Invisible is Better: Decrease of Subliminal Priming with Increasing Visibility[1]

Abstract

Comparisons of indirect measures (e.g., subliminal priming) with direct measures (e.g., conscious reports, or prime discriminability) can help elucidate the relationship between nonconscious and conscious perception. We report three experiments on masked word priming in which we observed that priming (RT) decreased with increasing prime visibility (d'). This is predicted by the Conscious Override Account and the Confusion Discounting Account, whereby a decrease of priming is expected when prime visibility increases from below threshold to perithreshold levels. Therefore, we suggest that negative priming-d' relationships are most likely observed when the d' measure assesses prime visibility at a level of representation that is below the level of representation at which priming arises, in terms of a putative hierarchy of word processing.

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The readers of this journal will probably agree on one point with respect to consciousness: If consciousness is not a mere epiphenomenon of mental experience, then it makes sense to try to understand its role in mental functioning. Most researchers investigate consciousness by concentrating on describing and explaining the mental and neural properties of conscious experience, and explaining why consciousness might be a relevant factor in understanding mental processes. Fewer researchers use an alternative approach, which is to focus on nonconscious processes and describe and explain the conditions under which some of the processes that are usually associated with conscious experience occur without consciousness. During the last decades, this latter approach has evolved from

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comparing conscious and nonconscious processes (and showing qualitative differences, e.g., Debner & Jacoby, 1994; Jacoby, 1991; Jacoby & Whitehouse, 1989; Meier, Morger, & Graf, 2003; Merikle, Joordens, & Stolz, 1995) to an exclusive focus on nonconscious processes. Given that the methodical problems of such an approach are not yet solved satisfactorily, it is worth reconsidering the use of the conscious/nonconscious comparison, which indeed leads to interesting insights on the relationship of conscious and nonconscious processes in this article.

The terms *conscious* and *nonconscious* are unfortunately used in many senses. In this article, we stick to the terminology used in masked priming research, whereby the terms consciousness and *awareness* are used interchangeably and nonconsciousness refers to conditions where participants report no awareness for visually masked (i.e., putatively subliminal) prime stimuli. By using this terminology, we do not imply that our participants are not in a conscious state when they do the task, and in this sense, we cannot rule out that the conditions identified with conscious and nonconscious are, in fact, two points on a continuum that covers a larger range of mental states of varying consciousness. For this type of research, it suffices to accept that the main aim is to compare two mental states that differ in consciousness. We therefore suggest that the basic interpretation of the data should not substantially change even if we identify these points with *phenomenal awareness* and *reflective awareness* (e.g., Snodgrass, Bernat, & Shevrin, 2004), *P-conscious* and *A-conscious* (Block, 1995) or involving *C-processes* and not (Jack & Shallice, 2001).

If consciousness is a relevant variable in explaining mental processes, then there must be cases of experimental *dissociations* between conscious and nonconsious processes, whereby the same processes have one effect in behavior and experience when accompanied by awareness, but a qualitatively different effect when they are not accompanied by awareness. A good example of such an approach is the process dissociation paradigm (PDP, Jacoby, 1991). The elegance of the PDP approach lies in one crucial task manipulation that ensures the effects of conscious memory are opposed to the effects of nonconscious memory. For example, when participants are asked to complete a word stem with any word except a previously shown target word, they tend to complete the target word more often than chance when it was invisible, but not when it was visible (Debner & Jacoby, 1994; Jacoby & Whitehouse, 1989; Meier et al., 2003; Merikle et al., 1995). Hence, dissociation is found between conscious and nonconscious perception. However, this approach has only rarely been used in research on nonconscious perception in the last two decades, probably due to the difficulty of transferring it to paradigms involving other types of priming and priming measures. Instead, more often, researchers have aimed to measure nonconscious perception in experimental conditions that try to exclude conscious perception entirely (e.g., Abrams & Greenwald, 2000; Abrams, Klinger, & Greenwald, 2002; Damian, 2001; Dehaene, Naccache, Le Clec'H, & Le Bihan, 1998; Naccache & Dehaene, 2001a, 2001b; Draine & Greenwald, 1998; Greenwald & Abrams, 2002; Greenwald, Abrams, Naccache, & Dehaene, 2003; Greenwald & Draine, 1998; Greenwald, Klinger, & Schuh, 1995; Kiefer, 2002; Kiesel, Kunde, & Hoffmann, 2007; Kouider, Dehaene, Jobert, & Bihan, 2007; Kunde, Kiesel, & Hoffmann, 2003).

The present study is a typical example of this approach. A priming difference between responses to target words that are preceded by unrelated and related prime words is used to assess unconscious perception in a priming test. The prime words are presented such that they are subjectively invisible. In order to confirm this subjective report using an objective measure, prime visibility is later assessed, using an additional test wherein participants are asked to classify the primes according to two categories (scored with the d' measure of discriminability). This discrimination test thus aims to measure conscious perception. The main aim of such a procedure is to demonstrate priming by some properties of the prime (as assessed in the priming test) whereby conscious perception of these properties (as assessed in the discrimination test) can be ruled out. However, this latter requirement is difficult to fulfill, because of methodical reasons (statistical inference that d' is zero is non-trivial) and practical reasons (a small positive value is indeed often observed in such tests). Some researchers indeed have argued that this *zero awareness* problem is insoluble, and therefore this approach is doomed to fail (Merikle & Reingold, 1998; Snodgrass et al., 2004): It is always possible to argue that a priming effect can be explained by residual visibility, for which the conscious visibility test was simply not sensitive enough (i.e., the test is never an *exhaustive* measure of conscious perception). Hence, it is preferable to avoid approaches that depend on defining zero visibility. Instead, Reingold and Merikle (1988) suggested an alternative constraint for the priming test (indirect measure of perception) and the discrimination test (direct measure of perception): If the direct test is *more sensitive* to conscious perception than the indirect test, and both tests use the same metric in comparable test conditions, then any result showing a greater effect in the indirect than in the direct test is a sufficient evidence for nonconscious processes.

