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Short Communication

Immediate and long-term priming effects are independent of prime awareness

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ABSTRACT

Subliminal primes are assumed to produce weaker and short-lived effects on subsequent behavior compared to clearly visible primes. However, this difference in priming effect may be due to differences in signal strength, rather than level of awareness. In the present study we manipulated prime discriminability by using metacontrast masks and pseudo-masks, while keeping the prime strength equal. This manipulation resulted in large differences in discriminability of the primes. However, both immediate response priming and long-term response priming (measured with conflict adaptation) was equal for the poorly discriminable and well discriminable primes, and equal for groups that differed markedly in terms of how well they could discriminate the primes. Our findings imply that discriminability of information is independent of both the immediate and long-term effects that information can have on behavior.

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1. Introduction

Many studies have shown how a masked (subliminal) visual stimulus can nevertheless influence processing of a subsequent stimulus, putatively by activating visual, semantic and/or response attributes related to the stimulus (Dehaene et al., 1998; Greenwald, Draine, & Abrams, 1996; Naccache & Dehaene, 2001). While subliminal primes can elicit reliable priming effects, the size of the priming effect is almost always markedly smaller than for supraliminal (perceived) primes (Greenwald et al., 1996; Kouider, Dehaene, Jobert, & Le Bihan, 2007; Merikle & Joordens, 1997; van Gaal, Lamme, & Ridderinkhof, 2010). Also, longer-lasting priming effects like conflict adaptation are typically abolished (Ansorge, Fuchs, Khalid, & Kunde, 2010; Frings & Wentura, 2008; Greenwald et al., 1996; Kunde, 2003) or greatly reduced (Bodner & Mulji, 2010; van Gaal et al., 2010).

Why do subliminal primes have weaker and only short-lived effects on behavior, compared to supraliminal primes? One common explanation is that the reduced priming effect is a direct result of the reduced (or abolished) perceptual awareness of subliminal primes. Neurophysiological (Lamme & Roelfsema, 2000) and neuroimaging (Dehaene et al., 2001; Haynes, Driver, & Rees, 2005) studies have showed that subliminal primes are associated with a lack of neural amplification (possibly resulting in weaker priming) and lack of neural reverberation (possibly resulting in more short-lived priming) (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006).

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However, subliminal primes usually differ not only in terms of perceptual visibility but also in terms of ‘signal strength’ (Lau & Passingham, 2006). Namely, in order to render primes invisible, subliminal primes are typically displayed for a shorter duration or followed after a shorter delay by the mask than supraliminal primes, reducing the time that the prime can have an impact on processing (Ansorge et al., 2010; Kunde, 2003; van Gaal et al., 2010; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Therefore, the weaker and fleeting nature of invisible primes could be simply due to differences in prime strength (see also Schlaghecken, Blagrove, & Maylor, 2008). In line with this ‘signal strength’ interpretation, Vorberg et al. (2003) observed an increase in response priming as a function of prime–mask interval for primes that were all equally invisible, suggesting a dissociation between priming and awareness (see Mattler (2003) for similar results). In a similar vein, differences in prime strength may also underlie the attenuation or absence of long-term priming effects such as conflict adaptation (Egner, 2007; Kunde, 2003; van Gaal et al., 2010).

In this study, we compared immediate and long-term priming effects of well discriminable and poorly discriminable primes, while keeping prime duration, mask duration and prime–mask interval equal. In line with a ‘signal-strength’ account of priming, we observed identical priming of well and poorly discriminable primes, despite large differences in discriminability between them. These results imply that the discriminability of information is independent from the effects the information can have on behavior, at both short and longer time scales.

2. Method

2.1. Participants

Fourteen volunteers (8 females; age range: 22–33 years; 13 right handed) with normal or corrected-to-normal vision participated in a prime recognition and a response priming paradigm, measured on separate days. All subjects started with the response priming paradigm. The study was approved by the regional ethics committee, and a written informed consent was obtained from the subjects according to the Declaration of Helsinki.

