rouder, J. N., & Speckman, P. L. (2004). An evaluation of the Vincentizing method of forming group-level response time distributions. *Psychonomic Bulletin & Review, 11*(3), 419–427.
Schmidt, T. (2015). Invisible stimuli, implicit thresholds: Why invisibility judgments cannot be interpreted in isolation. *Advances in Cognitive Psychology, 11*(2), 31.
Shanks, D. R. (2017). Regressive research: The pitfalls of post hoc data selection in the study of unconscious mental processes. *Psychonomic Bulletin & Review, 24*(3), 752.
Sklar, A. Y., Levy, N., Goldstein, A., Mandel, R., Maril, A., & Hassin, R. R. (2012). Reading and doing arithmetic nonconsciously. *Proceedings of the National Academy of Sciences, 109*(48), 19614–19619.
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental Psychology, 18*(6), 643.
Tagliabue, C. F., Mazzi, C., Bagattini, C., & Savazzi, S. (2016). Early local activity in temporal areas reflects graded content of visual perception. *Frontiers in Psychology, 7*.
Tapia, E., Breitmeyer, B. G., & Shooner, C. R. (2010). Role of task-directed attention in nonconscious and conscious response priming by form and color. *Journal of Experimental Psychology: Human Perception and Performance, 36*(1), 74.
Timmermans, B., & Cleeremans, A. (2015). How can we measure awareness? An overview of current methods. In M. Overgaard (Ed.). *Behavioural methods in consciousness research* (pp. 21–46). Oxford: Oxford University Press.
Van den Bussche, E., Notebaert, K., & Reynvoet, B. (2009). Masked primes can be genuinely semantically processed: A picture prime study. *Experimental Psychology, 56*(5), 295–300.
van den Bussche, E., Vermeiren, A., Desender, K., Gevers, W., Hughes, G., Verguts, T., & Reynvoet, B. (2013). Disentangling conscious and unconscious processing: A subjective trial-based assessment approach. *Frontiers in Human Neuroscience, 7* Article 769.
Van Gaal, S., & Lamme, V. A. (2012). Unconscious high-level information processing implication for neurobiological theories of consciousness. *The Neuroscientist, 18*(3), 287–301.
Van Gaal, S., Lamme, V. A., Fahrenfort, J. J., & Ridderinkhof, K. R. (2011). Dissociable brain mechanisms underlying the conscious and unconscious control of behavior. *Journal of Cognitive Neuroscience, 23*(1), 91–105.
Van Gaal, S., Lamme, V. A., & Ridderinkhof, K. R. (2010). Unconsciously triggered conflict adaptation. *PLoS One, 5*(7), e11508.
Van Gaal, S., Naccache, L., Meuwese, J. D., Van Loon, A. M., Leighton, A. H., Cohen, L., & Dehaene, S. (2014). Can the meaning of multiple words be integrated unconsciously? *Philosophical Transactions of the Royal Society B, 369*(1641), 20130212.
Van Gaal, S., Ridderinkhof, K. R., Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. (2008). Frontal cortex mediates unconsciously triggered inhibitory control. *Journal of Neuroscience, 28*(32), 8053–8062.
Van Opstal, F., Calderon, C. B., Gevers, W., & Verguts, T. (2011). Setting the stage subliminally: Unconscious context effects. *Consciousness and Cognition, 20*(4), 1860–1864.
Van Opstal, F., de Lange, F. P., & Dehaene, S. (2011). Rapid parallel semantic processing of numbers without awareness. *Cognition, 120*(1), 136–147.
Van Opstal, F., Gevers, W., Osman, M., & Verguts, T. (2010). Unconscious task application. *Consciousness and Cognition, 19*(4), 999–1006.
Xiao, K., & Yamauchi, T. (2017). The role of attention in subliminal semantic processing: A mouse tracking study. *PloS One, 12*(6), e0178740.