In a similar vein, Sondgrass et al. (2004) suggest investigation of "strong qualitative differences", which are characterized by a negative relationship between priming and the conscious perception index, that is, stronger effects at lower visibility. This is the same logic as mentioned earlier in discussion of the PDP paradigm: An ideal effect of unconscious perception is one that decreases with conscious visibility. In this study, we report a series of three experiments where we observed such a pattern, that is, a significant decrease of masked semantic priming with increasing prime visibility. We decided to document these results because this was an unusual observation which was nevertheless reliable across similar experiments. After reporting the experiments, we will discuss the reasons why we think that these experiments yielded a negative correlation, compared to other studies, and how this can be explained in theoretical terms. In short, we suggest that the observed correlation was negative because our prime visibility tests were affected by consciousness at a level of representation that was *lower* in the word perception hierarchy than the level relevant for priming.

Experiments

The basic design was taken from Experiment 1 in Quinn and Kinoshita (2008), in which semantic priming by animal words and high- and low-frequency nonanimal words was investigated. Experiment 1 used the original word set and sandwich masking (SOA = 80ms) and Experiments 2 and 3 used an adapted word set and mirror masking (cf. Figure 1 for an example; Figure 4 at the end of the text for a more readable version; cf. Perrig & Eckstein, 2005). Priming was assessed by differences in Reaction Times (RTs) for primed versus unprimed trials. Two putative semantic effects of subliminal perception were measured, which were *congruency* and *relatedness priming*. Congruency priming was defined as the difference between response times (RTs) to targets that were preceded by a word of the same category (congruent, i.e. animal – animal or non-animal – non-animal) and RTs to targets that were preceded by a word of another category (incongruent, i.e. animal – non-animal or non-animal – animal). Relatedness priming was defined as the difference between RTs to incongruent targets and RTs to related targets (i.e., where the prime was both congruent and associatively related to the target). Given that there was no significant difference between the congruent and the relatedness conditions, data from the two conditions were collapsed into one "relatedness" condition. Prime visibility was first assessed by self-report, and then by objective d' for a categorisation task performed on the prime rather than target (under the same presentation conditions). In Experiment 1, participants were asked to decide whether they perceived the letter *a* in the primes; in Experiments 2 and 3, they were asked to decide whether the mirror masked word was an animal word or not. Two analyses were performed: The first with participants who reported having not seen any of the primes in the priming test (called henceforth "*initially-unaware*"), and the second with the remaining participants that reported having noticed at least once that a word or string preceding the target (called henceforth "*initially-aware*"). In all experiments, though overall effects of priming were small or non-significant, priming correlated negatively with d' (regardless of whether priming was indexed by a subtractive or proportional measure).

Figure 1. Example of the mirror masked words *horse* (top) and *ocean* (bottom; see also Figure 4).

Method

Participants

Participants were 117 volunteers of the MRC volunteer panel who were paid for participating in the experiments. The age range and sex proportion of participants in each Experiment is given in Table 1 (data of 6 participants was excluded from analysis, see results). All participants had normal or corrected to normal vision. The experiments were of the type approved by a local research ethics committee (CPREC reference 2005.08).

Design

The priming condition was used as a two level factor varied within participants (unrelated prime-target trials vs. related prime-target trials). Differences between the experiments were included into analyses using an additional between-participant factor Experiment (1, 2, 3).

Material and Apparatus

Because the experiments were closely modelled after Experiment 1 in Quinn and Kinoshita (2008), most words were taken from this article, except that a couple of words were exchanged because they were not familiar to participants in Cambridge. In Experiment 1, 45 low-frequency non-animal words (LF), 45 high frequency non-animal words (HF) and 45 animal words (AN) were each combined with a related, congruent and incongruent word. These word quadruples were divided in groups of 15 animal and 15 non-animal word quadruples equated with respect to word length (M = 6.5 for AN and LF words, M = 5.5 for HF words), lemma frequency per million (M = 6.5, 10 and 98 for AN, LF and HF words, respectively according to the CELEX database,) and orthographic prime-target similarity (ranging between 80 and 150, i.e., low similarity, Weber, 1970). In order to obtain a balanced design, 45 filler word pairs with animal targets were used, of which 15 were paired with a related animal word, 15 with an unrelated animal word and 15 with a non-animal word. An additional 12 animal and 12 non-animal word tuples were used for practice and warm-up trials. In Experiments 2 and 3, this word set was reduced and adapted because characters with descenders cannot be displayed in the mirror mask font (see Appendix): 45 animal words and 45 non-animal words were each combined with a related, congruent and incongruent word. These word quadruples were divided in groups of 15 animal and 15 non-animal word quadruples equated with respect to word length (M = 5.5), lemma frequency per million (M = 10 for animals, M = 52 for nonanimals, according to CELEX) and orthographic similarity (M = 90, i.e., low similarity, Weber, 1978). An additional 12 animal and 12 non-animal word tuples were used for practice and warm-up trials. Because the discrimination task in Experiment 1 was used to measure d’ for two consecutive experiments, the congruent and incongruent pairs were combined with an additional 144 non-animal word pairs from the other experiment for the discrimination task. This word pair pool was divided in 4 groups that were balanced with respect to the occurrence of an *a* in the target and prime words.