2.2. Stimuli

Stimuli were presented using a PC running Presentation software (Neurobehavioral systems, Albany, USA) on a 60-Hz Samsung SyncMaster 940BF monitor placed at a viewing distance of 75 cm. We used a chin and forehead rest to restrain head and eye position. Stimuli were presented in black ($<1 \text{ cd/m}^2$) on a light-gray background (59 cd/m^2). Primes consisted of a left or right pointing arrow (width 1.36° , height 0.59°). The mask stimuli (width 2.72° , height 0.86°) were constructed such that the outer contours of the primes either touched the inner contours of the mask stimuli (metaccontrast mask) or were rectangularly shaped (pseudomask), leading to poorly discriminable and well discriminable primes respectively. Metaccontrast masks and pseudomasks were equal in terms of overall luminance. The shape of the mask could be a left/right pointing arrow. In the prime recognition task, we additionally used square-shaped masks (see Fig. 1).

2.3. Prime recognition task

During the prime recognition task, subjects had to decide on the identity of the prime stimuli. Each trial started with a central fixation cross (duration between 1250 and 1750 ms). Then, a prime was briefly flashed (duration 17 ms), followed by a blank interval (duration 33 ms), after which a mask was presented (duration 150 ms). Participants decided on the orientation of the prime by pressing a left or right button with their right hand, while ignoring the masks. To prevent direct priming effects on recognition, subjects were cued to respond at least ~ 600 ms after the mask, when the fixation cross reappeared (Vorberg et al., 2003). After the response, subjects received feedback (indicated by a green or a red fixation cross for correct and incorrect responses, respectively) which was displayed for 500 ms. In addition to arrow-shaped masks, we used rectangular masks to assess the effects of mask identity on prime recognition. The prime recognition task consisted of twenty blocks of 60 trials (leading to a total of 1200 trials). Trials were presented in a random order each block. Before the experiment, participants practiced 24 trials. Summary feedback was given after each block (number of correct and incorrect trials).

2.4. Response priming task

During the response priming task, subjects had to decide on the identity of the mask stimuli. Each trial started with a central fixation cross (duration between 1250 and 1750 ms). Then, a prime was briefly flashed (17 ms), followed by a blank interval (duration 33 ms), after which a mask was presented (duration 150 ms). Participants decided as quickly and accurately as possible on the orientation of the mask by pressing a left or right button with their right hand, while ignoring the primes. After they responded, the fixation cross was presented for 500 ms. The task consisted of twenty blocks, each containing 80 trials (leading to a total of 1600 trials). Trials were presented in a random order each block. Before the experiment, participants practiced 24 trials. Performance feedback was given after each block (in terms of average response time and number of correct/incorrect trials).

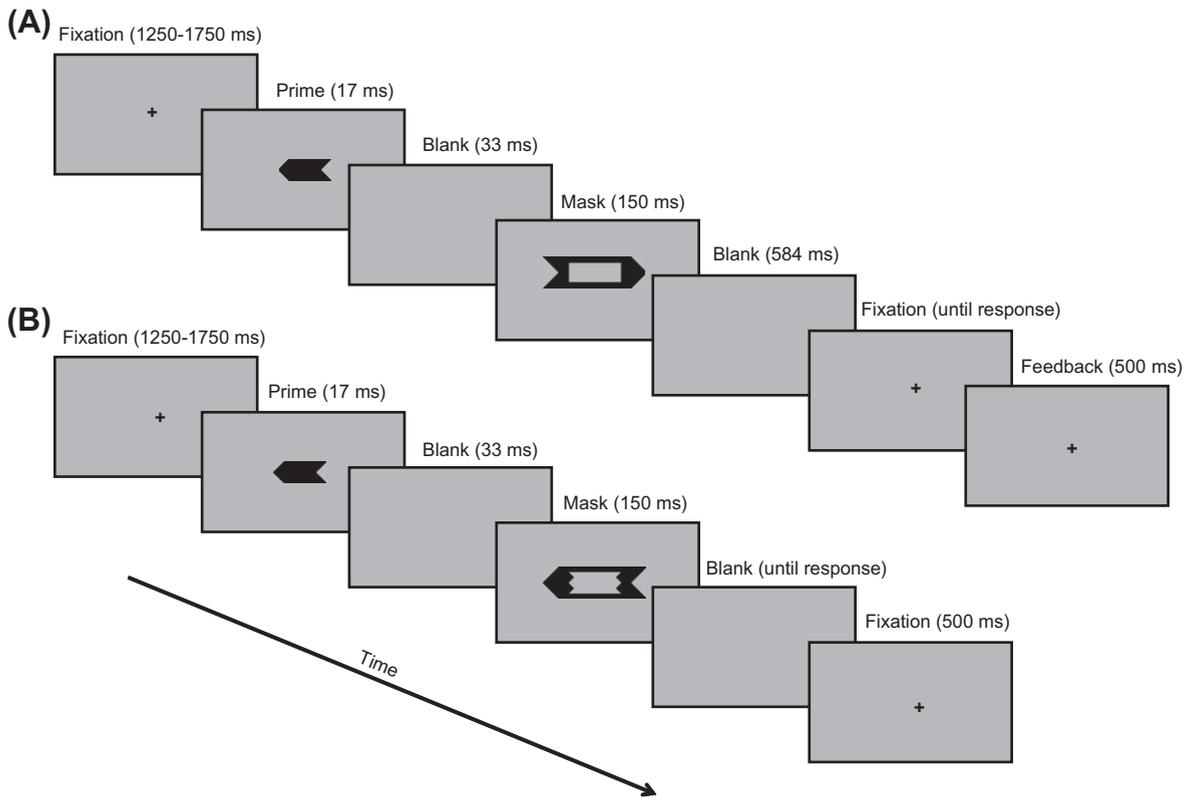


Fig. 1. Experimental design. (A) Prime recognition task. A left/right pointing arrow is masked by a pseudomask (example shown in A) or a metacontrast mask (example shown in B), depending on the inner contours of the mask. The outer contours of the mask form a left/right arrow. For the recognition task, also square-shaped masks were used. Approximately 600 ms after the offset of the mask, subjects decided on the orientation of the prime, while ignoring the mask. Subjects were given trial-by-trial feedback. (B) Response priming task. The response priming task was very similar to the prime recognition task. Here, subjects decided on the orientation of the arrow mask, while ignoring the primes. No square masks were used, and subjects were prompted to respond as quickly as possible when the mask appeared.

2.5. Data analysis

Prime discriminability was quantified by computing the signal-detection-theoretic (SDT) measure d' (Macmillan and Creelman, 2005). d' is a measure of a subject's stimulus discriminability that is independent of eventual biases induced by the mask orientation. Immediate response priming was quantified by calculating the difference in reaction time (RT) and error rate (ER) between trials in which the prime and mask were congruent and those in which they were incongruent. Long-term response priming (conflict adaptation) was quantified by comparing response priming depending on prime-mask congruency in the preceding trial (Gratton, Coles, & Donchin, 1992) and collapsed across conditions on the current trial. For the prime recognition data, trials with RTs smaller than 500 ms were excluded from the analyses (in total 0.25%). For the response priming data, trials following errors, trials that were the first trial of a block, and trials with RTs smaller than 100 ms or larger than 500 ms were excluded from the analyses (in total 1.9%). We tested for differences in prime discriminability, immediate response priming and long-term response priming between metacontrast masked and pseudo-masked stimuli using paired-samples T -tests. Additionally, we split the participants in two groups using a median-split procedure, on the basis of their difference in discriminability performance between metacontrast masked and pseudo-masked primes. This allowed us to test whether individual differences in prime discriminability bore any relationship to response priming differences. In particular, one may expect that subjects who are better at perceiving the primes also demonstrate, on average, larger immediate and long-term priming effects. Note that equivalent results were obtained when splitting the group into three subgroups in order to increase the difference between prime discriminability between good and poor perceivers even more.

The commonly used frequentist statistics provide a measure of confidence in rejecting the null hypothesis, but not a measure of confidence in the null hypothesis itself. In order to quantify the confidence in the null hypothesis, we calculated Bayes Factors (BF) for each of the statistical tests. Bayes Factors express evidence ratios between hypotheses, and therefore provide direct information about the relative likelihood of the alternative vs. the null hypothesis. A BF of ~ 1 indicates no preference for either the null or the alternative hypothesis, and in large samples BF will converge to either 0 or infinity when the null or alternative hypothesis is true respectively (Rouder, Speckman, Sun, Morey, & Iverson, 2009). By convention a BF likelihood ratio of $>3/1$ provides moderate evidence for the alternative hypothesis, $>10/1$ provides strong evidence for the alternative

hypothesis, and $>30/1$ provides very strong evidence for the alternative hypothesis (Jeffreys, 1961). Equivalently, BF of $<1/3$ provides moderate support for the null hypothesis, $<1/10$ provides strong support for the null hypothesis and $<1/30$ provides very strong support for the null hypothesis. BF ratios between $1/3$ and $3/1$ provide no evidence for either the null or the alternative hypothesis.