The experiment was conducted on an IBM-compatible PC using an external button box to collect responses. A CRT monitor was used for display of stimuli using a 75Hz refresh rate.

Procedure

The experiment consisted of two sessions: A priming session and a prime discrimination session. In all sessions, the task was to decide whether the word in question (i.e., target in the priming session, prime in the discrimination session) was the name of an animal, and participants responded by pressing one of two keys using their left and right hands. The left key was assigned to the *no* response and the right key was assigned to the *yes* response.

In the priming session, participants were informed of the nature of the tasks and were instructed that they should ignore the meaningless patterns appearing before each word. Participants were instructed to respond as quickly as possible without making mistakes. 12 practice trials were given using a set of words not used in the test. After practice, 12 warm-up trials were first shown, which were otherwise not discernable from the succeeding experimental trials. There were 180 experimental trials in Experiment 1 and 120 experimental trials in Experiments 2 and 3. In half of the trials, animal targets were used, an in the other half, non-animal targets were used. These trials were balanced with respect to prime-target conditions. The use of word pairs in the three conditions was counterbalanced across participants, and the order of trials was randomised with respect to conditions.

After the priming session, the experimenter asked the participants whether they had seen any of the primes, after which they were informed about the presence of the prime words, and performed the second prime discrimination session. The instruction screen for this session emphasized that this time, response should be given to any word *preceding* the target word, whereby participants were asked to decide whether there was a letter *a* in the prime word (Experiment 1) or whether the prime word was the name of an animal or not (Experiments 2 and 3). Participants were encouraged to guess their response in the discrimination task, if they were not sure. After a practice sequence of 12 trials, 78 (Experiment 1) or 60 (Experiments 2 and 3) test trials followed, which were randomised with respect to prime-target conditions.

The timing for each trial in Experiment 1 was as follows: After a 300ms forward mask (XMGHWRXKZB), the prime was shown for four screen refreshes (53ms), then replaced by the backward mask (MYWXHBRZKG) for two refreshes (27ms), followed by the probe, which stayed on the screen for 2s or until a response was given, whichever was shorter. Intertrial interval was 700ms. The response window duration was unlimited in the discrimination session. Stimuli were written in a white 20pt OCR A Extended font on a black background. The prime was written in small letters and the target was written in capitals. No forward or backward mask was shown in the trials of Experiments 2 and 3, and the prime was instead shown for 500ms using a mirror masked font.

Analysis

Trials with outlier responses (defined by RTs smaller or larger than 3 standard deviations from each participant's average RT) and trials that produced too many errors (classification accuracy < 90% across a sample) were excluded from analysis. Two analyses were done on the data from the priming session: (a) a basic omnibus analysis of variance (ANOVA) on RTs using one two-level factor priming (unrelated, related; within-participants) and one three-level factor experiment (1,2,3; between participants); and (b) a regression analysis on relative priming, computed as (RTunr-RTrel)/RTunr, using d' as a predictor. In order to estimate whether the d' task was performed on the basis of orthographic word characteristics or on the basis of lexical word characteristics, a by-word regression analysis on d' was additionally done for each sample.

Results

Data from four participants were excluded because their response accuracy in the categorisation task was lower than 90% and data from two participants were excluded because their d' performance was greater than 3 standard deviations from the mean.

Basic Analysis

Seventy-three participants reported not having seen any word previous to the targets (initially-unaware group). As can be seen in Table 1, the mean d' for these participants was greater than zero in Experiments 2 and 3, but not in Experiment 1. We return to this point in the Discussion. The mean priming effect was not significant in any of the experiments, but correlations between priming and d' were negative in all experiments, and reliably so on average across experiments.

For the remaining 37 participants who reported having realised that prime words were shown prior to the targets (initially-aware group), the data were collapsed across experiments (given the small numbers of such participants in some of the experiments). Mean d' was greater than zero and there was no mean effect of priming but this time, the correlation between d' and priming was not significant.

Omnibus analysis of variance (ANOVA)

An ANOVA on RTs for initially-unaware participants, using the within-participant factor Prime and the between-participant factor Experiment, yielded no significant main effect of Prime ($F < 1.0$), reflecting the 1ms difference between the related and unrelated conditions (which was not significant when tested separately for each experiment either, $t < 1.2$). Reaction times were longer in Experiment 1 compared to the following experiments, which was reflected in a main effect of Experiment, $F(2,71) = 3.28$, $p = .043$. However, there was no reliable interaction between priming and Experiment, $F(2, 71) = 0.42$, $p > .20$.

As can be seen in Figure 2 (left panel) however, there was a negative correlation between priming and d' for these initially-unaware participants, $r(73) = -.26$, $p = .025$. Given that d' also correlated with overall RTs (the correlations within each experiment were significant and ranged between -.18 and -.39), the correlation was repeated on a "relative" (proportional) measure of priming, that is ([primed-unprimed]/unprimed). The correlation between this relative priming and d' was similar to before, $r(73) = -.27$, $p = .020$ (Figure 3).