3. Results

3.1. Prime discriminability

Prime discriminability was markedly lower when primes were masked with a metacontrast mask ($d' = 0.89$) than when masked with a pseudomask ($d' = 1.68$; $t(13) = 3.07$, $p = 0.004$; Fig. 2A). Thus, we obtained poorly discriminable and well discriminable primes by using these two different types of masks. However, there was large inter-subject variability in the prime discriminability differences between the two mask types. Therefore, we additionally split our subjects into two subgroups, in order to assess whether differences in prime discriminability affects priming magnitude. The group with large discriminability differences (Fig. 2B, left) showed better discriminability performance for pseudo-masked primes for all mask types (left mask: d' difference = 0.97 , $t(6) = 2.04$, $p = 0.044$; right mask: d' difference = 0.76 , $t(6) = 2.08$, $p = 0.041$; square mask: d' difference = 2.17 , $t(6) = 3.48$, $p = 0.007$). The group with small discriminability differences (Fig. 2B, right) showed no differences in discriminability performance between pseudo-masked and metacontrast masked primes for the left and right mask, and a smaller but significant difference for the square mask (left mask: difference = -0.03 , $t(6) = 0.30$, $p = 0.61$; right mask: difference = -0.20 , $t(6) = -2.0$, $p = 0.95$; square mask: difference = 1.06 , $t(6) = 3.60$, $p = 0.006$). For both groups, discriminability was markedly better when square masks were used than when arrow masks were used (both $p < 0.001$), suggesting that the difficulty to report the orientation of the prime may not only be caused by visual masking, but also be partly caused by interference from the mask arrow with the memory trace of the prime arrow.

3.2. Immediate response priming: correspondence effect

Error rates (ERs) were smaller when masks were preceded by congruent primes (ER = 0.4%) than incongruent primes (ER = 11%; Fig. 3A). This ER correspondence effect (ER incongruent trials – ER congruent trials) was observed both when the prime was masked by a metacontrast mask (ER correspondence effect = 11%; $t(13) = 11.2$, $p < 0.001$) and when the prime was masked by a pseudomask (ER correspondence effect = 11%; $t(13) = 9.6$, $p < 0.001$). Similarly, response times (RTs) were shorter when masks were preceded by congruent primes (RT = 293 ms) than incongruent primes (RT = 361 ms; Fig. 3C). Again, this RT correspondence effect (RT incongruent trials – RT congruent trials) was equally large when the prime was masked by a metacontrast mask (RT correspondence effect = 67 ms; $t(13) = 21.4$, $p < 0.001$) and when the prime was masked by a pseudomask (RT correspondence effect = 67 ms; $t(13) = 23.7$, $p < 0.001$). A direct comparison confirmed that there was no difference in the amount of response priming between metacontrast and pseudo-masked stimuli (RT: $t(13) = 0.22$, $p = 0.83$; ER: $t(13) = 0.33$, $p = 0.74$). Moreover, when we compared response priming effect for the two groups, with large and small discriminability differences respectively, both groups showed strong but equal ER (Fig. 3B) and RT (Fig. 3D) correspondence effects for the two mask types (ER correspondence: $p < 0.001$ for each group, $p = 0.25$ for the group difference; RT correspondence: $p < 0.001$ for each group, $p = 0.13$ for the group difference).

Using Bayesian statistics (see Methods for details), we observed very strong evidence (BF $> 30/1$) for immediate response priming effects for both meta- and pseudo-masked primes, both in terms of RT and ER. When directly comparing immediate response priming between meta- and pseudo-masked primes, the BF for immediate priming differences was BF = $1/4.9$ for RT