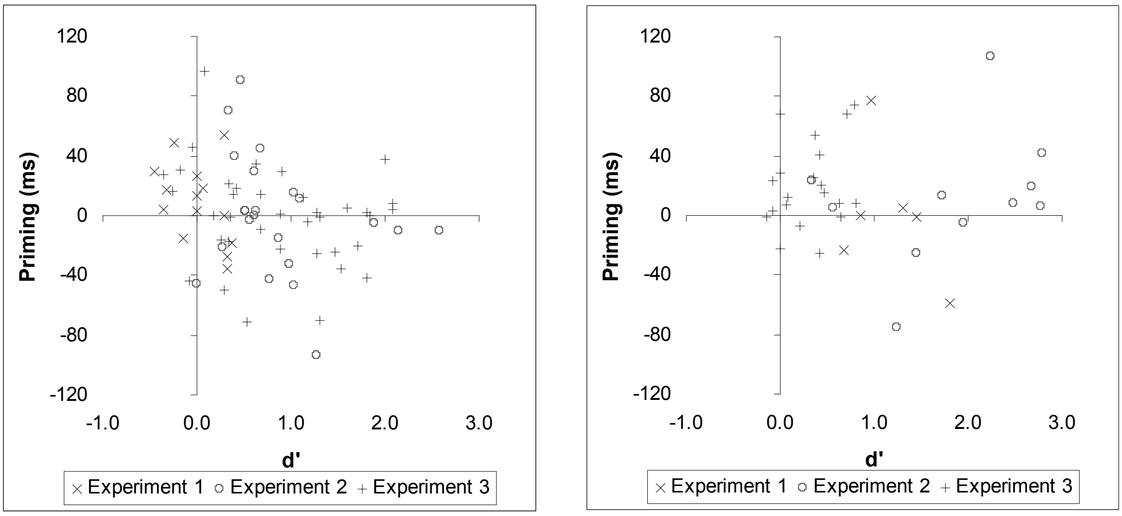

Figure 2. Scatter plots of priming versus d' for initially-unaware participants (on the left) and initially-aware participants (on the right).

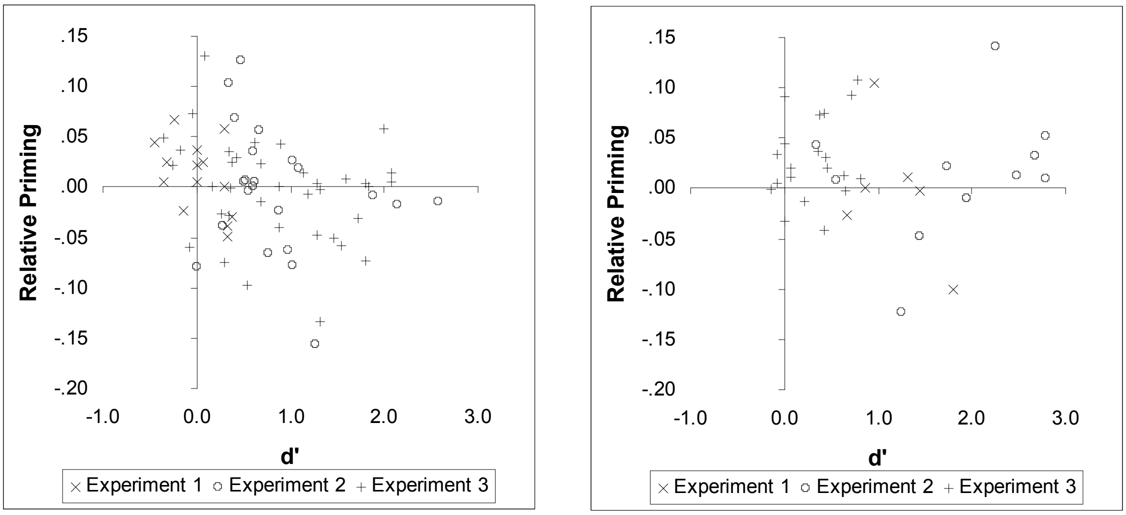

Figure 3 As for Figure 2, except using a relative (proportional) index of priming.

The same ANOVA on RTs for initially-aware participants yielded no significant effect of Priming, $F(1, 35) = 1.93$, $p = .17$ and no other effect reached significance ($F < 1.0$). The correlation between d' and priming was numerically negative but not significant.

Regression of Relative Priming on d'

A linear regression was also performed on relative priming against d' to distinguish the intercept and slope. There was a significant negative slope, b2 = -.020, $t(70) = -2.38$, $p = .020$, 95%CI = [-0.038, -0.002], two-tailed, though the positive intercept was not significant, b1 = 0.013, $t(70) = 1.57$, $p = 0.12$, 95%CI = [-0.005, 0.031]. However, this regression analysis is biased by the fact that there is measurement error in the predictor (d'), and by the fact that the true d' cannot be less than zero. Nonetheless, the presence of measurement noise actually tends to increase the magnitude of estimated slopes. Moreover, we repeated a regression analysis using a less biased method (Klauer, Draine, & Greenwald, 1998), according to which the slope was still negative (and slightly more so) and approached significance, b2 = -.023, t(70) = -1.86, p = .067, 95%CI = [-0.050, 0.005], two-tailed (the positive intercept was again not significant, b1 = 0.015, t(70) = 1.45, p = 0.14, 95%CI = [-0.008, 0.037]).

We note that the plots in Figures 2 and 3 suggest that the true relationship between d' and priming is not linear across the whole range of d' values here (if anything, it looks like a negatively-accelerated relationship, whereby priming becomes independent of d' for larger d' values - i.e., flatter). We did test for a quadratic component, but it was not significant, 95%CI = [-.005, .037]. While we could fit more complex functions (e.g. exponential), we feel that for the present purposes, it is sufficient to note that the relationship includes a reliable linear *component* (i.e, we are not claiming that the relationship itself is linear).

Analysis of the prime discrimination task

In order to determine the level at which primes were processed in the prime visibility test, a "by-item" regression analysis was done on response accuracies for both types of the classification (*a vs. non-a* word in Experiment 1, with sandwich masking; *animal* vs. *non-animal* in Experiments 2 and 3, with mirror masking; excluding words with outlier values), using word length, word frequency, bigram frequency, trigram frequency and *prime readability* as predictors. The latter readability index was developed based on earlier unpublished studies using forced-choice performance for identification of mirror masked words. It is computed as the sum of the letter readability index for each letter in the word. Letters that are easy to read, as for instance the letters *b*, *f* and *t* (that resemble their original shape in mirror masked format) are rated with *1* and letters that are difficult to read, as for instance the letters *c*, *n* and *r* (which form the capital letters *E*, *O* and *C* in the mirror masked form, respectively) are rated with -1. As can be seen in Table 2, accuracies tended to vary with the trigram frequencies in Experiment 1, indicating that the decision for or against an *a* word was influenced by orthographic frequency information. In Experiments 2 and 3, accuracy increased with word readability for animal words, but decreased with word frequency for non-animal words, indicating the animal decision was facilitated by single-letter readability and the non-animal decision was impeded by more frequent words. Together, these correlations suggest that d' in Experiment 1 reflects discrimination at the orthographical level, whereas d' in Experiments 2 and 3 reflects a mixture of orthographic and lexical levels.

Discussion

It has been argued that increases in masked priming that are associated with decreases in prime visibility constitute evidence for nonconscious perception (Snodgrass et al., 2004). In the three experiments presented here, we observed such a negative relationship between RT priming and prime discriminability. Although, in the past, we have occasionally observed negative correlations in our experiments, the present experiments were not designed to produce this negative priming-d' relationship. The consistency of this relationship across a series of experiments, however, made us suspect that it might be related to a common characteristic in the experimental designs. Before we consider this aspect of experimental design, we discuss two theories that predict negative d'-priming relationships, the *conscious override* (CO) and the *confusion discounting* (CD) theory.

The Conscious Override (CO) and the Confusion Discounting (CD) Accounts

According to the conscious override account discussed in Snodgrass et al. (2004), conscious processes are prioritized compared to nonconscious processes and they thus override nonconscious processes when both are in conflict. One possibility how such an override mechanism could function is that conflicts between processes at different levels of consciousness are experienced as "confusion" or "uncertainty" which lead to greater emphasis of conscious processes by means of attention or concentration. For instance, let us assume that a) masked words are conscious at the level of phenomenal consciousness, but not at the level of reflexive consciousness; b) reflexive consciousness is the basis for directing attention; and c) attention is usually directed to a point in time or place where we expect relevant stimuli. In the example of masked primes, attention is directed towards target words, and masks are ignored. At the same time, the prime information is available to phenomenal consciousness, which provokes priming due to spreading activation. In this case, there is no conflict between the two levels of consciousness. If primes are slightly more visible, however, such that it becomes evident that the masks and the prime are distinct strings, then the contents of phenomenal consciousness are in conflict with the contents of reflexive consciousness, owing to their similarity. In this situation, attentional focus is narrowed to optimize response to the target, which leads to an active inhibition of the prime information, and therefore the effect of priming is reduced. Thus, the conscious override account predicts a decrease, or even an inversion of priming, around the subjective visibility threshold.

As an alternative explanation, it is possible that we generally, and automatically, compensate for any influence that is perceived to be distracting or detrimental to task performance by counteracting its possible effects. For instance, such a compensation has been reported in the context of the influence of priming on judgments: Judges assimilate their judgment to primed information only if the priming procedure is subtle, whereas they sometimes even overcompensate the influence when priming is blatant (e.g., Mussweiler & Neumann, 2000). Such CD has been described and modeled in the context of word priming by Huber and colleagues (Huber, Shiffrin, Lyle, & Ruys, 2001; Huber, Shiffrin, Quach, & Lyle, 2002; Huber, Shiffrin, Lyle, & Quach, 2002). They found that in a setting where confusion between visible primes and a subsequent masked target can occur, participants tend to overcorrect for the priming influence when they actively process the prime (i.e., when they make a judgment about it), which is not the case when they process the primes passively (i.e., when primes are declared as being irrelevant to the task). Huber et al.'s model postulates that this discounting depends on the amount of "confusion", which participants estimate on the basis of the feature overlap between the stimuli that are subject to source confusion. Although such CD theories do not make direct assumptions about awareness of the source confusion, they would appear to predict that discounting rises with a rise in awareness of a confusion. Indeed, Huber et al, predicted and empirically confirmed that discounting is only applied when participants realize that they are influenced by primes, in contrast to when primes are invisible due to pattern masking (Huber, Shiffrin, Quach et al., 2002).

We do not believe that our results can differentiate between both the CO and CD accounts; however, it is interesting to consider how future research might. Although both accounts apply a similar logic in assuming that we compensate for a perceived confusion, they differ in important aspects. First, they attribute a different role to consciousness: The CO account assumes that the confusion is due to a conflict between processes that differ in their level of consciousness, whereas the CD account assumes that the confusion is due to a difficulty in discriminating two stimuli. Second, they differ in their assumptions about the source of compensation: The CO account assumes that conscious processes are inherently prioritized and thus automatically override any processes at lower levels of consciousness when there is a conflict; the CD account assumes that compensation is an active control process that aims to compensate for possible biased responses on the basis of estimations of feature overlap between the confused events. In short, the CD account assumes quite a sophisticated computation of prime and target feature overlaps, whereas the CO account assumes that different (and possibly partial) information can be available at different levels of consciousness.