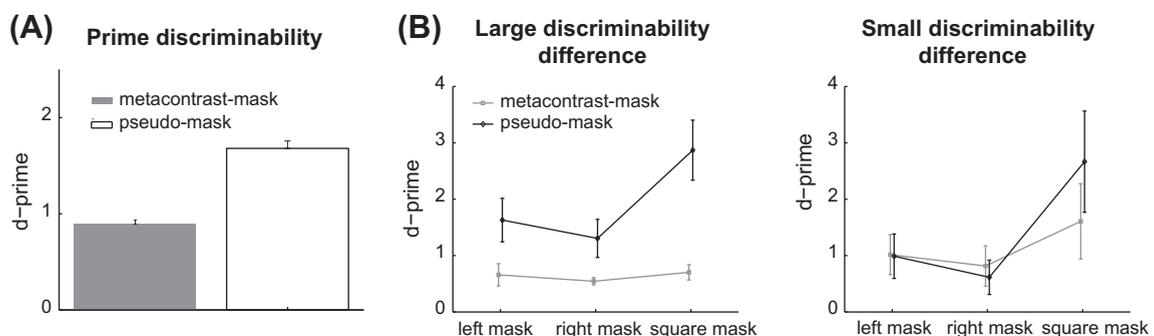


Fig. 2. Prime discriminability. (A) Group results for the prime recognition task. Discriminability performance (d') was significantly lower for metacontrast masked (poorly discriminable) than for pseudo-masked (well discriminable) primes. (B) We split the group into a group with 'large discriminability difference' (left) and 'small discriminability difference' (right) between metacontrast masked and pseudo-masked primes. For the former group, d' was significantly lower for all metacontrast masks compared to pseudomasks. For the latter group, d' was only significantly different between metacontrast masked and pseudo-masked primes for the square mask.