Why Have Negative Correlations Been Observed so Rarely?

The CO and CD accounts predict that priming is affected when the experimental conditions are such that a prime is close to the threshold of visibility. Therefore, a decrease in priming with increasing d’ is predicted when prime visibility ranges in sub- and near-threshold values. For instance, larger priming is predicted when prime visibility is at objective detection threshold (ODT), compared to when it is at objective identification threshold (see Snodgrass et al., 2004 for a theoretical explanation of the empirical finding that the detection threshold is usually lower than the identification threshold for words, as for instance in Greenwald et al., 1995). Thus, in order to observe a negative priming-d’ relationship, one must use a prime visibility test that is sensitive to variations of prime visibility below the objective identification threshold. For instance, such a test might produce low d’ scores when participants are totally unaware of the priming stimulus, but monotonically increasing d’ scores as they become aware of the presence of a prime, aware of partial information of the prime and then aware of semantic aspects of the prime, respectively (given the nature of d’, these scores always refer to average hit rates across trials). Clearly, in order to devise such a test, we need a theory of word perception that describes stages corresponding to gradual increases in visibility below the objective identification threshold. Snodgrass et al. (2004) developed this point, suggesting that the presumed hierarchical organization of word perception (e.g., letters – letter pairs – morphemes – word) is an appropriate guide for determining the right level for detection tasks aimed at measuring conscious perception, whereby the d’ measure should be chosen such that it indexes a lower level of analysis than that measured in the priming test. According to this logic, the most appropriate prime visibility test for assessment of sub-identification threshold levels is a test assessing perception at low levels in a putative word perception hierarchy, as for instance presence/absence judgments, or letter detection tasks.

However, this is not what is usually done in masked priming research. Instead, it is considered “best practice” to use the same task in the visibility test as in the priming test (Reingold & Merikle, 1988; Reingold & Merikle, 1990). Such a test produces a d’ range, which starts at an absolute zero value (corresponding to *no identification at all*), and increases with the accuracy of prime identification. This type of test is thus more sensitive to an increase in conscious perception of the task-relevant properties. Thus, with such a task, we expect to see a positive priming-d’ relationship with increasing d’, reflecting an increasing use of consciously perceived task-relevant prime information for responding. This might explain why most masked semantic priming studies more often report positive than negative correlations (e.g., Abrams & Greenwald, 2000; Eckstein & Perrig, 2007; Greenwald et al., 1995; Henson, Mouchlianitis, Matthews, & Kouider, 2008; Kiesel et al., 2006; Kiesel et al., 2007; Klauer, Eder, Greenwald, & Abrams, 2007; Klinger, Burton, & Pitts, 2000), although slopes were sometimes non-significant. These positive correlations are primarily an indication that common processes are used in the priming and discrimination test, which could be also due to shared processes of automatic responding, especially when d’ is assessed with forced choice tasks (cf. Reingold & Merikle, 1990), although it has been noted occasionally that increasing conscious perception was directly responsible for such a correlation (e.g. evaluative decision priming in Greenwald et al., 1995). Interestingly, all the studies mentioned here assessed d’ with semantic tasks: either a semantic classification, or a *meaningful* versus *neutral* decision. This finding supports our suggestion that the type of d’ task used determines the possible correlation outcomes.

There have, however, been previous reports of negative relationships when d’ was at, or even below, zero (Dagenbach, Carr, & Wilhelmsen, 1989; Greenwald et al., 1995; Kiefer, 2002; Klinger & Greenwald, 1995; for a comprehensive list, see Snodgrass et al., 2004). For instance, Klinger and Greenwald (1995) reported positive priming for novel primes and low d’ participants only, whereby d’ was assessed with a prime detection task. Dagenbach and collaborators, who varied prime visibility conditions, found higher priming at detection and lexical discrimination threshold than at the threshold for semantic discrimination. In both cases, the results were tentatively explained with interference processes between conscious and nonconscious processing. Finally, a U-curved relationship was reported in the multi-experiment study of Greenwald et al. (1995), which comprised 20 experiments with 2026 participants. The authors used a position detection task for the prime, which thus assessed visibility at a lower level than the level used in the direct tests (most of them using an evaluative decision). The interesting finding in this study was a negative priming-d’ relationship in a range of d’ values that were negative, and a positive relationship at clearly greater than zero ranges of d’. Given that d’ ranged from -1 to 3 in this study, it is possible that the same task was not performed in the same fashion across the d’ range. Participants whose detection performance was at zero might have relied more on guessing strategies, compared to participants whose performance was clearly higher than zero, who were likely to occasionally see a letter. Nonetheless, these studies had one common design element, which was the use of a d’ test assessing perception at a level of analysis below the priming-relevant level.

The Prime Discrimination Measure

Indeed, we suspect that this is what happened in our tests. In Experiment 1, we used a letter detection task, which is presumed to rely on low levels of word perception (e.g., McClelland & Rumelhart, 1981; Coltheart, Sartori, & Job, 1987). In Experiments 2 and 3, in which we used mirror masked words, the prime visibility test was prima face, a semantic test. Nonetheless, because participants were not informed about the construction of mirror masked words, and because the words in the patterns in Figure 1 do not just "jump out" for readers that are unfamiliar with this font, participants are forced to figure out a strategy in order to make their decision. According to reports of participants, most participants based their decision on familiarity of letter combinations – for example, to give a *non-animal* response except when they had some additional clue that suggested a familiar animal word. Therefore, this task might rather be a mixture of a reading task and a semantic decision task. Confirming this impression, a regression analysis on the prime discrimination performance across each sample indicated that d' was predicted by orthographic and, to a lesser extent, lexical levels. Therefore, we suggest that our prime visibility tests in Experiments 2-3, and in Experiment 1, were influenced by letter combinations in the words. In other words, the prime visibility tests used in the presented experiments were probably sensitive to conscious perception at a level of word analysis that was lower (sub-lexical) than the level at which priming operates (semantic).

Initially aware vs. initially-unaware participants

The data for initially-unaware and initially-aware participants were similar, except that the negative linear component between priming and d' was not significant with the latter group. As can be seen in Figure 2, initially-aware participants showed a similar distribution across a range of low d', but priming appeared to increase again at high d' values. Although the scatter plots indicate an U-curved relationship, this qualitative difference is difficult to test with only 36 participants, and thus we did not venture to model nonlinear d'-priming relationships with these participants. As one incidental observation, one might infer from the similarity of the d' distributions for the initially-aware and initially-unaware, that reports at the end of a test are not apt for assessing whether participants were able to *read* primes or not: Some of the initially-unaware participants were eventually quite good at reading primes in the discrimination test (reflected by high d' scores), whereas quite a few of the initially-aware participants showed a bad performance at classifying primes in the discrimination test (reflected by low d' scores). This underlines the importance of conducting an extended, objective assessment of prime awareness.

Does Priming Decrease Monotonically?

We report a reliable negative linear component in the priming-d' relationship. However, we suspect that we encountered the same problems as other studies reporting negative linear relationships, such as the identification-ODT and oddball P300-ODT relationships discussed in Snodgrass et al. (2004). Basically, the d'-priming relationships observed in all experiments resemble more a step function than a continuous decrease of priming with d': Priming was positive-signed across a range of low d' and decreased to zero or negative levels at higher d' ranges. Furthermore, in Experiment 1, d' distribution was only slightly skewed to positive values (cf. Figure 2), indicating that most of the variation of d' around zero reflected measurement error. Therefore, the negative correlation in this experiment might hinge on a few participants showing negative priming at slightly higher-than-zero d'. In Experiment 2, the d' range where mean priming was positive extended from about 0 to 0.8 and in Experiment 3, this range extended from about -0.5 to 0.5. Therefore, although we found a significant component of linear decrease in priming, it is probable that more experiments with a large number of participants will be needed to determine the precise shape of the priming-d' function. A further complication of such a measurement might arise from nonlinearities at the lower and higher boundary of any prime visibility measure – due to decreasing sensitivity when values approach zero, and ceiling effects when values reach clear visibility levels. Hence, it would be interesting to investigate the priming-d' relationship *between* these lower and higher bounds of d' in future studies.

Conclusion

In summary, we suggest that the negative priming-d' relationship observed in the present experiments reflects interference between processes of perception operating at different levels of consciousness. That is, the better a participant was in the prime discrimination test, the nearer he or she was presumably to perceiving something "letter-like" or "word-like" in the primes, leading to a conflict between nonconscious and conscious perception, which was resolved by suppressing the effect of masked primes. This decrease in priming would reflect a decrease in the conflict between conscious and nonconscious processes in such a setting. We suggest that this observation was possible because our prime visibility tests could be solved by using single and multiple letter information, and thus measured visibility at a level that was "earlier" in a putative word-processing hierarchy than the semantic level of analysis needed for the priming effect. In other words, the prime visibility test d' assessed a decrease in visibility in ranges that were clearly below subjective perception of whole words. Finally, it is necessary to emphasize that the present claims were post hoc, and it is important to confirm them in planned experiments. From a theoretical view point, congruency priming is a good candidate for such experiments, because it is semantic in character (and therefore at a high level in the word recognition hierarchy, offering greater scope for lower-level measures of d') and because it is the most reliable type of semantic priming in other types of paradigms.

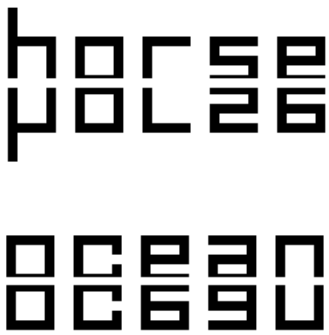

Figure 4. Illustration of the mirror masking principle, using the words in Figure 1: The letters of a word are mirrored on the baseline of the letters and merged with their normally oriented counterparts.

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Table 1: Results of Experiments 1 - 3

Experiment	*N*	*M,F*	*age*	*Unrelated*		*Related*			
				M	*SD*	*M*	*SD*	*d'*	*r*
"Initially-unaware" Participants									
Experiment 1	14	4,10	44.2 (14.3)	701	88	692	80	0.01 (0.28)	-.42
Experiment 2	22	8,14	34.3 (14.6)	627	81	628	73	0.88* (0.62)	-.25
Experiment 3	37	17,20	34.1 (8.0)	635	93	636	90	0.87* (0.72)	-.23
Total	*73*	*29,44*	*36.1 (12.1)*	*645*	*92*	*644*	*86*	*0.71* (0.71)*	*-.26**
"Initially-aware" Participants									
Experiments 1-3	38	10,28	43.8 (13.4)	649	86	636	81	0.42* (0.44)	-.07

Remarks: M, F: number of male/female participants, *: $p < .05$. Standard deviations are given in parentheses.