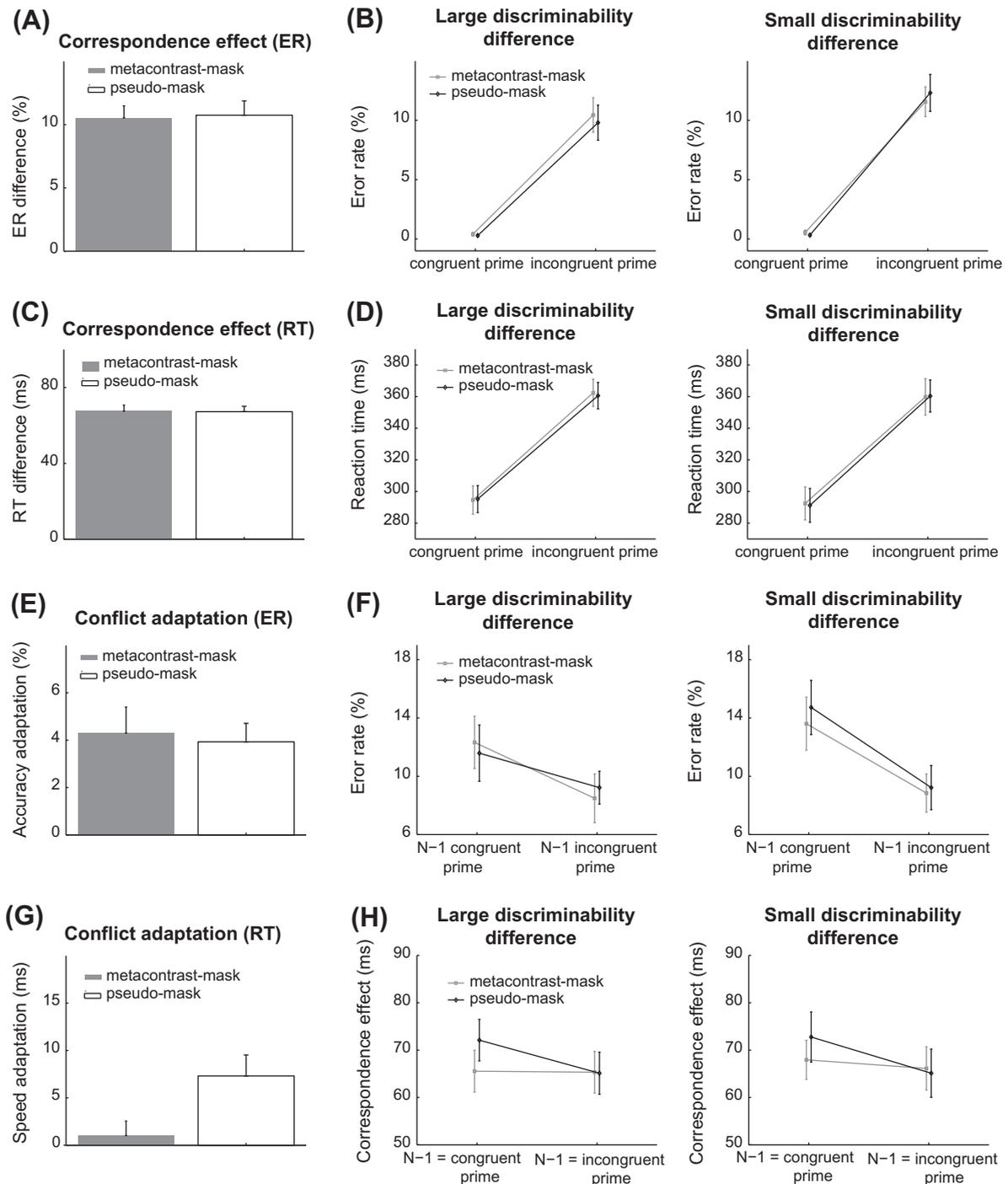


Fig. 3. Immediate and long-term priming effects. (A) Response priming task – error rates. The correspondence effect in terms of error rate (ER) is highly significant but not different for poorly discriminable and well discriminable primes. (B) There is no difference in ER correspondence effects between the low-discriminability and high-discriminability difference subgroups. (C) Response priming task – reaction times. The correspondence effect in terms of reaction time (RT) is highly significant but not different for poorly discriminable and well discriminable primes. (D) There is no difference in RT correspondence effects between the low-discriminability and high-discriminability difference subgroups. (E) Conflict adaptation – error rates. The amount of conflict adaptation (ER correspondence effect in the current trial as a function of prime-mask correspondence in the previous trial) is highly significant but not different for poorly discriminable and well discriminable primes. (F) There is no difference in ER conflict adaptation between the low-discriminability and high-discriminability difference subgroups. (G) Conflict adaptation – reaction times. RT conflict adaptation (correspondence effect in RTs in the current trial as a function of prime-mask correspondence in the previous trial) is weak but only significant for well discriminable primes. (H) There is no significant difference in RT conflict adaptation between the low-discriminability and high-discriminability difference subgroups.

and $BF = 1/4.7$ for ER, indicating moderate evidence for the null hypothesis that there are no differences in priming between pseudo- and metacontrast masked primes. Therefore, these results suggest that immediate response priming was independent of prime discriminability.

3.3. Long-term response priming: conflict adaptation

When prime and mask were incongruent on the previous trial, the ER correspondence effect on the current trial was attenuated (from 13.0% to 8.9%; Fig. 3E). This ER conflict adaptation was observed both when the prime was masked by a metacontrast mask (ER conflict adaptation = 4.3%; $t(13) = 3.90$, $p = 0.0018$) and when the prime was masked by a pseudo-mask (ER conflict adaptation = 3.9%; $t(13) = 5.04$, $p < 0.001$). Although ER conflict adaptation was numerically larger for metacontrast masked primes, the ER correspondence effect was not significantly different between mask types ($t(13) = -0.26$, $p = 0.80$), nor was there a difference in ER conflict adaptation between the low-discriminability and high-discriminability groups ($p = 0.25$, Fig. 3F). In terms of reaction times, prime-mask incongruence on the previous trial led to a very small reduction of the RT correspondence effect (from 69 ms to 65 ms; Fig. 3G). However, although small, this was significant when the previous trial was masked by a pseudomask (RT conflict adaptation = 7.3 ms; $t(13) = 3.30$, $p = 0.006$), but not visible when the previous trial was masked by a metacontrast mask (RT conflict adaptation = 1.0 ms; $t(13) = 0.67$, $p = 0.52$), leading to a significant difference between mask types ($t(13) = 2.42$, $p = 0.031$). However, the RT conflict adaptation was relatively small (representing an 11% change in RT correspondence effect), compared to the ER correspondence effect (39% change), and there were no differences in RT conflict adaptation between the poor discriminability and high-discriminability groups ($p = 0.38$, Fig. 3H), suggesting that conflict adaptation is not related to individual differences in prime discrimination ability.

This conclusion was further supported by Bayesian statistics. Bayesian statistics revealed strong evidence ($BF > 10/1$) for long-term priming effects in terms of ER for both meta- and pseudo-masked primes, and moderate evidence for the null hypothesis that there is no difference between these long-term priming effects between meta- and pseudo-masked primes ($BF = 1/4.5$). For long-term priming effects on RT, we found moderate evidence ($BF = 8.6/1$) for long-term priming for pseudo-masked primes, and we found moderate evidence ($BF = 1/4.0$) for the null hypothesis for metacontrast masked primes. Crucially however, there was no evidence for either null or alternative hypothesis when directly comparing long-term RT priming effects between conditions ($BF = 2.0/1$), precluding a straightforward interpretation of the long-term priming effects on RT.

4. Discussion

This study shows a clear dissociation between the discriminability of a stimulus and its direct and longer-lasting effects on behavior. By manipulating prime discriminability using metacontrast masks and pseudomasks instead of varying the strength of the prime signal, we establish that the amount of immediate and long-term response priming is equal for well discriminable and poorly discriminable primes. Converging evidence was obtained by the median-split analysis: response priming was equally strong for both mask types in the group that had large discriminability differences and the group that had small discriminability differences. Moreover, using Bayesian statistical analyses, we could garner statistical support in favor of the null hypothesis, beyond the inability to refute it. Together, this extends earlier behavioral observations of a dissociation between direct response priming and discriminability (Mattler, 2003; Schlaghecken et al., 2008; Vorberg et al., 2003). Furthermore, these findings nicely fit with recent results on the role of prime awareness in the negative compatibility effect (NCE) (Schlaghecken et al., 2008). In the NCE, responses are faster when prime and target are incongruent, compared to congruent. This effect is observed when the interval between the prime and target is increased to approximately 150 ms. Schlaghecken et al. used a learning experiment to show that increases in prime discriminability (as a result of learning) left the NCE unaffected, suggesting that prime awareness may not directly relate to the NCE, even though typically no NCE is observed for primes that are well discriminable.

In addition, and perhaps more surprisingly, we show that long-term priming effects (conflict adaptation) appear also independent of prime discriminability. We observed strong ER conflict adaptation effects for both metacontrast masked (4.9% reduction) and pseudo-masked primes (3.9% reduction). In terms of RTs, conflict adaptation was small but significant for pseudo-masked primes (7.3 ms reduction), but not for metacontrast masked primes (1.0 ms reduction). Since ER conflict adaptation was numerically larger (although not significantly) for metacontrast masked primes, the difference in RT conflict adaptation between conditions might be due to a speed/accuracy trade-off, leading to stronger ER conflict adaptation but weaker RT conflict adaptation for metacontrast masked primes than for pseudo-masked primes. It should be noted that RT conflict adaptation effects were small in general for both conditions, since previous studies observed conflict adaptation effects of approximately 50 ms in similar masked priming paradigms, though with longer prime durations (Ansoorge et al., 2010; Kunde, 2003; van Gaal et al., 2010). Bayesian analyses provided moderate support for the null hypothesis of no conflict adaptation differences between pseudo- and metacontrast masked primes, while there was neither support for the null nor the alternative hypothesis of conflict adaptation differences in terms of RT. Median-split analyses showed that ER and RT conflict adaptation was equally strong in the group that had large discriminability differences and the group that had small discriminability differences, further suggesting that conflict adaptation and prime awareness are likely to be independent. While we have manipulated discriminability, while keeping prime strength equal, follow-up studies could further dissociate

these concepts by using different prime-target SOAs potentially resulting in different prime strength but equal prime discriminability. This may further strengthen the dissociation between discriminability and immediate and long-term priming.

It should be noted that the difference in discriminability between poorly discriminable and well discriminable primes was quantitative, rather than qualitative. Therefore, we do not compare fully conscious with fully unconscious primes. This however does not confute our conclusion that quantitative differences in prime discriminability bear no relationship to priming strength. While this independence of priming on discriminability suggests that similar effects could be observed under fully subliminal conditions, this remains to be tested. It should also be noted that our measure of awareness relates to discriminability, rather than detection performance. Detection and discrimination likely relate to different levels of depth of awareness: while partial awareness of a stimulus (Kouider, de Gardelle, Sackur, & Dupoux, 2010) may result in successful detection of a stimulus, full awareness of the stimulus appears necessary in order to successfully discriminate it from a perceptually similar but different stimulus.

It may be rather surprising that prime discriminability bears no relationship to the amount of influence the prime had on subsequent behavior. After all, awareness of information leads to prolonged and sustained processing of the stimulus (Gaillard et al., 2009), which should enhance the influence of the stimulus on subsequent behavior. What could explain the dissociation between discriminability and priming? One possible explanation is that discriminability changes the availability of the information to other neural systems, without fundamentally altering its initial quantitative properties and neural trajectory (also referred to as the fast feedforward sweep (Lamme & Roelfsema, 2000)). Indeed, a recent study showed that unconscious conflict-eliciting stimuli still trigger activity in the human medial frontal cortex (Ursu, Clark, Aizenstein, Stenger, & Carter, 2009) but see (Dehaene et al., 2003), which is known for its involvement in the monitoring of conflict and the occurrence of errors (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). One study even observed stronger prefrontal activity for subliminal stimuli than for supraliminal stimuli. In this case the authors cleverly used a U-shaped masking design in which the signal strength of the subliminal stimulus was stronger than that of the supraliminal stimulus (Lau & Passingham, 2007). Since the strength of the prime is equated in our study (leading to equal immediate priming effects, and thus equal response conflict), long-term conflict adaptation effects that depend on the strength of response conflict (evaluated by the medial frontal cortex) may be directly modulated by the conflict signal itself, rather than the visual awareness of such conflict. The present results suggest that 'broadcasting' of conflict signals to other systems is not necessary for conflict adaptation to occur, but however might be necessary for other subsidiary cognitive processes (e.g. working memory).