Table 2: Result of regression analyses of psycholinguistic variables on prime discrimination performance

	non-a/non-animal word				a word/animal word			
Predictor	beta	t	df	p	beta	t	df	p
Experiment 1								
(Constant)		9.50	72	.000		8.49	71	.000
Lemma f	-0.394	-1.13	72	.263	-0.084	-0.25	71	.804
Word f	0.639	1.83	72	.072	0.193	0.57	71	.568
Digram f	0.236	1.82	72	.073	0.251	1.73	71	.089
Trigram f	-0.278	**-2.13**	72	.037	-0.300	**-2.17**	71	.033
Word length	0.113	1.02	72	.312	0.037	0.32	71	.753
Experiment 2								
(Constant)		8.79	34	.000		3.27	38	.002
Lemma f	1.275	1.81	34	.079	-0.366	-0.32	38	.753
Word f	-1.423	**-2.03**	34	.050	0.521	0.45	38	.656
Digram f	0.363	**2.12**	34	.041	-0.295	-1.56	38	.128
Trigram f	-0.308	-1.78	34	.084	0.124	0.66	38	.514
Word length	-0.074	-0.47	34	.642	0.224	1.51	38	.139
Readability	0.040	0.25	34	.805	0.440	**2.91**	38	.006
Experiment 3								
(Constant)		8.04	36	.000		3.12	38	.003
Lemma f	2.041	**2.24**	36	.031	-1.601	-1.49	38	.145
Word f	-2.084	**-2.28**	36	.029	1.678	1.55	38	.130
Digram f	0.018	0.11	36	.914	-0.225	-1.29	38	.206
Trigram f	-0.227	-1.36	36	.183	0.171	0.96	38	.345
Word length	0.230	1.50	36	.143	0.266	1.90	38	.065
Readability	0.182	1.19	36	.240	0.504	**3.62**	38	.001

Remark: Parameter valued in bold were significant at the .05 level.

Appendix Words used in Experiments 2 and 3

Target	*Rel*	*Cong*	*Inc*	*Target*	*Rel*	*Cong*	*Inc*
JACKET	coat	barn	emu	DOG	cat	emu	train
PIE	cake	lane	cow	BULL	cow	cat	comb
SHED	barn	coat	cat	FLAMINGO	emu	cow	coat
ALLEY	lane	cake	boar	STAG	boar	moth	cake
BASEMENT	cellar	train	swan	PIGEON	owl	rabbit	skirt
BUS	train	cellar	moth	PENGUIN	swan	boar	lane
TYRE	wheel	skirt	owl	BUTTERFLY	moth	swan	cellar
DRESS	skirt	wheel	finch	CANARY	finch	owl	wheel
BRIDGE	tunnel	toaster	beaver	DOLPHIN	whale	finch	mixer
MARKET	store	mixer	whale	COYOTE	rabbit	whale	barn
BLENDER	mixer	comb	hamster	OTTER	beaver	hamster	hammer
RIVER	stream	store	rabbit	IGUANA	lizard	beaver	stream
BRUSH	comb	stream	lizard	MINK	hamster	lizard	toaster
MALLET	hammer	tunnel	caribou	CHIMP	caribou	cockroach	tunnel
KETTLE	toaster	hammer	cockroach	BEETLE	cockroach	caribou	store
PIN	tack	fork	wolf	FOX	wolf	bear	tack
MOON	star	tack	fawn	DEER	fawn	snail	star
SPOON	fork	wallet	mole	EAGLE	falcon	wolf	wallet
WAGON	cart	star	robin	GOPHER	mole	falcon	fork
DINNER	lunch	cart	tuna	GORILLA	bear	calf	cart
MICROWAVE	oven	lunch	hare	SARDINE	tuna	mole	lunch
CHAPEL	church	heart	ostrich	PORCUPINE	hare	ostrich	truck
PURSE	wallet	truck	falcon	PONY	horse	robin	ocean
LUNG	heart	oven	horse	PELICAN	stork	horse	beard
JEANS	trousers	rifle	calf	DONKEY	calf	tuna	trousers
WATER	ocean	trousers	moose	ELK	moose	hare	heart
PISTOL	rifle	ocean	bear	SPARROW	robin	moose	rifle
MUSTACHE	beard	chandelier	snail	SLUG	snail	stork	church
VAN	truck	beard	stork	TURKEY	vulture	fawn	oven
LAMP	chandelier	church	vulture	KANGAROO	ostrich	vulture	chandelier
RAIN	snow	couch	dove	GOOSE	chicken	lion	snow
AUTOMOBILE	car	snow	toad	FROG	toad	chicken	car
STICK	club	car	lion	TIGER	lion	clam	club
KEY	chain	town	clam	OYSTER	clam	cheetah	chain
CAPE	cloak	chain	crab	LOBSTER	crab	toad	cloak
SHAWL	scarf	club	chicken	SEAGULL	dove	crab	clock
CITY	town	scarf	mouse	RAT	mouse	dove	town
CHAIR	couch	cloak	raven	CROW	raven	bison	scarf
WATCH	clock	onion	snake	PYTHON	snake	raven	couch
GARLIC	onion	motor	bison	BUFFALO	bison	snake	onion
ENGINE	motor	revolver	walrus	SEAL	walrus	crocodile	motor
CUCUMBER	tomato	clock	salmon	TROUT	salmon	stork	tomato
ROBE	sweater	tomato	cheetah	LEOPARD	cheetah	salmon	sweater
DRAPE	curtain	sweater	tortoise	TURTLE	tortoise	mouse	curtain
GUN	revolver	curtain	crocodile	ALLIGATOR	crocodile	tortoise	revolver