In sum, our findings show that immediate and long-term response control, as measured with the correspondence effect and conflict adaptation, can operate independently from discriminability of information. Future neuroimaging investigations may shed light on the neural mechanisms underlying the (potentially complex) role of visual awareness in immediate and long-term response priming.

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References

- Anson, U., Fuchs, I., Khalid, S., & Kunde, W. (2010). No conflict control in the absence of awareness. *Psychological Research Psychologische Forschung*.
- Bodner, G. E., & Mulji, R. (2010). Prime proportion affects masked priming of fixed and free-choice responses. *Experimental Psychology*, *57*(5), 360–366.
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.
- Dehaene, S., Artiges, E., Naccache, L., Martelli, C., Viard, A., Schurhoff, F., et al (2003). Conscious and subliminal conflicts in normal subjects and patients with schizophrenia: The role of the anterior cingulate. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(23), 13722–13727.
- Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends Cogn Sci*, *10*(5), 204–211.
- Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B., et al (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, *4*(7), 752–758.
- Dehaene, S., Naccache, L., Le Clec, H. G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., et al (1998). Imaging unconscious semantic priming. *Nature*, *395*(6702), 597–600.
- Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive and Affect Behavioral Neuroscience*, *7*(4), 380–390.
- Frings, C., & Wentura, D. (2008). Trial-by-trial effects in the affective priming paradigm. *Acta Psychologica (Amst)*, *128*(2), 318–323.
- Gaillard, R., Dehaene, S., Adam, C., Clemenceau, S., Hasboun, D., Baulac, M., et al (2009). Converging intracranial markers of conscious access. *PLoS Biology*, *7*(3), e61.
- Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*(4), 480–506.
- Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*(5282), 1699–1702.
- Haynes, J. D., Driver, J., & Rees, G. (2005). Visibility reflects dynamic changes of effective connectivity between V1 and fusiform cortex. *Neuron*, *46*(5), 811–821.
- Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford: Oxford University Press, Clarendon Press.
- Kouider, S., de Gardelle, V., Sackur, J., & Dupoux, E. (2010). How rich is consciousness? The partial awareness hypothesis. *Trends in Cognitive Sciences*, *14*(7), 301–307.
- Kouider, S., Dehaene, S., Jobert, A., & Le Bihan, D. (2007). Cerebral bases of subliminal and supraliminal priming during reading. *Cerebral Cortex*, *17*(9), 2019–2029.

- Kunde, W. (2003). Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin and Review*, *10*(1), 198–205.
- Lamme, V. A., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing 1. *Trends in Neurosciences*, *23*(11), 571–579.
- 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 of the United States of America*, *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.
- Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide*: Lawrence Erlbaum Associates.
- Mattler, U. (2003). Priming of mental operations by masked stimuli. *Percept & Psychophys*, *65*(2), 167–187.
- Merikle, P. M., & Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Consciousness and Cognition*, *6*(2–3), 219–236.
- Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80*(3), 215–229.
- Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science*, *306*(5695), 443–447.
- Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian *t*-tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin and Review*, *16*(2), 225–237.
- Schlaghecken, F., Blagrove, E., & Maylor, E. A. (2008). No difference between conscious and nonconscious visuomotor control: Evidence from perceptual learning in the masked prime task. *Consciousness and Cognition*, *17*(1), 84–93.
- Ursu, S., Clark, K. A., Aizenstein, H. J., Stenger, V. A., & Carter, C. S. (2009). Conflict-related activity in the caudal anterior cingulate cortex in the absence of awareness. *Biological Psychology*, *80*(3), 279–286.
- van Gaal, S., Lamme, V. A., & Ridderinkhof, K. R. (2010). Unconsciously triggered conflict adaptation. *PLoS ONE*, *5*(7), e11508.
- Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(10), 6275–6280.